DEVELOPMENT OF CONTINUOUS PROCESSING METHOD FOR POUCHES IN ROTARY RETORTS

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THESIS

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ABSTRACT

The benefits of retort pouches compared to metal cans include a smaller weight and volume and an easier and safer opening process. Decreasing the weight and volume would improve the packing and shipping efficiency of Unitized Group Rations\textsuperscript{TM}. Metal cans are efficiently processed in continuous retorts; however, pouches are not compatible with these continuous retorts and must be processed in less efficient batch retorts, resulting in higher operating costs.

The overall objective of this study was to supply vegetables packaged and processed in retort pouches for UGR\textsuperscript{TM} packages at a lower cost. The overall objective consisted of three specific aims. The first aim of this study was to develop a retort pouch and a stainless steel container to be processed in existing rotary retorts, increasing processing efficiency at a minimal cost to the processor. The second aim was to determine if the developed retort pouches and stainless steel containers processed in existing continuous rotating retorts can be a viable alternative to pouches processed in less efficient batch retorts. The third aim was to evaluate the effect of product viscosity and residual gas volume in the pouch on the processing time.

In order to accomplish these objectives, processed green beans in three packaging options, the developed rotating pouch, a No. 10 can, and an institutional size pouch, were compared in consumer acceptance and physical properties directly after processing and after six months of storage at 100°F. Results of the consumer acceptance tests showed that there was no difference in consumers’ overall liking of the three green bean samples directly after retorting. After six months, consumers rated the green beans from the No. 10 can higher in overall liking than the green beans from either type of pouch.
To investigate the effect of viscosity and residual gas volume on processing time, the processing times of rotating pouches and No. 10 cans filled with two different amounts of tomato concentrates were compared. All packages filled with the higher amount of product had significantly lower residual gas volumes than the packages filled with the lower amount of product. The processing times decreased by lowering the product fill by 10% for both the rotating pouches and the No. 10 cans, especially with the more viscous concentrates. Decreasing the product fill led to an increase in residual gas volume, which increased agitation.

The findings of this study show that it is possible to process pouches in existing retorts designed for No. 10 cans. Increasing the residual gas volume in rotating pouches can shorten processing times for liquids with higher viscosities due to enhanced agitation. Due to the widespread use of continuous rotary retorts and the advantages and growing popularity of retort pouches, food manufacturers may benefit by using stainless steel baskets for restraining pouches during rotary retorting as an alternative to investing in new pouch compatible retorts.
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Chapter 1. Introduction

1.1 Motivation

Retort pouches are made of a multilayer laminate film material that can withstand the retort process and produce a shelf stable food product (Froio and others 2012; Selke and others 2008). The packaging material is currently used to package numerous components of United States military rations as well as commercially-available food products for general consumers.

In the late 1940’s, the United States military started the process of switching from rigid cans to flexible pouches in individual combat rations and became the first major consumer of retort pouches (Whiteside 2005). Today the U.S. military, first-adopters of the retort pouch, desires to eliminate the need for No. 10 metal cans in Unitized Group Rations™ (UGR™) by switching to retort pouches.

UGR™ are used to provide group meals to Warfighters in the field. The UGR™ family includes UGR H&S (heat and serve), UGR-E (express), UGR-A (with perishable and frozen items), and UGR-B (contains dehydrated commercial items). Each type includes breakfast and lunch/dinner options. All of the components for each meal are packaged together in cardboard boxes, and many of those components are in flexible plastic trays and pouches. However, metal No. 10 cans containing various types of vegetables are also included in UGR™ (Froio and others 2012).

The transition from traditional rigid containers, such as metal cans, to flexible pouches in military rations is driven by the specific set of benefits provided by flexible packaging materials. The greatest advantage of flexible packaging is a more efficient use of packaging material and packing space, which reduces costs associated with storage and
transportation and also reduces waste for disposal. Transportation related costs are further reduced because of the significantly lighter weight of retort pouches compared to metal cans. Also retort pouches are quicker and easier to form than metal cans and require less storage space prior to filling (Selke and others 2008; Froio and others 2012). They also have improved safety and convenience over metal cans due to the absence of both sharp edges and the need for a can opener (Whiteside 2005).

There are several disadvantages associated with the processing of flexible retort pouches. Metal cans are efficiently processed in continuous agitating retorts; however, due to their flexible nature, retort pouches are not compatible with this equipment as it is designed for holding and moving cylindrical cans. They must therefore be processed in less efficient batch retorts resulting in higher operating costs. Processing times can be significantly reduced by rotating containers during processing, causing agitation which increases convective heat transfer (Ansar Ali and others 2006). Batch operations are less efficient than continuous operations because of time needed for loading and unloading between batches (Whiteside 2005). Retorts with new technology, such as oscillating retorts, are available that can process pouches and provide some agitation during processing, similar to rotary retorts (Yang 2012). However, purchasing retort equipment specifically for pouches would require a larger upfront investment for retort operations than repurposing existing retort equipment designed for processing metal cans (Roop and Nelson 1981).

Besides amount of agitation, processing time depends on the size and shape of the container and the material being processed. Smaller and thinner containers require shorter processing times because of the shorter heat transfer distance (Chia and others 1983). Whether the material is a solid, solid in liquid, or liquid will determine the dominant
mechanism of heat transfer such as conductive or convective heat transfer. Solid materials heat predominantly through conductive heat transfer, and liquid materials heat mainly through convective heat transfer. Solid in liquid materials, such as green beans in brine, will heat through mainly convective heat transfer. It takes longer for foods to be heated through conductive heat transfer to reach the desired temperature than foods heated through convective heat transfer. The viscosity of a liquid material impacts the mechanism of heat transfer as well. Highly viscous liquids will be heated more similarly to solids through conductive heat transfer (Erdoğdu and others 2010).

Residual gas volume, the gases trapped in a sealed container, can affect processing times too. In containers processed in still retorts, any entrapped air can insulate the material and slow heat transfer (Weintraub and others 1989; Joseph and others 1996). Headspace, the total volume of the package minus the volume of the filled material, is important for agitation in cans (Tewari 2007). The headspace in cans typically is a vacuum and not entirely trapped air. However, creating a headspace in a retort pouch by entrapping air may help increase agitation and shorten processing time.

1.2 Objectives

The overall objective of this study was to supply vegetables packaged and processed in retort pouches for UGR™ packages at a lower cost. The overall objective consisted of three specific aims. The first aim of this study was to develop a retort pouch and a stainless steel container to be processed in existing rotary retorts, increasing processing efficiency at a minimal cost to the processor. The second aim was to determine if the developed retort pouches and stainless steel containers processed in existing continuous rotating retorts can be
a viable alternative to pouches processed in less efficient batch retorts. The third aim was to evaluate the effect of product viscosity and residual gas volume in the pouch on the processing time.

In order to accomplish these objectives, a prototype retort pouch and stainless steel basket system was developed and compared with No. 10 metal cans and with institutional size retort pouches (ISPs). Processing times for all three container types filled with green beans in water were compared, and green beans retorted for equivalent processing times in each container type were evaluated using a consumer acceptance test as well as texture and color analysis before and after an accelerated shelf life study. The same retort pouch and stainless steel basket system was used to evaluate the effect of product viscosity and residual gas volume in the package on processing time.

1.3 Literature Cited


2.1 Retort Thermal Processing

The canning process was famously invented by Nicolas Appert in 1795 in response to the French military’s need for a new method to preserve food. He won a cash prize from Napoleon Bonaparte for his method of packaging food in glass jars, sealing them with cork and wax, and heating the sealed containers in boiling water (Yang 2012).

Significant improvements to the basic process have been made since then, and today, the canning industry represents a significant portion of the food industry. The canned foods industry is expected to reach almost $80 billion by 2014 (Eagle 2013).

Retort thermal processing, also referred to as “canning,” is a method of achieving commercially sterile food products. Commercial sterility is defined as the “degree of sterilization at which all pathogenic and toxin-forming organisms have been destroyed, as well as all other types of organisms which, if present, could grow in the product and produce spoilage under normal handling and storage conditions (Vaclavik and Christian 2003).” Essentially, commercially sterilized foods may still contain a few heat-resistant bacterial spores, but they will be unable to grow under normal product storage conditions. No other pathogenic, toxin-producing, or spoilage-causing organisms remain in a commercially sterile food product. These products, therefore, have very long shelf lives of 2 to 5 years, limited by degradation of food quality and not bacterial spoilage (Jahner and Nummer 2008).

The basic method for retorting a food product is placing the food inside a can or a retort pouch, sealing the container, and then placing the container in a retort, which is a large industrial-scale pressure cooker. The retort is sealed and heated to a specific temperature, generally exceeding the boiling point of water (Singh and Heldman 2009). The food is then
heated for a specific length of time depending of the nature of the food and several other factors. The processing time and temperature must be sufficient to render the product commercially sterile. After cooking, the container is cooled to room temperature.

The severe heat treatment of retort processing can also destroy essential nutrients and negatively affect sensory properties. The goal when choosing a processing temperature and time for a retorted food product is to maximize the quality retention and prevent overcooking, while maintaining the safety of the product (Ansar Ali and others 2006).

D, z, and F values are used to determine the correct processing temperature and time. The decimal reduction time, D, is defined as the time required to kill 90%, or to achieve a one log reduction, of organisms in the bacterial population. The thermal resistance constant, z, represents the increase in temperature required to reduce the D value by one log (Vaclavik and Christian 2003). The thermal death time, F, is the total time required to achieve a specific reduction of organisms (Singh and Heldman 2009). F is frequently written with the process temperature as a subscript and the z value for the microorganism being targeted as a superscript. Therefore, $F_{121}^{10}$ indicates the processing time for a given reduction in population of a microbial spore with a z value of 10°C at 121°C. This F value, $F_{121}^{10}$, is often simplified to $F_o$ (Singh and Heldman 2009).

Determining a process’ equivalent $F_o$ value is done by measuring the cold point in a container during processing. The cold point is defined as the slowest heating point in a container (Adams and Moss 2008). For foods heated primarily through conduction, the cold point is located at the geometric center of the container. For foods heated primarily through natural convection, it is located along the central axis of the container but below the center. For liquid foods that are agitated during processing, the cold point moves to the geometric
center (Adams and Moss 2008). If the slowest heating point of a container has reached the necessary $F_o$ value, then it can be assumed that the entire container has reached at least the minimum. This can lead to overcooking issues in large containers of solid material, as the product towards the outer walls of the package can become overcooked before the cold point has undergone the minimum heat treatment.

Anaerobic bacteria are the biggest concern with canned foods. Anaerobic bacteria are defined as bacteria that do not require oxygen for growth. Some species may not grow or live when oxygen is present, while some are not affected by its absence or presence (Jay and others 2005).

The most dangerous pathogen associated with canned foods is *Clostridium botulinum*. It is the bacterium that produces the botulinum toxin that causes botulism, a deadly form of food poisoning. The anaerobic microorganism produces the toxin while growing in foods. *C. botulinum* has heat-resistant spores, and the bacteria can grow in low acid (pH > 4.6) foods with a water activity of 0.94 or above (Jay and others 2005). A low acid canned food at high enough water activity and temperature provides favorable conditions for *C. botulinum* spores to become vegetative microorganisms (Clark 2009).

The canning industry has long used the 12-D concept to determine necessary process lethality for foods with a pH of 4.6 or greater. The 12-D concept is that the minimum thermal process should reduce the probability of survival of the most heat resistant *C. botulinum* spores to $10^{-12}$. This probability means that the process should reduce the spore count to one spore in one out of a billion containers (Jay and others 2005).

The destruction of *C. botulinum* spores is the minimum requirement for retorted food products. Other more heat resistant spoilage bacteria may be present in the food, so
containers are usually subjected to more than the minimum treatment (Abdul Ghani Al-Baali, A. G. and Farid 2006). *Bacillus stearothermophilus* is often used as a surrogate strain to test the effectiveness of the processing time at a specific temperature because it is nonpathogenic and more heat resistant than *C. botulinum* spores (Murano 2003).

### 2.2 Types of Retorts

Various types of retorts have been developed to handle different packaging and manufacturing requirements. They can be classified in three main ways: method of heating, batch vs. continuous, and mode of agitation. The different methods of heating include saturated steam, water immersion, water spray, and steam-air retorts (Hardt-English 2003).

Saturated steam retorts are typically used for processing cans. They consume a lot of energy, but are less expensive compared to other types of retort. Since any air inside the retort could insulate the containers being heated, the retort has to be saturated with steam while air escapes through vents. Often, overpressure air can be applied during cooling to prevent deformation of containers. Water immersion retorts are commonly used to process containers using an overpressure process. Overpressure means they can process many types of containers, not just metal cans. Fragile containers, such as glass, and flexible containers, such as pouches, generally require some overpressure. Water spray retorts are also less expensive compared to other types of retort. They differ from saturated steam retorts in that air can be present in the retort during processing, meaning it can be an overpressure process. Steam-air retorts can also provide an overpressure process. In these retorts, a large fan is used to mix steam with the air to prevent any cold spots inside the retort (Williams 2013).
Retorts can also be divided into batch and continuous systems. In a batch retort process, containers are loaded into the retort and heated with either water or steam. Then the cans are cooled, often with positive pressure maintained in the retort to prevent stress on the packaging. After cooling, the containers are unloaded. The loading and unloading steps add a considerable amount of time and labor to the process (Hardt-English 2003).

In a continuous retort process, necessary time and labor is reduced by removing the loading and unloading steps as well as the time for the retort to heat up and cool down. The process is made continuous by allowing cans to enter and exit the retort while maintaining a constant temperature and pressure inside the retort. This can be achieved either through valves, as in continuous rotary retorts, or through columns of water, as in continuous hydrostatic retorts, at the can feed and discharge locations (Singh and Heldman 2009). Containers are carried through a continuous retort on an automated conveyor, and residence time for containers in the retort is directly related to the speed of the conveyor.

Dividing retorts by presence and mode of agitation gives three categories: static or still, rotary, and oscillating. During static processing, containers are simply held inside the retort, either in a crate or jumble loaded. A still batch retort system with a crate is typically used to process flexible retort pouches (Singh and Heldman 2009). In rotary retorts, the container, generally a can, rotates during processing. Rotation can be either end-over-end or axial. Cans are loaded into a crate which is rotated for end-over-end agitation. For axial rotating, cans are loaded into a reel that carries them around the top two-thirds of a turn and drop off the reel to roll around the bottom third of the turn. Continuous rotary retorts are very common in the United States and are used to process metal cans (Hardt-English 2003). In oscillating processes, the containers are moved from side to side in order to agitate the
Oscillating retorts are relatively new to the food industry, but can be used to agitate different container types, including semi-rigid trays and flexible pouches (Trevino 2009).

2.3 Retort Pouches

Retort pouches are made of a laminate film material that can undergo the same retort process as metal cans (Selke and others 2008). They were first used to package food in the 1940’s to replace metal cans in United States military rations. Today, the packaging material is used in numerous components of U.S. military rations as well as a growing number of commercially-available food products for general consumers (Whiteside 2005; Mykytiuk 2002).

The laminate film structure usually consists of four layers (figure 2.1). The four layers are, from inside to outside, polypropylene, aluminum, oriented polyamide, and polyethylene. Polypropylene is used as a retort-stable heat sealing layer. The thickness of this layer affects the seal strength. Aluminum serves as a barrier to oxygen, light, and water vapor. The oriented polyamide layer’s role is to provide mechanical strength. The polyethylene layer on the outside adds stiffness and tensile strength (Amezquita and Almonacid 2009). In some laminates, the polyamide and aluminum layers’ positions may be switched (Froio and others 2012).
The increasing use of retort pouches in place of metal cans is due to the unique benefits provided by flexible packaging materials. The greatest advantage of flexible packaging is a more efficient use of packaging material and packing space, which reduces costs associated with storage and transportation and reduces waste for disposal. Due to the rigid and cylindrical nature of metal cans, there are gaps when packaged together. Flexible pouches can be boxed together with much smaller gaps, leading to smaller storage or transportation space needed to contain the same amount of product. Transportation related costs are further reduced because of the significantly lighter weight of retort pouches compared to metal cans (Williams and others 1982). Also, retort pouches are quicker and easier to form than metal cans and require less storage space prior to filling, as pouches are flat before filling (Selke and others 2008). They also have improved safety and convenience
over metal cans due to the absence of both sharp edges and the need for a can opener (Whiteside 2005). Pouches can also be made resealable, further increasing convenience (Mykytiuk 2002).

There are also disadvantages associated with retort pouches. One disadvantage is the lack of strength of the material compared to metal cans. Retort pouches are much more prone to abrasions and punctures that ruin package integrity and potentially the product (Amezquita and Almonacid 2009). More care and expense is needed when packaging retort pouches. In U.S. military rations, pouches are usually protected by a paperboard container to prevent damage (Froio and others 2012). The paperboard container is an added expense not needed for metal cans. During retorting, the pressure in the pouch and in the retort must be monitored more closely than with rigid metal cans to ensure the pouches do not expand too much and strain the seals (Ghai and others 2011). If the pouches are expanding excessively, then the pressure in the retort must be increased as a counterbalance.

Another disadvantage of retort pouches in the mode of retort generally used. Many continuous agitating retorts currently in use in industry were designed for compatibility with metal cans, and retort pouches cannot be processed in the same equipment. Therefore, retort pouches are frequently processed in less efficient still batch retorts resulting in higher operating costs. Batch operations are less efficient than continuous operations because of time needed for loading and unloading between batches (Whiteside 2005). Processing times can be significantly reduced by agitating containers during processing, which increases convective heat transfer (Ansar Ali and others 2006). Oscillating retorts are becoming more prevalent, and retort pouches can be processed with them (Trevino 2009; Yang 2012). However, purchasing a retort and related equipment specifically for pouches would require a
large upfront investment for retort operations (Roop and Nelson 1981; Williams and others 1982). The prevalence of metal can processing equipment in the food industry, and companies’ reluctance to purchase new equipment, is likely the biggest hurdle to the widespread adoption of retort pouches in the United States (Mykytiuk 2002). Therefore, it is desirable to create a system for sterilizing pouches in the existing continuous retorts.

2.4 Importance of Agitation During Retorting

In general, food processors like to have as short a processing time as possible while maintaining a safe, tasty, and nutritious final product. The processing time for a product depends on the size and shape of the container as well as the rate of heat transfer to the cold point of the container. Smaller and thinner containers require shorter processing times because of the shorter heat transfer distance (Chia and others 1983). Heat transfer can be either conductive or convective depending on the nature of the food. Conduction is the transfer of heat from molecule to molecule. Convection on the other hand is the result of motion of the molecule, such as when warmer sections of a fluid become less dense and flow upward, while cooler sections flow downward. This phenomenon sets up natural currents in a heated liquid (Vaclavik and Christian 2003). In addition, convection can be further enhanced by agitation of the fluid.

Solid materials heat predominately through conductive heat transfer, and liquid materials heat mainly through convective heat transfer. Mixtures of solids and liquids, such as green beans in brine, will also heat mainly through convective heat transfer. It generally takes longer for foods heated through conductive heat transfer to reach the desired temperature than foods heated through convective heat transfer. The viscosity of a liquid
material influences whether the heat transfer is predominately conductive or convective as well. Highly viscous liquids will heat more similarly to solids (Erdoğdu and others 2010).

The amount of agitation during processing can greatly affect the processing time. Mixing food during heating will shorten the necessary processing time by enhancing convective heat transfer. Cans processed in a rotary retort need a shorter amount of time to reach the same $F_0$ value as cans processed in a still retort (Ortiz and Alves 1995). Also, as the rotational speed increases, the processing time decreases up to a specific point (Ale and others 2008).

Residual gas volume, the gases trapped in a sealed container, can affect processing times too. Headspace, sometimes called residual air or residual gas in pouches, is the total volume of the package minus the volume of the filled material (Tewari 2007). The headscape in cans is typically a vacuum and not entirely entrapped air. A headscape cannot be a vacuum in a retort pouch because of the flexibility of the laminate film; the walls of the pouch will simply be pulled in. Therefore, some residual gas must be left in pouches in order to obtain headspace.

Headspace is needed in rotating containers in order to create a “stirring effect.” Cans with some headspace heat quicker than cans with no headspace when processed in a rotary retort (Hardt-English 2003). As the container rotates, the headspace bubble will always move to the top of the container, forcing the food material to move around the container during rotation. In containers processed without agitation, any entrapped air can insulate the material and slow heat transfer (Weintraub and others 1989; Joseph and others 1996). For retort pouches processed in still retorts it is important to minimize the amount of trapped air so as to have shorter processing times and better quality final products (Huerta-Espinosa 1981).
The technique most commonly used to measure residual gas volume is a destructive method. For the destructive method, sealed pouches are opened under water, and the residual gas allowed to escape from the pouch. The resulting drop in the water level corresponds to the residual gas volume (Huerta-Espinosa 1981).

Another technique for measuring residual gas volume is the calculation method. This method assumes that the volume of a sealed pouch is directly correlated to the volume of entrapped air (Huerta-Espinosa 1981). For this method, the residual gas volume is found by subtracting the volume of product and pouch material from the total volume of the filled and sealed pouch. The total volume of the filled and sealed pouch is determined by weighing it in air and in water to find the specific gravity. The specific gravity of the sealed pouch is converted to density using the density of water, then to volume using the weight of the pouch (Evans 1977; Huerta-Espinosa 1981). The calculation method allows the residual gas volume in a pouch to be measured without damaging the pouch, so it can be done prior to retorting if desired.

2.5 Literature Cited


Chapter 3. Development of Retort Pouch and Consumer Acceptance Test for Green Beans

3.1 Introduction

Retort pouches are packages made from a multilayer laminate film material that can undergo the retort process and produce a shelf stable food product (Froio and others 2012). Numerous components of United States military rations as well as commercially-available food products for general consumers are packaged in retort pouches.

Unitized Group Rations™ (UGR™) are used to provide group meals to Warfighters in the field. There are two main choices for packaging thermally processed vegetables in UGR™. No. 10 metal cans are currently used (Froio and others 2012). Institutional size pouches (ISPs) are a potential alternative; however, the increased cost over No. 10 cans has prevented the U.S. military from adopting them. ISPs are large flat retort pouches formed of two 11 in by 16 ½ in panels capable of holding the same amount of product as a No. 10 can. They are processed in batch still retorts, which is a more time consuming and less efficient processing method than the continuous agitating or rotating retorts designed for No. 10 cans.

There were two objectives of this study. The first objective was to develop a retort pouch and a stainless steel container system to be processed in existing rotary retorts, which would increase processing efficiency at a minimal cost to the processor. The second objective was to determine if using stainless steel containers to process retort pouches in existing continuous rotating retorts can be a viable alternative to less efficient batch retort processes. A viable alternative retort pouch to institutional size pouches would improve packing and shipping efficiency of military rations by eliminating the need for No. 10 metal cans.
No. 10 cans are currently used instead of ISPs because the cost of vegetables packaged in ISPs is too high compared to vegetables packaged in No. 10 cans. Vegetables packaged in a pouch that is compatible with existing continuous retorts should bring the relative cost compared to No. 10 cans down, allowing the switch to pouches in UGR™ to be made. The viability was assessed by comparing processing times, container weights, consumer liking, color, and texture of green beans processed in No. 10 cans, ISPs, and the prototype rotating retort pouch system. Consumer liking, color, and texture were assessed both before and after accelerated shelf-life storage.

3.2 Materials and Methods

Packaging Options

Three packaging options were used for processing: a retort pouch in a stainless steel basket, a No. 10 can, and an institutional size pouch (ISP). Both the retort pouch in basket and No. 10 can were rotated during processing, while the ISP was processed without rotation.

The prototype container for rotating retort pouch processing can be seen in figure 3.1. A metal container, or “basket,” for holding pouches during the rotating retort process was developed. The basket has the same dimensions, an outside diameter of 6-1/8 in and a height of 7 in, as the No. 10 cans currently used in the rotary retort. It consists of two ¼ in-thick stainless steel rings at the top and bottom connected by perforated stainless steel sheet metal formed into a cylinder. The bottom panel is also made of perforated stainless steel sheet metal.

To prevent pouches sliding out of the top opening during axial rotation, two 5 in long stainless steel springs were attached parallel to one another across the top of the basket. This
arrangement is designed to allow the pouch to be dropped into the basket and fall out of it when the basket is flipped over, but prevent the pouch from sliding out during rotation. Prototype baskets were manufactured at the Electrical and Computer Engineering Machine Shop at the University of Illinois at Urbana-Champaign.

The rotating pouch design is a flat pouch, consisting of two panels with dimensions shown in figure 3.2. The rotating pouch was developed to be compatible with the prototype basket and with existing filling and sealing equipment. It also was designed to contain half the amount of green beans as a No. 10 can or ISP. All pouches were made with the same multilayer laminate film used for military rations. Panels were cut by hand and sealed using a hand-held retort pouch sealer at 300°F for 10 seconds.

Besides the rotating pouch in basket system, lined No. 10 cans and institutional size pouches (ISPs) made of the same multilayer laminate film used for rotating pouches were also tested. The No. 10 cans had an outside diameter of 6-1/8 in and a height of 7 in. The ISPs were made from 2 flat rectangular panels with dimensions 11 in by 16 ½ in. The No. 10 cans and ISPs were capable of holding the same quantity of product.

Earlier Prototypes

Several prototype rotating pouches and baskets were developed prior to the final prototypes used in this study. Pictures of the earlier versions can be found in Appendix A, along with brief descriptions of the reasons why they were not used.
Green Bean Preparation

Raw green beans were purchased at a local grocery store and cut into 1 in to 1-1/2 in lengths. Cut green beans were blanched in 180°F water for 3 minutes immediately prior to packaging. No. 10 cans and ISPs were filled with 1.7 kg blanched green beans and 1.16 kg blanching water and sealed. No. 10 cans were sealed using a manual can sealer, and ISPs were sealed using a hand-held retort pouch sealer at 300°F for 10 seconds. Rotating pouches were filled with 0.85 kg blanched green beans and 0.58 kg blanching water and sealed using a hand-held retort pouch sealer at 300°F for 10 seconds. After sealing, all packaging types were held at room temperature for 45 minutes before retorting.

Retort Process

Each of the three packaging options were processed in a Steritort (FMC Corp., California, USA) set to 250°F with no additional pressure. No. 10 cans and rotating pouches in baskets were retorted while rotating axially. ISPs were retorted while stationary at the bottom of the retort. After heating, each container type was pressure cooled with domestic cold water while stationary in the retort for 10 minutes. The pressure applied during the pressure cool cycle was 21 psig.

Determination of Green Bean Processing Times

The processing time for each of the three packaging options was determined using the time-temperature profile at the cold point. The cold point in both rotating containers, the No. 10 can and the rotating pouch, was assumed to be the geometric center. The coldest point in the ISP was determined by measuring the temperature change at the geometric center and 1/3
of the distance from the bottom along the center axis. The point below the geometric center was determined to be the cold point, and all subsequent measurements were taken at that point.

The temperature over time was measured using wireless temperature probes (Wireless Micropack III Temperature Data Loggers, Mesa Laboratories Inc., Colorado, USA). The temperature probes were located at the cold point in each container. Metal holders were used to secure the temperature probes at the cold point in rotating pouches and ISPs. An externally mounted fitting was used to hold the temperature probes in the cold point in No. 10 cans. $F_o$ values were calculated using DataTrace software with a $Z$ value of 10°C (DataTrace for Windows Version 4.05, Mesa Laboratories Inc., Colorado, USA). Processing time was defined as a time to reach a process equivalent to $F_o$ of 5 minutes. Three replications were measured to determine the processing time for each filled container.

**Container Weights**

Samples for each package, No. 10 can, ISP, and rotating pouch, were weighed prior to filling with green beans and water. Three replicates were measured for each packaging option.

**Initial Consumer Acceptance Test**

Green beans for the consumer acceptance test were prepared and processed in No. 10 cans, ISPs, and rotating pouches for the determined processing time at 250°F with no additional pressure. No. 10 cans were retorted while rotating for 14 minutes. ISPs were retorted while stationary for 40 minutes. Rotating pouches were retorted while rotating for 18
minutes. At the end of the processing time, all type of packages were pressure cooled with domestic cold water while stationary in the retort for 10 minutes. The pressure applied during the pressure cool cycle was 21 psig. After pressure cooling, the containers were placed in an ice water bath until all containers were finished processing. All packages were then moved to refrigeration (4°C). After 12 hours, 1 No. 10 can, 1 ISP, and 2 rotating pouches were removed from refrigeration, opened, and the contents warmed in crockpots (Hamilton Beach, North Carolina, USA) at the lowest setting, 100°F.

One hundred and eight panelists were recruited by email and flyers from the University of Illinois community. The consumer testing took place in the Spice Box, a restaurant style dining room located in Bevier Hall at the University of Illinois at Urbana-Champaign. Each panelist was presented with 4 to 5 pieces of warm green beans for each of the three treatments simultaneously. Samples were presented in 2 oz. plastic cups coded with 3-digit randomized numbers. Each sample was rated for overall liking first, and then liking of several specific attributes. The specific attributes that were evaluated were aroma, appearance, taste, mouthfeel, and texture by hand. Samples were evaluated using 9-point hedonic scales with 1 “dislike extremely” and 9 “like extremely” for each scale. The order that samples were evaluated in was randomized.

Panelists were instructed to consume the green beans from the treatments separately and assess overall liking on a 9-point hedonic scale on a paper ballot (Appendix B). Then the panelists were presented with a new paper ballot and asked to assess their liking of aroma, appearance, flavor, mouthfeel, and texture by hand for each green bean sample separately on 9-point hedonic scales. Between samples, the panelists were asked to rinse their mouth with room temperature water. For texture by hand, panelists were instructed to touch and squeeze
the samples. Panelists’ comments on the samples were also collected on paper ballots (Appendix B).

**Initial Quality Measurements**

Green beans for initial quality measurements were sampled from the green beans for the initial consumer acceptance test after being warmed in a crockpot. The color of the green bean samples was measured using a LabScan XE Colorimeter (Hunter Associates Laboratory Inc., Virginia, USA). Samples were placed in petri dishes for measurement. Twelve replicates for each treatment were measured for color.

The maximum force and energy to break the green beans were measured using a TA-XT2i Texture Analyzer with a TA-91M Mini Kramer press (Texture Technologies, New York, USA). Eight replicates were measured with the texture analyzer for each treatment. Two 1-inch pieces of intact green bean at room temperature were placed in the base of the press for each replicate. The probe speed was 2 mm/s.

**Accelerated shelf life study**

Packages for the accelerated shelf life study were processed concurrently with packages for the initial consumer acceptance and quality tests. After the 12 hours of refrigeration, these packages were moved to a temperature controlled storage room set at 100°F. The packages remained at 100°F for 6 months.
Follow-up Consumer Acceptance Test

After 6 months of storage at 100°F, 1 No. 10 can, 1 ISP, and 2 rotating pouches were removed from the temperature controlled storage and warmed in crockpots (Hamilton Beach, North Carolina, USA) at the lowest setting, 100°F.

One hundred and ten panelists were again recruited from the University of Illinois community using emails and flyers. All consumer testing took place in the Spice Box, a restaurant style dining room located in Bevier Hall at the University of Illinois at Urbana-Champaign. Each subject was presented with 4 to 5 pieces of warmed green beans for each of the three treatments simultaneously. Samples were presented in 2 oz. plastic cups coded with 3-digit randomized numbers. Each sample was rated for overall liking first, and then liking of several specific attributes. The specific attributes that were evaluated were aroma, appearance, and texture by hand. Samples were evaluated using 9-point hedonic scales with 1 “dislike extremely” and 9 “like extremely” for each scale. The order that samples were evaluated in was randomized.

Panelists were instructed to not consume the green beans because the rotating pouch is not certified to produce shelf stable vegetables. Panelists were first presented with a paper ballot (Appendix B) to evaluate overall liking of each sample on a 9-point hedonic scale. Then panelists were presented with a new paper ballot and asked to assess aroma, appearance, and texture by hand for each green bean sample separately on 9-point hedonic scales. For texture by hand, panelists were instructed to touch and squeeze the samples. Panelists’ comments on the samples were also collected on paper ballots (Appendix B).
Follow-up Quality Measurements

Green beans for follow-up quality measurements were sampled from the green beans for the follow-up consumer acceptance test after being warmed in a crockpot. The methods used to analyze color and texture after storage were the same as the methods used prior to the storage.

Statistical Analysis

Analysis of variance (ANOVA) and significant differences among sample means were analyzed using the Fisher’s Least Significant Difference (LSD) test with a probability level of $p < 0.05$. Significant differences between sample means from initial consumer test and quality measurements and the follow-up consumer test and quality measurements were analyzed using Student’s T-test with a probability level of $p < 0.05$. All statistical analysis was done using Microsoft Excel (Microsoft, Washington, USA).

3.3 Results and Discussion

Green Bean Processing Times

Figure 3.3 shows the measured processing times to reach $F_o = 5$ min for all three package types. The time/temperature curves can be found in Appendix C. The processing time for No. 10 cans was shorter than the processing time of rotating pouches. The shorter time is most likely due to a higher degree of agitation in the No. 10 can from the difference in package geometry. Since the rotating pouch is not as round as the metal can, green beans may not be as free to move around the package during rotation.
Both rotated packaging options, the No. 10 cans and the rotating pouches, had significantly shorter processing times than the ISPs. This difference is due to the lack of agitation of green beans in the ISP during retorting. Heat transfer in ISPs is due only to natural convection. Heat transfer in the No. 10 cans and rotating pouches is accelerated due to forced convection from the agitation (Vaclavik and Christian 2003).

**Container Weights**

Table 3.1 contains the average weights of each package type. The weight of two rotating pouches is compared to the weight of one ISP and one No. 10 can because two rotating pouches are needed to contain the same quantity of green beans. The weight of two empty rotating pouches is slightly less than the weight of one empty ISP. Both pouch packaging options are much lighter than the No. 10 can. When filled with 1.7 kg blanched green beans and 1.16 kg blanching water, an ISP weighs 7.7% less than a No. 10 can. Two rotating pouches weight 7.8% less than a No. 10 can and 0.1% less than an ISP.

**Initial Consumer Acceptance Test**

The initial consumer acceptance test (figure 3.4) demonstrated that there was no overall difference in overall liking between three packaging options. There was also no difference in liking of aroma, taste, or mouthfeel. There were significant differences observed in the liking scores of appearance and texture by hand. For both of those specific attributes, green beans packaged in the rotating pouches were liked significantly less than green beans in either ISP or No. 10 can. No other significant differences were observed.
The appearance of green beans from rotating pouches was likely affected by the skin peeling off the green beans from the rotating pouch sample. Many participants commented that the skin was peeling off on that sample and that it was off-putting.

The liking of texture by hand did correlate somewhat with the liking of mouthfeel. Figure 3.5 shows the correlation between panelists’ texture by hand and mouthfeel liking scores. A basic trend of increased liking of mouthfeel with increased liking of texture by hand can be observed. Panelists’ liking of texture by hand and mouthfeel were both based mainly on the firmness of the samples, but liking of texture by hand was also influenced by the skin peeling off of the green beans from the rotating pouch. Many participants commented that the rotating pouch green beans were slimier than the other two samples. The sliminess could be attributed to the loose skins. Sliminess was not a factor commented on regarding mouthfeel.

The sloughing off of the green bean skins was likely due to errors made during the blanching and or waiting period prior to retorting of the rotating pouches. One reason for blanching prior to high-temperature processing is to increase the activity of the enzyme pectin methylesterase already present in the green beans (Stolle-Smits and others 2000). Pectin methylesterase helps to maintain firmness and prevent the sloughing of skin of green beans after high-temperature processing by demethylating cell wall pectins (Anthon and Barrett 2006). The green beans may have not been blanched for long enough to activate the pectin methylesterase or the wait time prior to retorting may not have been long enough for it to be effective. It is also possible that the green beans packaged in the rotating pouches incurred more mechanical damage during the retort process due to the higher level of flexibility of the package compared to the No. 10 can.
Initial Quality Measurements

Figures 3.6 and 3.7 show the maximum force and energy to break obtained during compression measurements of all the green bean samples. The maximum force of green beans packaged in ISPs was significantly higher than the maximum force of either No. 10 can or rotating pouch green beans. There was no significant difference in energy to break among the samples. The higher maximum force of green beans packaged in ISPs is likely due to the lack of agitation during processing. Green beans packaged in ISPs incurred the least amount of mechanical damage during the retort process due to being processed while stationary.

Although there was a significant difference, it does not explain consumers’ low liking scores of the texture by hand of green beans packaged in the rotating pouch. It is likely then that the lower texture by hand score for green beans from the rotating pouch is due primarily to the skins sloughing off and not any differences in firmness.

Consumer liking of texture of all the green bean samples could be improved by the addition of a calcium salt (Stanley and others 1995). Calcium chloride is added to green beans during blanching by many commercial green bean processors because it can help prevent some of the softening of green beans during processing (Lin and Schyvens 1995). Calcium in combination with pectin methylesterase, an enzyme naturally present in green beans, increases the firmness of canned green beans by forming cross-links between pectin chains (Canet and others 2005). A higher degree of pectin methylesterase activity increases the number of calcium binding sites in the pectin chains, and thus allows for an increased level of calcium cross-linking. Adding a calcium salt during blanching allows for more cross-
linking than relying solely on calcium naturally present in green beans. More cross-linking results in a firmer texture (Anthon and others 2005). The addition of a calcium salt to green beans processed in each packaging type would increase the firmness and prevent skins sloughing off after processing, increasing the texture and overall liking scores.

Figure 3.8 shows the L, a, and b color values for all of the green bean samples. Pictures of the green bean samples can be seen in figure 3.9. Green beans packaged in No. 10 cans had a significantly lower “L” value. Green beans packaged in ISPs had a significantly lower “a” value. No other significant differences in color were observed. In summary, green beans packaged in No. 10 cans were darker than green beans packaged in both pouch types. Green beans packaged in ISPs were less red than green beans from No. 10 cans or rotating pouch. No consumer acceptance test participants commented on the color of the samples, so it is unlikely the differences in color greatly affected their liking of appearance.

Follow-up Consumer Acceptance Test

Figure 3.10 contains the results of the follow-up consumer acceptance test. Consumers’ overall liking and liking of appearance and texture by hand was significantly higher for green beans packaged in the No. 10 can than either of the other two samples. The liking of aroma of green beans packaged in the ISP was significantly lower than the other two samples.

Because participants were instructed not to consume the samples, overall liking is based only on liking of aroma, appearance, and texture by hand. Many participants commented that the aroma of the green beans packaged in the ISP was sourer than the aromas of the other two samples. The sourer aroma is a possible cause of the lower liking of
the aroma of ISP green beans and could have contributed to the lower overall liking of ISP green beans. Consumers noticed that green beans packaged in both pouches were more broken than green beans packaged in No. 10 cans and stated that whole pieces were preferred. Participants commented that No. 10 can green beans were firmer than the other samples and that firmer green beans were preferable. The prevalence of broken green beans in the pouch samples explains consumers’ lower liking scores of appearance of those samples.

Follow-up Quality Measurements

Figures 3.11 and 3.12 show the maximum force and energy to break obtained during compression measurements of all the green bean samples after storage. The maximum force of green beans packaged in the No. 10 can was significantly higher than the maximum force of green beans packaged in either the ISP or the rotating pouch. There was no significant difference in energy to break among the samples. Participants in the consumer acceptance test commented that green beans packaged in the No. 10 can were firmer than the other samples and that firmer green beans were preferable, causing the higher liking of texture by hand of green beans packaged in the No. 10 can. The firmness of green beans from No. 10 cans also explains why there were more whole pieces of green beans in the No. 10 can sample compared to the pouch samples.

A small amount of corrosion was observed inside the No. 10 can. Internal can corrosion is a known issue in canning green beans due to the high nitrate content (Davis and others 1980). The metal ions released from the corroding cell wall may have had the effect of increasing the firmness of the green beans processed in the No. 10 can, in the same way the
addition of calcium chloride can increase the firmness. Green beans processed in both retort pouch types would not have undergone this effect due to the differences in packaging material. A metal ion analysis of green beans packaged in a No. 10 can exhibiting corrosion could reveal if this could have occurred (Debost and Cheftel 1979).

Figure 3.13 shows the L, a, and b color values for all of the green bean samples. Pictures of the green bean samples after storage can be seen in figure 3.14. Green beans packaged in the rotating pouch had a significantly higher “L” value than either of the other two samples. For “a” values, green beans from the No. 10 can were the lowest, green beans from the rotating pouch were the highest, and green beans from the ISP were in the middle. No other significant differences were observed. Several consumer acceptance test participants commented that the color of the green bean samples could be distinguished, but that none were especially appealing or unappealing.

Comparison Before and After the Storage

Figures 3.15, 3.16, and 3.17 compare the liking scores for aroma, appearance, and texture by hand of green beans packaged in the ISP, No. 10 can, and rotating pouch from the initial and follow-up consumer acceptance tests. The liking of the aroma of green beans packaged in ISPs did not significantly change, while the liking of both appearance and texture by hand significantly decreased. The liking of aroma, appearance, and texture by hand of green beans packaged in No. 10 cans and rotating pouches all significantly increased after storage.

The increase in the liking of aroma, appearance, and texture by hand of green beans packaged in No. 10 cans and rotating pouches is most likely not a true increase. This increase
can be attributed to error from the context effect. When evaluating samples on a scale, consumers are not rating samples absolutely, but comparing them to one another to gain a frame of reference (Lawless and Heymann 1999). Consumers disliked green beans from the ISP so much that their dislike of one sample inflated their liking of the other two samples in the follow-up consumer acceptance test. Bias from the context effect was not as clear in the initial sensory test because the test participants liked all of the samples similarly. The increased liking of texture by hand of green beans packaged in No. 10 cans, however, may be partially due to the increase in firmness.

Figures 3.18 and 3.19 compare the maximum force and energy to break of green bean samples before and after storage. The maximum force of green beans packaged in No. 10 cans increased, while the maximum force of green beans packaged in both pouch types did not significantly change. The energy to break of green beans packaged in No. 10 cans also increased, while the energy to break of green beans packaged in both pouch types did not significantly change.

The increase in the maximum force and energy to break of green beans packaged in the No. 10 can over the storage period may have been caused by metal ions from the corrosion of the can wall. The maximum force and energy to break of green beans packaged in both retort pouch types did not significantly change over the storage period due to the differences in packaging material; no metal ions were released into the green beans in retort pouches. The initial maximum force and energy to break of all green bean samples could be improved through the addition of a calcium salt (Lin and Schyvens 1995). The addition of a calcium salt would also increase the maximum force and energy to break of green beans after the shelf life storage. Texture, specifically firmness, is a very important factor in consumers’
overall liking of canned green beans (Godwin and others 1978). Increasing the firmness of the processed green beans should increase the liking scores.

Figures 3.20, 3.21, and 3.22 compare the color of green bean samples before and after storage. Green beans from the ISP significantly increased in “a” and “b”. Green beans from the No. 10 can underwent no significant changes. Green beans from the rotating pouch, similar to green beans from the ISP, increased in “a” and “b”. Green beans packaged in pouches changed color over the storage time, while green beans packaged in the No. 10 can did not.

3.4 Conclusions

For this study, a rotating pouch and stainless steel basket system was developed for processing pouches in rotating retorts designed for No. 10 cans. Rotating pouches, despite having a longer processing time than No. 10 cans, have a significantly shorter processing time than ISPs. A 7.8% reduction in packaging weight of 2.86 kg green beans in water can be achieved by replacing No. 10 cans with rotating pouches. There was no difference in consumers’ overall liking when green beans were tested shortly after processing. The overall liking of No. 10 can green beans was higher than both pouches after 6 months of storage at 100°F, but the overall liking scores of green beans packaged in both pouch types were not significantly different from one another. Liking scores could be improved by adding a calcium salt to green beans prior to retorting to increase the firmness after processing. In conclusion, using stainless steel baskets to process retort pouches in existing continuous rotating retorts can be a viable alternative to less efficient batch retort processes.
3.5 Literature Cited


3.6 Tables and Figures

**Figure 3.1** Basket for rotating pouch processing

**Figure 3.2** Rotating pouch
Figure 3.3 Time for green beans in each packaging option to reach $F_0 = 5$ min.

Different letters indicate significant difference ($\alpha = 0.05$) in processing time. Errors bars show $\pm 1$ standard deviation.

Table 3.1 Weight of empty packages.

<table>
<thead>
<tr>
<th></th>
<th>ISP</th>
<th>No. 10 Can</th>
<th>Rotating Pouch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>46.17 ± 0.06</td>
<td>288.23 ± 1.83</td>
<td>21.57 ± 0.15</td>
</tr>
<tr>
<td>Weight of two (g)</td>
<td>n/a</td>
<td>n/a</td>
<td>43.14 ± 0.30</td>
</tr>
</tbody>
</table>

Values include ± 1 standard deviation. n/a represents not applicable. Two rotating pouches are needed to contain the same amount as one No. 10 can or ISP.
**Figure 3.4** Consumer liking data from initial consumer acceptance test.

Different letters indicate significant difference ($\alpha = 0.05$) in liking between samples. Error bars show ± 1 standard deviation.
Figure 3.5 Correlation between panelists’ texture by hand and mouthfeel liking scores.

![Graph showing correlation between texture by hand and mouthfeel liking scores with R² values of 0.5256, 0.4249, and 0.3873 for different conditions.]
Figure 3.6 Initial maximum force data.

Different letters indicate significant difference ($\alpha = 0.05$) in maximum force between samples. Error bars show ± 1 standard deviation.

Figure 3.7 Initial energy to break green beans.

Different letters indicate significant difference ($\alpha = 0.05$) in energy to break between samples. Error bars show ± 1 standard deviation.
Different letters indicate significant difference (\( \alpha = 0.05 \)) between samples. Error bars show ± 1 standard deviation. L (0=black; 100=diffuse white); a (-50=green, 50=red); b (-50=blue, 50=yellow)

**Figure 3.9** Green bean samples from initial consumer acceptance and quality tests
**Figure 3.10** Consumer liking data from follow-up consumer acceptance test.

Different letters indicate significant difference ($\alpha = 0.05$) in liking between samples. Error bars show ± 1 standard deviation.
Different letters indicate significant difference ($\alpha = 0.05$) in maximum force between samples. Error bars show $\pm 1$ standard deviation.

Different letters indicate significant difference ($\alpha = 0.05$) in energy to break between samples. Error bars show $\pm 1$ standard deviation.
**Figure 3.13** Color of green beans after accelerated shelf-life.

Different letters indicate significant difference (α = 0.05) between samples. Error bars show ± 1 standard deviation.

L (0=black; 100=diffuse white); a (-50=green, 50=red); b (-50=blue, 50=yellow)

**Figure 3.14** Green bean samples from follow-up consumer acceptance and quality tests

Institutional Size Pouch  |  No. 10 Can  |  Rotating Pouch
Figure 3.15 Comparison of liking of green beans packaged in ISP before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) in liking before and after storage. Error bars show $\pm 1$ standard deviation.

Figure 3.16 Comparison of liking of green beans packaged in No. 10 can before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) in liking before and after storage. Error bars show $\pm 1$ standard deviation.
**Figure 3.17** Comparison of liking of green beans packaged in rotating pouch before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) in liking before and after storage. Error bars show $\pm 1$ standard deviation.

**Figure 3.18** Comparison of maximum force before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) in maximum force before and after storage. Error bars show $\pm 1$ standard deviation.
Figure 3.19 Comparison of energy to break before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) in energy to break before and after storage. Error bars show ± 1 standard deviation.
**Figure 3.20** Comparison of color of green beans packaged in ISP before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) before and after storage. Error bars show ± 1 standard deviation.
Figure 3.21 Comparison of color of green beans packaged in No. 10 can before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) before and after storage. Error bars show ± 1 standard deviation.
**Figure 3.22** Comparison of color of green beans packaged in rotating pouch before and after accelerated shelf-life.

Different letters indicate significant difference ($\alpha = 0.05$) before and after storage. Error bars show ± 1 standard deviation.
Chapter 4. Effect of Viscosity and Residual Gas Volume on Thermal Processing of Tomato Concentrates in Rotating Retort Pouch

4.1 Introduction

Heat transfer depends on several factors, including the product being retorted and any agitation during heating. Whether the product is a solid, liquid, or solids in liquid will determine if the dominant method of heat transfer is conductive or convective. In solid materials, thermal energy is predominantly transferred through conductive heat transfer, and in liquid materials thermal energy is mainly transferred through convective heat transfer. Solid in liquid materials, such as green beans in water, will heat through mainly convective heat transfer. In general, it takes longer for foods to be heated through conductive heat transfer to reach the desired temperature than foods heated through convective heat transfer. The viscosity of a liquid material affects whether the heat transfer is conductive or convective as well. Highly viscous liquids, such as pumpkin puree, will heat more similarly to solids (Erdoğdu and others 2010).

Added agitation during heating can reduce processing time as well by enhancing convective heat transfer. It helps by mixing the food, heating it more uniformly throughout (Singh and Heldman 2009). It has been demonstrated that metal cans processed in a rotary retort need a shorter amount of time to reach the same $F_o$ value than cans processed in a still retort (Ortiz and Alves 1995). Also, as the rotational speed increases, the processing time decreases up to a point (Ale and others 2008).

Length of processing time for retorted food products depends on the rate of heat transfer and on the dimensions of the package being processed. Smaller and thinner
containers require shorter processing times because of the shorter distance for heat transfer (Chia and others 1983).

Residual gas volume, the gases trapped in a sealed container, can also affect the length of processing times. In containers processed in still retorts, any entrapped air can insulate the material and slow heat transfer (Joseph and others 1996). Headspace, the total volume of the package minus the volume of the filled material, is important for agitation in metal cans (Tewari 2007). The headspace in cans typically is a vacuum and not entirely entrapped air. However, creating a headspace in a retort pouch by entrapping air may help increase agitation and shorten processing time.

In the previous study described in chapter 3, the processing time for green beans in a rotating pouch was longer than in a No. 10 can, despite the rotating pouch containing half the amount of green beans and water. This discrepancy was due to a lower degree of agitation in the rotating pouch compared to the No. 10 can. The objective of this study was to evaluate the effect of changing product viscosity and residual gas volume in a rotating retort pouch on processing time. Increasing residual gas volume in the rotating pouch could enhance agitation, decrease processing time, and improve the practicality of the packaging option for green beans.

4.2 Materials and Methods

Preparation of Tomato Concentrates and Green Beans

Three tomato concentrates were prepared by mixing commercially available canned tomato paste (Meijer Naturals™, 340 g net weight) purchased at a local grocery store with
water. The tomato paste was diluted with water to concentrations of 5, 10, and 15° Brix. A
refractometer was used to determine °Brix (Bausch & Lomb, New York, USA).

Raw green beans were purchased at a local grocery store and cut into 1 in to 1-1/2 in
lengths. Cut green beans were blanched in water at 180°F for 3 minutes immediately prior to
packaging.

**Package Types**

Rotating pouches, No. 10 cans, and institutional size pouches (ISPs) were tested.

Table 4.1 summarizes all of the packaging options tested. Rotating pouches were processed
while held in metal baskets. The basket has the same dimensions, an outside diameter of 6-
1/8 in and a height of 7 in, as the No. 10 cans currently used in the rotary retort. It consists of
two ¼ in thick stainless steel rings at the top and bottom connected by perforated stainless
steel sheet metal formed into a cylinder. The bottom panel is also made of perforated
stainless steel sheet metal.

To prevent pouches sliding out of the top opening during axial rotation, two 5 in long
stainless steel springs were attached parallel to one another across the top of the basket. This
arrangement is designed to allow the pouch to be dropped into the basket and fall out of it
when the basket is flipped over, but prevent the pouch from sliding out during rotation.

Prototype baskets were manufactured at the Electrical and Computer Engineering Machine
Shop at the University of Illinois at Urbana-Champaign.

The rotating pouch design is a flat pouch, consisting of two panels with dimensions
shown in figure 4.1. The rotating pouch was developed to be compatible with the prototype
basket and with existing filling and sealing equipment. It also was designed to contain half
the amount of green beans as a No. 10 can or ISP. All pouches were made with the same multilayer laminate film used for military rations. Panels were cut by hand and sealed using a hand-held retort pouch sealer at 300°F for 10 sec.

Besides the rotating pouch in basket system, lined No. 10 cans and institutional size pouches (ISPs) made of the same multilayer laminate film used for rotating pouches were also tested. The No. 10 cans had an outside diameter of 6-1/8 in and a height of 7 in. The ISPs were made from 2 flat rectangular panels with dimensions 11 in by 16 ½ in. The No. 10 cans and ISPs were capable of holding the same quantity of product.

Water and tomato concentrates were processed in the rotating pouches and in the No. 10 cans. Green beans were processed in all three containers. Rotating pouches filled with water were also processed while stationary to analyze the effect of decreasing product fill on processing time and to compare the rotating and stationary processes.

**Residual Gas Volume Levels**

Two residual gas volume levels were created for each package type by varying the product fill. Tables 4.1 summarize the two levels of fill for each package type. All lower levels of product fill are a 10% reduction from the higher levels of product fill.

The residual gas volume inside each container was measured after filling and sealing. The DataTrace temperature probe (Wireless Micropack III Temperature Data Loggers, Mesa Laboratories Inc., Colorado, USA) was also put in each package before sealing. The sealed packages were first weighed. Then the specific gravity of each package was measured according to ASTM D 792-08 Standard Test Methods for Density and Specific Gravity of Plastics by Displacement. The total volume of the package was calculated. The volume of the
filled product and DataTrace temperature probe were subtracted from the total volume to
determine the residual gas volume. The volume of the DataTrace temperature probe was
measured using volume displacement of water in a graduated cylinder. The volume of the
filled product was measured with a graduated cylinder.

All residual gas volume measurements were conducted on packages at room
temperature. Temperature can affect both the density of water and the tomato concentrates
and the volume of the entrapped gases (Murano 2003). Both of these variables would affect
the total residual gas volume measurement. Measuring residual gas volume at room
temperature was done for consistency.

**Rheological Measurements**

Rheological properties of the tomato concentrates were obtained using a RFSIII
Rheometer (Rheometric Scientific, New Jersey, USA) with TA Orchestrator software
(Version V7.2.0.2, TA Instruments – Waters LLC, Delaware, USA). All samples were
measured with a 50 mm cross hatch metal parallel plate at 25°C with a gap of 1.5 mm. The
shear rate range used was from 1 to 100 s\(^{-1}\). Three replicates were measured for each tomato
concentrate.

**Determination of Processing Times**

The processing time was determined using the temperature at the cold point over
time. The cold point in all rotating containers was assumed to be the geometric center of the
package. The cold point in all stationary packages was considered to be in the center, 1/3 of
the distance from the bottom as was previously concluded.
The time-temperature profile was collected using wireless temperature probes (Wireless Micropack III Temperature Data Loggers, Mesa Laboratories Inc., Colorado, USA). The temperature probes were located at the cold point in each container. Metal holders were used to secure the temperature probes at the cold point in rotating pouches and ISPs. An externally mounted fitting was used to hold the temperature probes in the cold point in No. 10 cans. $F_o$ values were calculated using DataTrace software with a $Z$ value of 10°C (DataTrace for Windows Version 4.05, Mesa Laboratories Inc., Colorado, USA). Processing time was defined as the time to reach a process equivalent to $F_o$ of 5 minutes. Three replications were measured to determine the processing time for each filled package.

Water and tomato concentrates were filled and sealed at room temperature and retorted. Packages filled with blanched green beans and water were retorted 45 min after blanching. All packages were retorted using the Steritort (FMC, California, USA) in the University of Illinois Pilot Plant (Urbana, Illinois, USA). ISPs, which were retorted while stationary, were placed at the bottom of the retort, and the reel was not rotated during processing. Rotating pouches in baskets and No. 10 cans were placed in the slots in the reel and rotated during processing. Rotating pouches filled with water were also processed while stationary; these pouches were also placed in stainless steel baskets in slots in the reel.

**Statistical Analysis**

Analysis of variance (ANOVA) and Fisher’s Least Significant Difference (LSD) test with a probability of $p < 0.05$ were used to analyze significant differences among sample means within groups. Significant differences between pairs of sample means were analyzed
using Student’s T-test with a probability level of $p < 0.05$. All statistical analysis was done using Microsoft Excel (Microsoft, Washington, USA).

4.3 Results and Discussion

Residual Gas Volume Levels

The residual gas volume in packages filled with more product was always significantly lower than packages filled with the lower amount. Table 4.2 shows the residual gas volume levels in the rotating pouches and in the No. 10 cans. No significant differences in residual gas volume were found between tomato concentrates in rotating pouches with the same fill amount. Likewise, No. 10 cans with the same fill amount showed no significant differences in residual gas volume between tomato concentrates.

The residual gas volume in rotating pouches exhibited more variation than the residual gas volume amounts in No. 10 cans. This is due to inconsistencies from sealing the flexible pouch manually. The proportion of residual gas to product fill was significantly higher for the concentrates in the cans than in the rotating pouches because the total volume of the No. 10 cans is larger than twice the total volume of the rotating pouches (table 4.3).

Like the tomato concentrates, packages filled with the higher amount of green beans in water had significantly lower residual gas volumes than packages filled with the lower amount. Table 4.4 contains the residual gas volume levels for all green bean filled packages. The increase in residual gas volume does not directly equal the 10% decrease in fill amount in the rotating pouch because of the flexibility of the pouch material. As the pouches were sealed by hand, variations may have occurred.
Rheological Properties

The three tomato concentrates can be modeled using the Power Law Fluid Model, \( \tau = K \gamma^n \). Table 4.5 includes the average flow consistency indexes (K) and flow behavior indexes (n) for the tomato concentrates. The results show that all tomato concentrates were shear-thinning fluids, meaning they have a lower apparent viscosity at higher shear rates. As the tomato concentration increased, the flow consistency index increased, which leads to the increase of apparent viscosity. The rheological measurements for all tomato concentrates are graphed in figures 4.2, 4.3, and 4.4.

Processing Times for Water and Tomato Concentrates

Figure 4.5 and 4.6 show the measured processing times of tomato concentrates in the rotating pouches and in No. 10 cans. As expected, increasing the viscosity of the tomato concentrates lengthened the processing time to reach \( F_o = 5 \) min. In the rotating pouch, significant differences in processing time between fill levels was observed for 10° Brix and 15° Brix concentrates, but not water or the 5° Brix mixture. In the No. 10 can, significant differences in processing time between fill levels was seen for 5° Brix, 10° Brix, and 15° Brix concentrates, but not water. These significant differences can be attributed to two effects: the changes in amount of product and of agitation. A lower amount of product is expected to take less time to process, and the increased amount of residual gas volume enhances agitation.

Figure 4.7 compares all of the measured processing times of tomato concentrates in rotating pouches and in No. 10 cans. The No. 10 can is the more efficient packaging option for processing tomato concentrates at high concentration despite the rotating pouch only
containing half the amount as the No. 10 can. This suggests that agitation is more important than the amount of product when processing materials with higher viscosities. However, when processing materials with lower viscosities, the processing times of packages that received more and less agitation were similar.

Figure 4.8 shows the processing times for water in rotating pouches processed stationary. The pouch containing 1170 mL fill reached $F_0$ of 5 min quicker than the pouch with 1300 mL fill. Comparing the water filled rotating pouches processed while rotating and while stationary (figure 4.9), it can be observed that rotating significantly shortened processing time for both the 100% and the 90% fill levels. No tomato concentrates reached $F_0$ of 5 min before significant burning of product was observed, so processing times of tomato concentrates processed stationary were not collected. As all rotating containers of tomato concentrates reached $F_0$ of 5 min, agitation greatly decreased the length of processing time and is necessary to maintain product quality.

**Green Bean Processing Times**

Figure 4.10 shows the time to reach $F_0 = 5$ min for both fill amounts of green beans in ISP, No. 10 can, and rotating pouch. No significant differences in processing time between fill amounts was seen for the ISP, No. 10 can, or rotating pouch. These results are similar to the water filled packages, as these packages are green beans in water. The processing time for green beans in water is determined by targeting the temperature of the water and not the internal temperature of green beans. It is assumed that the inside of each green bean is sterile and that the outside of each green bean is the same temperature as the surrounding water.
(Murano 2003). Therefore, only the surrounding water needs to be targeted to achieve a safe product.

4.4 Conclusions

For this study, rotating pouches and No. 10 cans filled with water or tomato concentrates to one of two levels were compared. Rotating pouches, No. 10 cans, and ISPs filled with one of two amounts of green beans in water were also studied. All packages with the higher amount of product fill had significantly lower residual gas volumes than the packages filled with the lower amount of product fill. As the concentration increased, so did the viscosity of the tomato concentrates, which were all shear-thinning fluids.

The processing times of rotating pouches and No. 10 cans filled with the more viscous liquids were shortened by decreasing the product fill by 10%. Decreasing the product fill led to an increase in residual gas volume, which increased agitation. The increase in agitation did not have a significant effect for less viscous liquids or green beans in water in the rotating packages. No. 10 cans were the more efficient packaging option when only taking processing time per amount of product into consideration. In conclusion, increasing residual gas volume by decreasing product fill helps shorten processing times of highly viscous products processed in a rotating retort pouch by increasing agitation. However, the findings do not indicate that decreasing product fill by 10% would be helpful to increase processing efficiency of green beans in rotating pouches.

4.5 Literature Cited


4.6 Tables and Figures

Table 4.1 Summary of package types and fill levels of all products.

<table>
<thead>
<tr>
<th>Products</th>
<th>Rotating Pouch</th>
<th>No. 10 Can</th>
<th>ISP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rotating</td>
<td>Stationary</td>
<td>Rotating</td>
</tr>
<tr>
<td>Water</td>
<td>100% Fill</td>
<td>100% Fill</td>
<td>100% Fill</td>
</tr>
<tr>
<td></td>
<td>90% Fill</td>
<td>90% Fill</td>
<td>90% Fill</td>
</tr>
<tr>
<td>5° Brix Concentrate</td>
<td>100% Fill</td>
<td>-</td>
<td>100% Fill</td>
</tr>
<tr>
<td></td>
<td>90% Fill</td>
<td>-</td>
<td>90% Fill</td>
</tr>
<tr>
<td>10° Brix Concentrate</td>
<td>100% Fill</td>
<td>-</td>
<td>100% Fill</td>
</tr>
<tr>
<td></td>
<td>90% Fill</td>
<td>-</td>
<td>90% Fill</td>
</tr>
<tr>
<td>15° Brix Concentrate</td>
<td>100% Fill</td>
<td>-</td>
<td>100% Fill</td>
</tr>
<tr>
<td></td>
<td>90% Fill</td>
<td>-</td>
<td>90% Fill</td>
</tr>
<tr>
<td>Green beans</td>
<td>100% Fill</td>
<td>100% Fill</td>
<td>100% Fill</td>
</tr>
<tr>
<td></td>
<td>90% Fill</td>
<td>90% Fill</td>
<td>90% Fill</td>
</tr>
</tbody>
</table>

- Rotating pouch: 100% fill = 1300 mL liquid or 0.85 kg green beans and 0.58 kg blanching water; 90% fill = 1170 mL liquid or 0.756 kg green beans and 0.522 kg blanching water
- No. 10 can and ISP: 100% fill = 2600 mL liquid or 1.17 kg green beans and 1.16 kg blanching water; 90% fill = 2340 mL liquid or 1.053 kg green beans and 1.044 kg blanching water

Figure 4.1 Rotating pouch
Table 4.2 Summary of residual gas volume levels (mL) in packages.

<table>
<thead>
<tr>
<th></th>
<th>Rotating Pouch</th>
<th>No. 10 Can</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100% Fill</td>
<td>90% Fill</td>
</tr>
<tr>
<td>Water</td>
<td>102.4 ± 26.2</td>
<td>160.7 ± 58.0</td>
</tr>
<tr>
<td>5° Brix Concentrate</td>
<td>65.3 ± 30.3</td>
<td>162.2 ± 42.8</td>
</tr>
<tr>
<td>10° Brix Concentrate</td>
<td>50.3 ± 13.9</td>
<td>146.1 ± 21.0</td>
</tr>
<tr>
<td>15° Brix Concentrate</td>
<td>91.6 ± 19.5</td>
<td>171.7 ± 33.8</td>
</tr>
<tr>
<td>Average</td>
<td>71.0 ± 26.9</td>
<td>160.1 ± 47.5</td>
</tr>
</tbody>
</table>

Value is average residual gas volume (mL) in package ± one standard deviation. No significant differences (α = 0.05) in residual gas volume were found between mixtures in packages with the same fill amount. Residual gas volumes in packages 90% filled were significantly higher than packages 100% filled.

Table 4.3 Proportion of residual gas volume per product fill in packages filled with a tomato concentrate.

<table>
<thead>
<tr>
<th></th>
<th>Rotating Pouch</th>
<th>No. 10 Can</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Fill Tomato Concentrate</td>
<td>0.055&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.204&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>90% Fill Tomato Concentrate</td>
<td>0.137&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.342&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values are average residual gas volume (mL)/fill amount (mL). Superscripts indicate significant differences (α = 0.05) within rows.

Table 4.4 Residual gas volume levels (mL) in packages filled with green beans in water.

<table>
<thead>
<tr>
<th></th>
<th>Rotating Pouch</th>
<th>No. 10 Can</th>
<th>ISP</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Fill Green Beans</td>
<td>109.2 ± 25.8</td>
<td>180.6 ± 7.0</td>
<td>785.1 ± 62.6</td>
</tr>
<tr>
<td>90% Fill Green Beans</td>
<td>179.8 ± 36.4</td>
<td>447.1 ± 29.6</td>
<td>996.5 ± 16.5</td>
</tr>
</tbody>
</table>

Value is average residual gas volume (mL) in package ± one standard deviation. Residual gas volumes in packages 90% filled were significantly higher than packages 100% filled.

Table 4.5 Rheological properties of tomato concentrates at 25°C.

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>5° Brix Concentrate</td>
<td>5.6972 ± 0.3377</td>
<td>0.44677 ± 0.01903</td>
</tr>
<tr>
<td>10° Brix Concentrate</td>
<td>179.65 ± 31.580</td>
<td>0.24078 ± 0.00394</td>
</tr>
<tr>
<td>15° Brix Concentrate</td>
<td>4907.9 ± 319.93</td>
<td>0.1520 ± 0.0112</td>
</tr>
</tbody>
</table>

Values are average ± one standard deviation.
Figure 4.2 Rheological measurements for 5° Brix tomato concentrate.

Rate = shear rate;
\( \eta \) = apparent viscosity;
\( \tau(t) \) = shear stress
Figure 4.3 Rheological measurements for 10° Brix tomato concentrate.

Rate = shear rate;
η = apparent viscosity;
τ(t) = shear stress
Figure 4.4 Rheological measurements for 15° Brix tomato concentrate.

Rate = shear rate;
\( \eta \) = apparent viscosity;
\( \tau(t) \) = shear stress
Figure 4.5 Time to reach $F_0 = 5$ min for water and tomato concentrates in rotating pouch.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns within groups.

Figure 4.6 Time to reach $F_0 = 5$ min for water and tomato concentrates in No. 10 can.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns within groups.
Figure 4.7 Time to reach $F_0 = 5$ min for all rotating packages of water and tomato concentrates.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns within groups of same material.
Figure 4.8 Time to reach $F_0 = 5$ min for water in rotating pouch processed while stationary.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns.

Figure 4.9 Time to reach $F_0 = 5$ min for water in rotating pouch processed while stationary and while rotating.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns within groups.
Figure 4.10 Time to reach $F_o = 5$ min for green beans in ISP, No. 10 can, and rotating pouch.

Errors bars represent ± one standard deviation. Letters indicate significant difference ($\alpha = 0.05$) between columns within groups.
Chapter 5. Summary

In this study, retort pouches were developed to supply vegetables for UGR™ packages at a lower cost. The developed retort pouch was processed in an existing rotary retort while held and protected by a stainless steel basket in order to determine if this system is a viable alternative to processing pouches in still, batch retorts.

The processing times for green beans packaged in the three packaging options, the developed rotating pouch, a No. 10 can, and an institutional size pouch, were measured to be 17, 13, and 40 minutes, respectively. Rotating pouches, despite containing half the amount of green beans and water as No. 10 cans, have a longer processing time. The longer time is most likely due to a lower degree of agitation in the pouch. Since the rotating pouch is not as round as the metal can, green beans may not be as free to move around the package during rotation. Both rotating pouches and No. 10 cans have significantly shorter processing times than ISPs. This difference is due to the lack of agitation of green beans in the ISP during retorting.

Green beans packaged in three packaging options were compared directly after processing and after six months of storage at elevated temperature. No significant difference was observed in consumers’ overall liking of the three green bean samples before the storage. After six months of storage, consumers’ preferred green beans from the No. 10 can more in overall liking than the green beans from either type of pouch.

The effect of product viscosity and residual gas volume on the processing time of rotating pouches and No. 10 cans was also investigated. Despite the rotating pouch containing half the amount of green beans and water as the No. 10 can, the processing time for green beans in a rotating pouch was longer than in a No. 10 can, due to a lower degree of
agitation in the pouch. The processing times of rotating pouches and No. 10 cans filled with water, a tomato concentrate, or green beans in water to one of two levels were compared to investigate if agitation could be increased. All containers with the higher amount of product fill had significantly lower residual gas volumes than the containers filled with the lower amount of product fill. The processing times for rotating pouches and No. 10 cans filled with the more viscous liquids were shortened by decreasing the product fill by 10%. Decreasing the product fill led to an increase in residual gas volume, which increased agitation. The increase in agitation did not have a significant effect for water, green beans in water, or the lowest viscosity mixture in the rotating pouch.

The findings of this study show that processing pouches in existing retorts designed for No. 10 cans is possible. Due to the widespread use of continuous rotary retorts and the growing popularity of retort pouches, food manufacturers may consider using stainless steel baskets for restraining pouches during rotary retorting as an alternative to investing in new pouch compatible retorts. Increasing the residual gas volume in rotating pouches can shorten processing times for liquids with higher viscosities by increasing agitation. However, the findings do not indicate that decreasing product fill by 10% would be helpful to increase processing efficiency of green beans in rotating pouches. Further work on rotating retort pouches should be done to optimize the size of the pouch for compatibility with different applications and foods. More research into the impact of varying headspace in rotating pouches on processing time should be done as well; specifically, research should be done on varying headspace while maintaining the same level of product fill in the pouch. The effect of higher levels of entrapped air on the quality of the food after storage should also be evaluated.
Appendix A. Earlier Rotating Pouch and Basket Prototypes

Three-Sided Pouch

The three-sided pouch consists of 3 rectangular panels of 7.5 in by 9 in. Prototype was too difficult to drop into basket.
Four-Sided Pouch

The four-sided pouch consists of 4 rectangular panels. Two panels are 5.25 in by 11 in, and the other two panels are 4.75 in by 11 in. The equal sized panels are opposite one another.

This prototype was incompatible with existing filling and sealing equipment.
Holes in No. 10 Can

This option was rejected due to the sharp edges and lack of structural integrity. Cutting holes in the No. 10 can greatly weakened the structure.
Thin Metal Bars

This prototype did not protect the pouch adequately due to the large openings. It also did not rotate well in the retort.
Perforated Sheet Metal

This prototype did not adequately protect the pouch, allowing it to slide out during processing. It also was not strong enough to withstand repeated use.
Appendix B. Example Consumer Acceptance Test Ballots

Example ballot from initial consumer acceptance test

OVERALL ACCEPTANCE OF GREEN BEANS

Instructions:

1. Before each sample please rinse with room temperature water.
2. Check to ensure that the 3-digit code on the sample cup matches the one written in above the question.
3. Rate each sample for overall acceptance, saving some of the sample for questions later on.
4. Repeat the rinse procedure between each sample and evaluate the samples in the order they are presented on this page.

Sample Number: 938

How much do you like this sample overall?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 2 3 4 5 6 7 8 9

Dislike extremely
Neither like nor dislike
Like extremely

PLEASE RINSE NOW

Sample Number: 269

How much do you like this sample overall?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 2 3 4 5 6 7 8 9

Dislike extremely
Neither like nor dislike
Like extremely

PLEASE RINSE NOW

Continue to the next page
Sample Number: 741

How much do you like this sample overall?

1 2 3 4 5 6 7 8 9

Dislike extremely
Neither like nor dislike
Like extremely

You have now completed this portion of the test. Please proceed to the next portion of the test and do not go back and change these answers.
SPECIFIC ATTRIBUTE ACCEPTANCE OF GREEN BEANS – AROMA, APPEARANCE, TASTE, MOUTHFEEL, & TEXTURE BY HAND

Instructions:

1. Before each sample please rinse with room temperature water.
2. Check to ensure that the 3-digit code on the sample cup matches the one written below.
3. Rate each sample for each individual attribute asked below.
4. Repeat the rinse procedure between each sample and evaluate the samples in the order they are presented.

SAMPLE 938

How much do you like the aroma of this sample?

1 2 3 4 5 6 7 8 9

Dislike extremely

Neither like nor dislike

Like extremely

How much do you like the appearance of this sample?

1 2 3 4 5 6 7 8 9

Dislike extremely

Neither like nor dislike

Like extremely

How much do you like the taste of this sample?

1 2 3 4 5 6 7 8 9

Dislike extremely

Neither like nor dislike

Like extremely

Continue to the next page
How much do you like the **mouthfeel** of this sample?

1  2  3  4  5  6  7  8  9

- Dislike extremely
- Neither like nor dislike
- Like extremely

How much do you like the **texture by hand** of this sample?

1  2  3  4  5  6  7  8  9

- Dislike extremely
- Neither like nor dislike
- Like extremely

Any comments on this sample?

__________________________________________________________

Please rinse your mouth with room temperature water before tasting the next sample.
SAMPLE 269

How much do you like the **aroma** of this sample?

1 2 3 4 5 6 7 8 9

- Dislike extremely
- Neither like nor dislike
- Like extremely

How much do you like the **appearance** of this sample?

1 2 3 4 5 6 7 8 9

- Dislike extremely
- Neither like nor dislike
- Like extremely

How much do you like the **taste** of this sample?

1 2 3 4 5 6 7 8 9

- Dislike extremely
- Neither like nor dislike
- Like extremely

How much do you like the **mouthfeel** of this sample?

1 2 3 4 5 6 7 8 9

- Dislike extremely
- Neither like nor dislike
- Like extremely

Continue to the next page
How much do you like the **texture by hand** of this sample?

1. Dislike extremely
2. Neither like nor dislike
3. Like extremely

Any comments on this sample? ________________________________

Please rinse your mouth with room temperature water before tasting the next sample.
SAMPLE 741

How much do you like the **aroma** of this sample?

Dislike extremely  
Neither like nor dislike  
Like extremely

How much do you like the **appearance** of this sample?

Dislike extremely  
Neither like nor dislike  
Like extremely

How much do you like the **taste** of this sample?

Dislike extremely  
Neither like nor dislike  
Like extremely

How much do you like the **mouthfeel** of this sample?

Dislike extremely  
Neither like nor dislike  
Like extremely

Continue to the next page
How much do you like the texture by hand of this sample?

1 2 3 4 5 6 7 8 9

Dislike extremely

Neither like nor dislike

Like extremely

Any comments on this sample? __________________________________________

You have now completed the sensory test. Please turn in your consent form and ballot.
Example ballot from follow-up consumer acceptance test

OVERALL ACCEPTANCE OF GREEN BEANS

Instructions:

5. **DO NOT EAT THE SAMPLES.**
6. Check to ensure that the 3-digit code on the sample cup matches the one written in above the question.
7. Rate each sample for overall acceptance in the order they are presented on this page.

Sample Number: **903**

How much do you like this sample overall?

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<thead>
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<td>5</td>
<td>4</td>
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<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Dislike extremely
Neither like nor dislike
Like extremely

Sample Number: **336**

How much do you like this sample overall?

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<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>9</td>
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<td>7</td>
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<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Dislike extremely
Neither like nor dislike
Like extremely

Continue to the next page
Sample Number: **870**

How much do you like this sample overall?

- [ ] □ □ □ □ □ □ □ □ □

  - 1: Dislike extremely
  - 5: Neither like nor dislike
  - 9: Like extremely

You have now completed this portion of the test. Please proceed to the next portion of the test and *do not go back and change these answers.*
SPECIFIC ATTRIBUTE ACCEPTANCE OF GREEN BEANS – AROMA, APPEARANCE, & TEXTURE BY HAND

Instructions:

5. **DO NOT EAT THE SAMPLES.**
6. Check to ensure that the 3-digit code on the sample cup matches the one written below.
7. Rate each sample for each individual attribute asked below in the order they are presented.
8. To evaluate texture by hand, squeeze the sample.

SAMPLE 903

How much do you like the aroma of this sample?

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Dislike extremely  Neither like nor dislike  Like extremely

How much do you like the appearance of this sample?

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Dislike extremely  Neither like nor dislike  Like extremely

How much do you like the texture by hand of this sample?

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Dislike extremely  Neither like nor dislike  Like extremely

Any comments on this sample? ________________________________
SAMPLE 336

How much do you like the aroma of this sample?

1  2  3  4  5  6  7  8  9

Dislike extremely
Neither like nor dislike
Like extremely

How much do you like the appearance of this sample?

1  2  3  4  5  6  7  8  9

Dislike extremely
Neither like nor dislike
Like extremely

How much do you like the texture by hand of this sample?

1  2  3  4  5  6  7  8  9

Dislike extremely
Neither like nor dislike
Like extremely

Any comments on this sample?

__________________________________________________________________
SAMPLE 870

How much do you like the **aroma** of this sample?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 2 3 4 5 6 7 8 9

Dislike extremely  Neither like nor dislike  Like extremely

How much do you like the **appearance** of this sample?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 2 3 4 5 6 7 8 9

Dislike extremely  Neither like nor dislike  Like extremely

How much do you like the **texture by hand** of this sample?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

1 2 3 4 5 6 7 8 9

Dislike extremely  Neither like nor dislike  Like extremely

Any comments on this sample?

________________________________________

You have now completed the sensory test. Please turn in your consent form and ballot.

Please leave the samples on the table. Thank you for your participation.
Appendix C. Time/Temperature Curves

Green beans in rotating pouch

![Graph showing temperature over time for green beans in rotating pouch.]

Green beans in No. 10 can

![Graph showing temperature over time for green beans in No. 10 can.]

1. 100% Fill
2. 90% Fill
Green beans in ISP

Water in rotating pouch, rotating
Water in rotating pouch, stationary

5° Brix in rotating pouch
$10^\circ$ Brix in rotating pouch

$15^\circ$ Brix in rotating pouch
Water in No. 10 can

5° Brix in No. 10 can
10° Brix in No. 10 can

15° Brix in No. 10 can