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Transportation, Handling, and Microbial Comparison of Molded Fiber and Expanded Polystyrene Apply Trays

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TRANSPORATION, HANDLING, AND MICROBIAL COMPARISON OF MOLDED FIBER AND EXPANDED POLYSTYRENE APPLE TRAYS

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ABSTRACT

Washington Apples are shipped all over the United States for retail consumption. In order to survive the distribution cycle, the apples need adequate packaging to reduce damage. The two main materials used for the apple trays are expanded polystyrene (EPS) and molded fiber. An industrial switch from Molded Fiber to EPS trays provoked an interest in the difference between the two materials. Testing was required to conclude which tray material, if any, provided better protection for the apples. In order to determine the differences between the two trays, the physical and microbial characteristics were tested. The physical performance of the trays was tested through distribution, drop, and handling testing. A microbial analysis of the condensation was performed to determine the microbial protection that the trays offer. After performing a cost analysis, the EPS trays cost twice as much as the Molded Fiber trays. The testing proved that there is no difference in the physical and microbial protection that the two trays provide for the apples.

DEDICATION

Five years ago, my grandfather passed away at 88-years-young. He was a World War II vet, a self proclaimed politician, and a friend to everyone that he met. Bernie and I always had a special relationship. There is not a single important moment in my life that he missed. At the end of my freshman year in college, Bernie came down to Clemson to see my older sister graduate. The two of us got to spend time walking slowly around campus as I told him all about where I went to school. We often stopped for him to express how excited he was for me. About halfway through our walk, he asked me if I would ever stay in school to pursue another degree. At the time, I was more concerned about finishing up my first year and had not even thought about the future. He told me that Clemson was full of opportunities and that I should take advantage of every single one of them. I never thought that piece of advice would stay with me, but somehow it did. Two years later, I was offered a chance to apply for the BS/MS program at Clemson. My first thought was that Bernie would want me to do this; this is the opportunity he was talking about. This research is dedicated to my grandfather. Thank you for teaching me how to fight for your dreams, respect those around you, but most importantly, listen to what everyone has to say. Thanks for listening Bernie.

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INTRODUCTION

The United States produces over 4 million tons of apples each year. The abundance of apples allows the average US consumer to eat roughly 19 pounds of fresh apples per year. Washington State is responsible for producing over 50% (roughly 10-12 billion apples) of these apples per year (The US Apple Industry). The apples experience multiple hazards throughout the distribution environment before they make it to the retailer. Because of this, the packaging used must provide physical and microbial contamination protection for the apples. Currently, there are two different tray materials used for packaging apples; expanded polystyrene (EPS) and molded fiber. In order to determine which material provides the best protection for the apples, they are compared in terms of there response to physical hazards like shock, vibration, and compression as well as microbial hazards like condensation.

Expanded polystyrene and molded fiber are used throughout the packaging industry from the packaging of consumer electronics to eggs. Comparisons of their physical properties have been performed, but comparisons of their application in the packaging of fruits and vegetables have not been considered or at least widely published prior to this work with the exception of a study by Singh and Xu, (1993). Due to the large number of trays used for the packaging of fruits and vegetables, it is important to compare and analyze their performance throughout the distribution cycle.

The comparison of the tray's performance in this study starts when the apples are hand placed in the trays at the processing plant and ends with the unloading of the trays for retail display. Prior to being placed in the trays, the apples are washed, cooled, and sorted for distribution. At this stage in the sorting process, the apples are classified according to the United States Department of Agriculture Standards for Grades of Apples (United Stated Standards for Grades of Apples). These standards take into account size, color, bruising, and visual imperfections. Any damage that occurs after this sorting stage does not change the grade or classification of the apple. After the sorting phase, the apples are placed into the trays and are prepared for distribution. From this point on, the apples will remain in the trays throughout the cold chain distribution until they are placed on display in the retail environment (Washington State Apple Commission).

During the distribution cycle, the apples are subject to damage from shock, vibration, and compression (ISTA 3E). These hazards have the potential to cause bruising of the apples if the trays do not provide the necessary protection. Apples may also experience damage as they are being handled or unloaded from the cases that they are shipped in. Due to the weight variations in apples, each tray has to support approximately 3.6 kilograms as the trays are removed from the cases. There is a possibility for the trays to crack or flex such that the apples fall out of the tray when being removed from the case. This not only damages the apples, but it also deforms the trays such that they cannot be used in the retail shelf display.

During distribution, there are places where there is a potential for the cold chain to break, in which temperatures can exceed that of refrigerated conditions. It is during these time periods that condensation can form on the apples and the microbial populations have the potential to grow. The trays need to be able to prevent these existing populations from growing during these stages. Although there are no documented cases of outbreak, this study considers the potential for Listeria and E.coli growth.

In order to compare the performance between these two packaging materials, a comparison of their response to distribution, handling, and microbial testing is performed. The results of the tests aid in the selection of a tray material that provides better protection for apples from the orchard to the retailer.

REVIEW OF LITERATURE

In 2013, the average US consumer ate 117.2 lbs of fruit according to the USDA. The top fresh fruits that are consumed are bananas, apples, and grapes. In 2014, fruit and nut farming brought in a total of $30.1 billion dollars to US farmers (USDA ERS). The US produces over 4 million tons of apples each year. The abundance of apples allows the average US consumer to eat roughly 19 pounds of fresh apples per year (The U.S. Apple Industry). In order for these apples to reach consumers all over the United States, they must be able to survive the distribution environment from the orchard to the retailer. In this environment, the apples could potentially experience physical and microbial damage. Therefore, it is important for the packaging materials used to ship the apples provide protection from these hazards.

Packaging Materials

Since the 1920's, fresh apples have been packaged in Expanded Polystyrene (EPS) trays and molded fiber trays. Both materials are used in a variety of other packaging applications including electronics and consumer goods. Because of their large spectrum of uses, many comparisons between the two materials have been done, but the two materials have yet to be compared in the apple tray application. Before the distributor can decide which material they would like to use, they need to consider a few aspects. First and foremost, the cost of each material should be examined. Next the distributor will look into which tray will provide better protection for the apples during transit. Better protection will result in less damage costs and save the distributor money. Another point for consideration will be the end use, or recyclability, of the material. The choice of material is important because it has the potential to change the quality of the apples when they arrive at the retailers. In order for the correct material to be chosen, the history and manufacturing process of each material needs to be examined because the products or process can affect the physical properties of finished product.

Molded Fiber

Molded fiber has been used in the packaging industry for about one hundred years. The first patent for a molded fiber patent was granted to Martin L. Keyes in 1903 for equipment that produced molded fiber pieces. These pieces could be put together to create and egg carton. The egg carton was the earliest use of and still is the on of the most common uses of molded fiber. Today, molded fiber is manufactured for a variety of uses. This material is appealing because of its sustainable nature. Molded fiber supports every companies motive to maintain a strong environmental image through its use of recycled materials. (Molded Fiber History)

Manufacturing Process

The process to create molded fiber begins by bringing in bales of recycled paper and corrugated to the manufacturing plant. These bales are dumped into pulpers that blend the recycled materials, mix them with water, and remove the non-fiber materials. This mixture is then placed into holding tanks to clean the fiber. A food safe dye is added to the pulp mixture for color. This color can be changed depending on the end use or the customer request. The pulp mixture then enters machines that pull the pulp into molds through suction and removes the water from the pulp mixtures. It is during this phase of the manufacturing process that the four different types of molded fiber are created based off of the different molds that could be used. The water that is removed from the pulp is recycled and reused within the plant. The formed trays are then put through a drying process to evaporate any remaining water. The finished trays are sent off, palletized, wrapped, and used in their respective ways. The manufacturing process allows for certain physical characteristics of the molded fiber to be created. During this process, the finish of the molded fiber can be changed from rough to smooth, depending on its end use (Molded Fiber History).

Types

There are four main types of molded fiber trays that are currently manufactured. Type I (thick wall) is created from a single mold. This causes one side to be smooth and one side to be rough. The wall thickness will be between 3/16 to 3/8 inches. Type I is mainly used for non-fragile, heavier items like furniture or vehicle parts. Type II (Transfer molded) is created from one forming mold and one transfer mold. This allows for both surfaces to be smooth. The thickness of the wall varies between 1/8 to 3/16 inches. Type II is used for the packaging of electronics, but more importantly, the packaging of fruit. Type III (thermoformed) is created from multiple heated molds to form smooth surfaces with minimal draft angles. The wall thickness, considered to be thin, is between 3/32 and 5/32 inches. Because the molds used are heated, the molded fiber does not need to go through a drying oven. This caused the finished product to be more dense than the other types. Type III is most commonly used for cups, bowls, plates, and serving trays. Type IV (processed) refers to molded fiber products that have undergone a type of secondary treatment. These treatments range from die cutting to printing to embossing to special pulp formulas (IMFA).

Expanded Polystyrene

Expanded Polystyrene is one of the most versatile packaging materials on the market. It can be used for packaging, construction, and many other applications. EPS can be used for any size and shape products, but it is mostly used for high value and heavy products – like electronics. In terms of food packaging, EPS is known to keep foodstuff fresh through distribution and reduce the amount of food wasted.

Manufacturing Process

The raw material Expanded Polystyrene is created from oil through a chemical process. The first step is to use machines known as pre-expanders use steam to heat the raw material to a temperature between 80-100 degrees. In this step, the cells within the material expand through air retention. The cells are closed and hold the air within their interior. The particles then enter an intermediate maturing stage, which allows the cells to cool and create a vacuum in their interior. The cells are also dried during this stage. During the intermediate maturing stage, the cells develop their elasticity and improve their expansion capacity. The final stage is expansion and molding. In this stage, the particles are put into molds with steam to make sure the beads stick together. The particles are not stable and in the desired shape of the customer. (EPS and the Environment)

Physical Properties

Due to its versatile nature; EPS must have properties that protect its wide range of products. EPS has a high-energy absorption index which allows it to provide protection to the product from shock during transport. Because the cell structure is made up of 98% air, EPS is one of the lightest packaging materials available. EPS can also provide thermal insulation through its closed cell structure for products like pharmaceuticals and vaccines. A few other qualities include resistance to humidity, compressive resistance, and chemical resistance. (EPS and the Environment)

Cushioning Properties

Molded pulp cushioning properties are often compared to EPS because they are used for products that receive multiple impacts during shipment. Rather than comparing properties of the two materials using a specific product, one of the other ways to compare them is to use mathematical models. Cushion compression performance was calculated using stress strain curves from which a cushion coefficient-maximum stress curve was obtained (Li et al., 2014). In addition, rebound performance was using deformation (50%) for 3 minutes and measuring thickness 10 seconds after compression was lifted.

The compression and removal of load was repeated 3 times and measurements entered into a calculation yielding rebound performance. According to the final results, the cushion performance for biomass cushion material was smaller than EPS or EPE (expanded polyethylene) but they concluded that it fell within the region suitable for it to be used as a liner for small electronic products. Regarding rebound performance, it was found that the rebound ratio was higher for biomass cushion material than EPS but lower than EPE. Overall, it was found that the biomass cushion material, if formulated with a 2:5 fiber:starch ratio, could replace EPS and EPE as a protective cushioning material.

Molded pulp cushions can be made a variety of shapes and draft angles which can influence the performance as a protective material. Hoffman (2000) demonstrated that shapes such as cylinders and cones with rounded edges performed better than squares and rectangles with sharper edges under static compression. Other influencing factors included cushion height, drop height and product shape. All of these factors should be taken into account when designing an appropriate cushion design using molded pulp. According to Hoffman (2000), one variable not taken into account, that should be included in future studies, was static creep.

Hoffman's work along with others, has been used as a foundation for future development of mathematical models using Finite Element Analysis for creating molds for molded pulp cushion designs. Gurav et al., (2003) performed experiments as well as models on additional variables used to measure cushion and strength properties of molded pulp. They included wall thickness, test duration, presence of impurities in the fiber slurry, tensile-strain analysis and rib design. Based on their findings, it appears that the spread of the load across the surface of the material plays an important role in spread of the maximum product loading while thickness plays an even lesser role. However, in shorter test periods, wall thickness has a strong influence which the authors thought may have been due to local buckling during testing. They also found that high levels of impurities from using recycled content in the slurry had a strong influence on variation in test results. Guray et al., (2003) reported that using Finite Element Analysis (FEA) was a powerful tool for predicting reaction to stress forces, optimizing geometry, thickness and ribs for strength. One of the recommendations they suggested for future work was optimization of geometry for improvement of cushioning properties.

Apples

Washington State is responsible for producing over 50% (roughly 10-12 billion apples) per year (The U.S. Apple Industry). The six other states that produce the most apples are Michigan and New York with 10% each, California at 8%, Pennsylvania at 4%, and Virginia at 3%. Over 50% of the apples produced are used for fresh market. This means that these apples are to be used as is. The remaining percentage is used for apple products like apple juice and applesauce. The harvest of apples provides 16% of income to US farmers. (Washington State Apple Commission). Washington apples are harvested between August and November (Washington State Apple Commission). Because apples are produced in all regions of the United States, most apples will not have to make the full trek across the nation. There are exceptions, however, because Washington State apples are consumed in all regions of the United States.

Harvest

Washington apples are harvested between August and November (Washington State Apple Commission). The apples are hand picked in the orchard and gently placed into bins by placing the bag of apples in the bin and then slowly removing the bag allowing the apples to roll out into the bin. The bulk bins are transported to the packing facilities to undergo inspection, sorting, and packing before they are sent out to the retailers.

Standards

The United States Department of Agriculture provides apple orchards with a standard that sets forth the qualifications for the apples that they grow and distribute. The apples are first sorted by their grade. There are five major categories of grades; Extra Fancy, Fancy, No. 1, No. 1 Hail, and Utility. These grades can also form a combination grade of Extra Fancy and Fancy, Fancy and No. 1, and No. 1 and Utility. Apples are graded based off of their ripeness, bruising, and visual appearance. Extra Fancy apples are mature and free from injury while Utility grade are mature and contain some injury but no serious damage. Color requirements for the apples are based off of the percentages listed in the Fig. 1 below (United States Standards for Grades of Apples). The apples must meet a minimum color percentage base off of their variety in order to meet a certain grade.

Only the varieties listed below shall be required to meet a minimum color requirement.	U.S. Extra Fancy	U.S. Fancy	U.S. No. 1
Variety	Percent	Percent	Percent
Red Delicious	66	40	25
Red Rome	66	40	25
Empire	66	40	25
Idared	66	40	25
Winesap	66	40	25
Jonathan	66	40	25
Stayman	50	33	25
McIntosh	50	33	25
Cortland	50	33	25
Rome Beauty	50	33	25
Delicious	50	33	25
York	50	33	25

[1]Variations on varietal designations listed above must meet or exceed those color requirements listed.

Figure 1: USDA Color requirements

Because the grading requirements for the apples are strict, there are certain tolerances allowed for variations. In terms of size and defect, the standard allows for 10% of the apples to fail. The standard has also determined methods of sampling in order to correctly count and measure the weight of the cases of the apples. Any damage or deterioration that may occur during transport or storage will only affect the condition of the apple, not the grade of the apple. The packing requirements set forth by the USDA explain that the apples must be contained within a tray or cell that allow the apple to fit "fairly tight". This means that the tray or cell is the proper size for the apple. The outer containers of the apples are required to display the variety, grade, and count of the apples inside. The apples are sorted and graded prior to shipment to the retailers. Any damage that occurs to the apples during the distribution process will not change the grade and standard of the apple (United States Standards for Grades of Apples).

Bruising and Bruise Measurement

It is important to note that the quality of the apple is measured prior to the distribution cycle. Therefore, any damage that occurs during the distribution cycle will not affect the quality of the apple. A paper by Mitsuhashi-Gonzalez describes in the bruising profiles of apples in detail. The paper explains that when there is more intercellular space within an apple, there is a larger potential for bruising. The intercellular space increases as an apple matures. There are a number of different ways to measure a bruise on an apple. One paper on bruising by R. Lewis measures the bruise by using ultrasonic scans, while Singh and Xu measure the average area and size. In the Singh and Xu paper, the researchers went into further detail to use their measurements to re qualify the apples based on the USDA standard for rating apples. The method that is chosen by the researcher is dependent on the nature of the work and the data that needs to be collected.

Types of Apple Packaging

Despite constant changes and advances in technology, the process of packaging apples is still done by hand. After apples are picked, washed, and sorted, they travel down a conveyor to be hand packed in a variety of packages. Depending on the size, destination, and end use of the apples, they can be packed in a variety of packaging types. Apples are most commonly packed in cartons, cartons with trays, trays with over wrap, or bags. The cartons are made of varying strengths of corrugate, but typically follow a regular slotted container (RSC) or a full telescoping container (FTC) construction. Within these containers, the apples can be packed in EPS or molded fiber trays. The apples can also be placed loosely in the containers without any extra support. Apples can also be packed in bags made of polyethylene or mesh (AG – 414 -8 Packaging Requirements). Although this does provide the consumer with a visual of the apples, the polybag provides little to no protection for the apples during transport causing the consumer to see damaged apples. Another type of packaging consists of foam trays overwrapped in a shrinkable film. This type of packaging provides some protection as well as a visual of the apples for the consumer (Gurav, 2003).

A study performed by Singh and Xu, (1993), examined the effect of package type and truck suspension on the effects apple bruising. Two types of corrugated box styles were used: Regular slotted container (RSC) and Full telescopic half slotted (FTHS). Both were made using single wall C flute corrugated (200 psi burst strength) with paperboard dividers holding 120 apples laying on their sides. Two other styles of packages were used which were the same as the aforementioned package styles except an RSC with a higher burst strength (275 psi) was used. In addition, instead of paperboard dividers, 5 layers of molded pulp trays were implemented and the entire container held 100 apples. Finally, a fourth style of container was used with a FTHS style corrugated case constructed using the same type of corrugated FTHS mentioned previously but the main difference was that of 4 layers of polystyrene trays were placed in the case rather than paperboard dividers. This case held 96 apples.

Vibration simulation was created using leaf spring and air ride suspension. Apple bruising was evaluated using a computer program described by Brown et al., 1989 and top and bottom portions of the shipping cases were examined. Singh and Xu (1993) found that there was more damage on the top of each style of packages than the bottom and all package types using paperboard had a greater level of damage than the one style using an EPS tray. The difference was attributed to a higher level of static friction for paperboard compared to EPS. Since no statistical comparison was performed it is unknown whether the difference was significant.

Regarding suspension type, leaf spring suspension gave similar or higher level of damage for all styles of packages. Overall, the FTHS style box with EPS trays gave the least level of damage while the FTHS style box with molded pulp trays caused the most damage to the apples. Both box styles that used paperboard individual cell dividers provided similar damage levels when compared to one another.

Distribution Cycle

Before the apples arrive at the retailer, they must go through a vigorous distribution cycle. As explained in the harvest section, the apples are placed in bulk bins in the orchards. Following the distribution cycle in Fig. 2 (United States Standards for Grades of Apples), the apples will arrive at the packing house immediately after they leave the orchard.

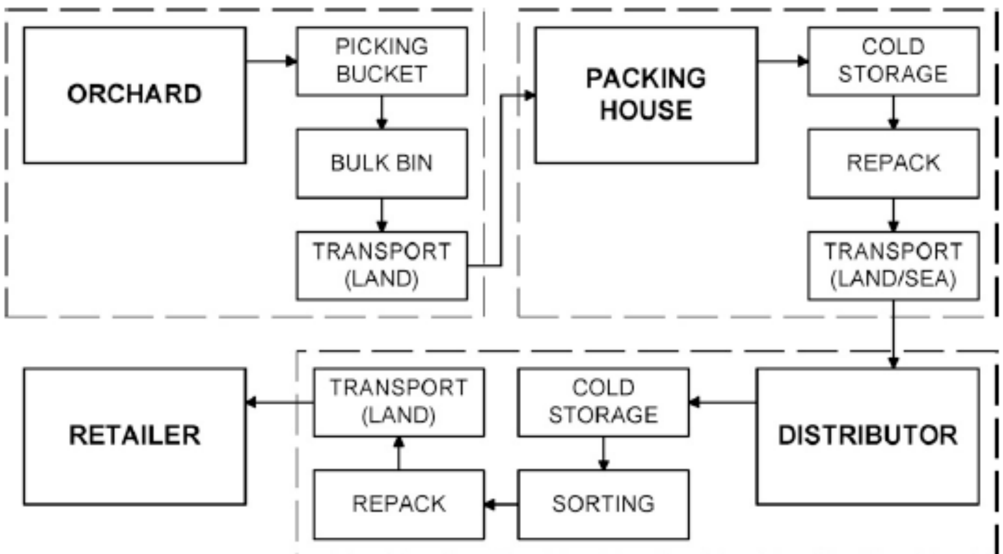

Figure 2: Distribution Environment from Orchard to Retailer

Orchard to Packing House

Because apples are a fragile fruit, every step of the handling process is done with care to make sure that the apples are not damaged before they go through distribution. Beginning in the orchard, the apples are picked by hand at their appropriate time and placed in cloth bags. Once the bag is full, the bag is lowered into large bins and the apples are slowly rolled out of the bags. The bins are then transported to the packing facility. Here they go through a series of steps before they are hand packed in their shipping trays and cases. Once the bins arrive at the plant, they are lowered into a water bath in order for the apples to float out of the bins. The water bath cleans the apples as well as begins the cooling process. The core temperatures of the apples do not yet reach the industrial standard of 2-4 Degrees Celsius because any wax or post treatment still needs to stick to the surface of the apple. The water bath, however, does begin the cooling process of the apples. After the apples are cleaned, and sometimes coated, they begin a sorting process. The apples are initially inspected by hand so that any apples with visual defects can be removed from the line. After a visual inspection, the apples go through another set of inspections done by a computer. These inspections are done based off of the United States Standards for Grades of Apples as previously described.

Packing House to Retailer

After the sorting process, the apples are hand packed into the trays. The apples are placed in the tray cells on their sides, which decreases the chance of any stem and blossom coming in contact with each other and the tray material. This orientation also reduces the chance that unwanted microorganisms would enter the core of the apple. After the apples are packed, they are placed in storage. The apples are then stored in cold storage to maintain the industry core temperature standard of 2-4 Degrees Celsius. They are kept in storage until the retailers demand the apples, allowing them to be placed in trays just prior (30 days maximum for fresh apples) to shipment (Riedinger, 2013). Once the apples are packed in their trays and cases, they enter the distribution environment. In order to maintain freshness, the apples are shipped and distributed in a cold chain environment. Depending on the end location, the apple cases will go through a few distribution centers to be unpacked and repacked onto a mixed load pallet. Once the apples reach the retailer, they are kept in refrigerated storage until they are placed on display for the consumers to purchase.

In a study performed in 1973 (Matson and Mohsenin), machinery was developed for packing apples, which would allow orientation of apples in a uniform manner. In preliminary studies they found that the retailers wanted apples shipped with all apples oriented in the same direction (cheek up or cheek down) to give a more appealing appearance to the consumer. They also found the apples with a more conical shape, such as red or golden delicious, were much more difficult to orient in a cup shaped foam tray than more round shaped apples, such as Rome Beauty or Macintosh. The machinery developed, involved an orientation section in which the apples were placed in a foam tray which were conveyed to a vertical vibration table which exposed apples to 1/16 to 3/16 inch amplitude and 0 to 1000 cycles per minute frequency for a minimum of 9.6 seconds. After orientation, the apples were shrink wrapped and placed in a shipping case either manually or automatically at a rate of 40 consumer units per minute.

Hazards

There are many obvious hazards that come about during the distribution and handling of apples. The distribution channel is going to be the same regardless of the tray material that is used for the apples. Because of this, the difference in the quality of the apples when they arrive at the retailer is going to be based on how the different materials handle the hazards that come about during distribution. The three main areas of concern are handling, distribution, and microbial contamination.

Handling and Distribution

The distribution cycle for any product can always cause damage to the product itself. Apple distribution is no exception to this rule. Apples are subject to damage from shock, vibration, and compression (International Safe Transit Association). All three of these elements will occur during the distribution cycle. Compression is experiences in two different forms, static and dynamic. Static compression occurs throughout the entire distribution process from the weight of the unit load. The bottom of the unit load will experience this the most, however, the top of the unit load will also experience static compression if the pallet is stacked in transit or in storage. Dynamic compression occurs during distribution through the movement of the unit load. Vibration occurs during distribution as well and it come from the input of the road, air, or water. Shock mainly occurs when a pallet jack or forklift is handling the pallet and any small drop or impact happens. The tray materials that are used to hold the apples are designed to protect them from these hazards.

Apples may also experience damage as they are being handled. The cases of apples have the potential to be dropped when being carried by personnel or when traveling across conveyors when they are sorted. This will cause the cases to experience a single drop from an average height of 0.6 meters (Lewis, 2008). Once the apples are ready to be put on display, they are removed from the cases by handling the trays. Because of this, each tray must be able to support the weight of the apples (roughly 3.6

kg) without cracking or dropping any apples (Riedinger, 2013). This could damage the apples and deform the trays such that they cannot be displayed on the retail shelves. The trays are supposed to protect the apples from the distribution hazards and the handling damages that can occur. In 1993, a study was done to determine the percent of bruised apples, the average number of bruised apples, and the average bruise area per apple that were packed in four different types of packages. This series of vibration tests proved that the foam, or EPS trays, produced the least damaged apples after testing while the molded fiber trays yielded the most damage (Singh, 1993).

Bruising

The physical hazards that the apples experience during distribution can cause the apples the bruise. Because apples are a sensitive and fragile fruit, this can happen easily depending on the type of apple. Therefore, the trays must protect the apples from these physical hazards so that the apples arrive at the retailer without bruises. They are a variety of ways to measure bruise depth, shape, size and intensity; however, in terms of tray protection it is important to measure the number of bruises and their average size. If a bruise is going to form on an apple, it will form within 24 hours of the damaging event (Lewis, 2004). A study done in 2009 revealed the profile of a bruise on an apple after a set force, one that was equal to the force of picking an apple from a tree, was applied. This research explained that a bruise can cause discoloration and internal cell damage to the apple (Mitsuhashi-Gonzalez). These characteristics are what cause the soft spot or bruise on the apple to be easily seen to the consumer.

Microbial

Throughout the distribution cycle, there are potential points at which the cold chain can be broken. The apples can be left on a loading dock or left on the warehouse floor for too long during the sorting process. At these points, there is a potential for microbial population to grow depending on the natural flora that already exists on the apples. According to one study, raw apples contain “a low to moderate microbial load, and no fecal coliform, *Salmonella*, or *E. coli* were found”. (Senkel, 1999). There are also no reported outbreaks of *Listeria* spp. or *E.coli* caused from the consumption of raw apples. This data creates the conclusion that there is no significant growth of existing flora if the apples experience condensation during the distribution cycle. This data provides information that microbial contamination is not a leading factor when it comes to picking a tray material. The microbial properties of the apples will be tested to make sure comparable results are found.

End of Life and Sustainability

There are many different approaches that can be taken to the end of life usage and the sustainability of a material. First, there are different definitions of what makes a material sustainable. Some methods only consider resources used, while other consider cost and recyclability. Based on the approach taken, the opinion on which material, EPS or molded fiber, is more sustainable can change. In regards to the weight of the materials, EPS is made up of 98% air (EPS and the Environment) making it much lighter than the molded fiber trays. Another way to approach sustainability is to look at the raw materials that are used to make each material. Molded fiber is made of 100% post consumer content (State of Oregon Department of Environmental Quality) while EPS is made of oil, styrene, and pentane all of which are virgin materials. Some EPS manufacturers will use up to 40% recycled material when manufacturing EPS. The energy used to manufacture each material is quite surprising. Molded fiber uses almost twice the amount of energy as EPS does to manufacture (EPS and the Environment). The recyclability of each material is most often considered in the life cycle analysis of the materials. Molded fiber is easily recyclable, however, the rate of recyclability is unknown. The rate at which EPS is recycled has increased by 33 million pounds since 1990 (EPS Recycling), however, EPS recycling programs can be difficult to find and difficult to comply with all the regulations.

The Alliance of Foam Packaging Recyclers did a direct comparison between molded pulp and EPS and published their findings in a 2011 brochure. One of the first areas discussed is that many people think that switching to molded pulp will save money but their brochure indicates that increased product damage can create increased cost as well as increase waste from product that must be disposed and energy spent to make additional replacement product. The brochure cites a study performed by the Oregon Department of Environmental Quality showing that molded pulp has a higher environmental impact owing mainly to the higher energy necessary to produce molded pulp compared to EPS. Further, it is stated that EPS has a known recycle stream with up to 19% post-consumer recycle rate and 25% post-industrial recycle rate. While molded pulp uses recycle content material, the shorter fibers from recycle pulp grade material can reduce the overall strength of the cushion material.

A Market Review of the UK market rated molded pulp and EPS on six different characteristics for the horticultural market. The scale was 1 = worst to 5 = best. Molded pulp ranked 5 for biodegradability/recyclable and organic-type aesthetics compared to a ranking of 1 for EPS on both characteristics. EPS ranked 5 for shape accuracy and water resistance while molded pulp ranked 4 for shape accuracy and 2 for water resistance. Regarding lowest price, EPS ranked 4 and molded pulp ranked 1 and EPS ranked 4 for product weight with molded pulping ranking 2. Overall, molded pulp ranked 19 and EPS came out only one point higher at 20. According to the study, the UK market saw a price decrease in molded pulp products imported from China but that the price for molded pulp still remained higher than for EPS and that the market for molded pulp in the UK would likely be static for the next 2 years. (PendlePace LTD, 2005).

EXPERIMENTAL

Distribution Environment Simulation

The main purpose of distribution simulation testing is to determine if there is a difference in the physical protection that the two different trays provided for the apples during distribution.

Apples

A sample size of 400 apples, 200 for each tray material, was used for distribution testing. The apples used in this experiment were Ginger Gold apples harvested on August 12, 2013. The Hess Brothers in Pennsylvania donated the pallet of fresh apples (chlorine washed) to be tested in this experiment. The apples were shipped in corrugated cases (C-flute, single wall) directly from harvesting to Clemson University (Clemson, SC) for testing.

Materials

Two different tray materials were tested: molded pulp and expanded polystyrene (EPS). The trays were obtained from Keyes Packaging in Washington. Both types of materials are typical of that which is used in industry to ship fresh apples to grocery store where the trays area also used for retail display. The cases used to contain the trays for testing were C-flute single corrugated were provided by The Hess Brothers. The pallet was 40 x 48 inches in length and width and was provided by Hess Brothers.

Preparation and Inspection

Both the trays and the apples were preconditioned to refrigerated conditions (5.5-8.3°C) for 24 hours prior to testing. Five apples were evaluated from each tray utilizing the sampling pattern illustrated in Fig. 3 to reduce cell location effects.

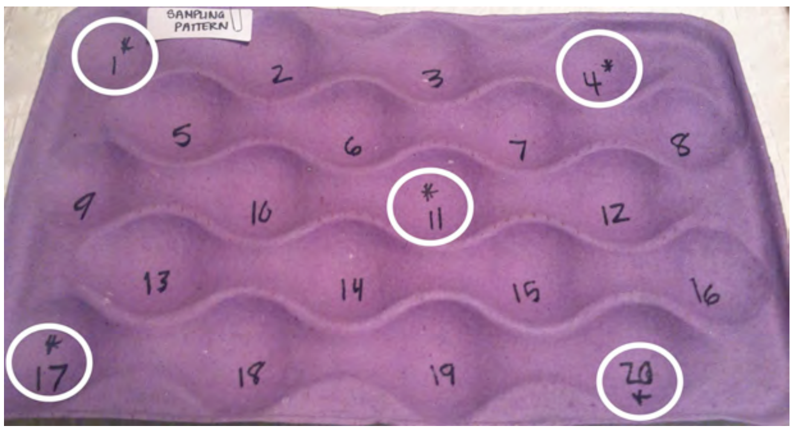

Figure 3: Tray Sampling Locations.

Apples were visually inspected for number of bruises before testing, immediately after testing, and 24 hours after testing. The size of the bruises, inspected at the same time increments, were measured using digital calipers to estimate a square area of the bruise. The apples were inspected at 24 hours because prior work suggests that any bruise that was going to form from damage would be fully visible within 24 hours (Lewis, 2007). During pretest-inspection, any bruising that was found was recorded, but apples with virtually no bruising were moved into the sample areas as seen in Fig. 3.

Each case sampled was packed with new trays and pre-inspected apples. The cases were reloaded onto the pallet. The pallet and layer configuration can be seen in Fig. 4.

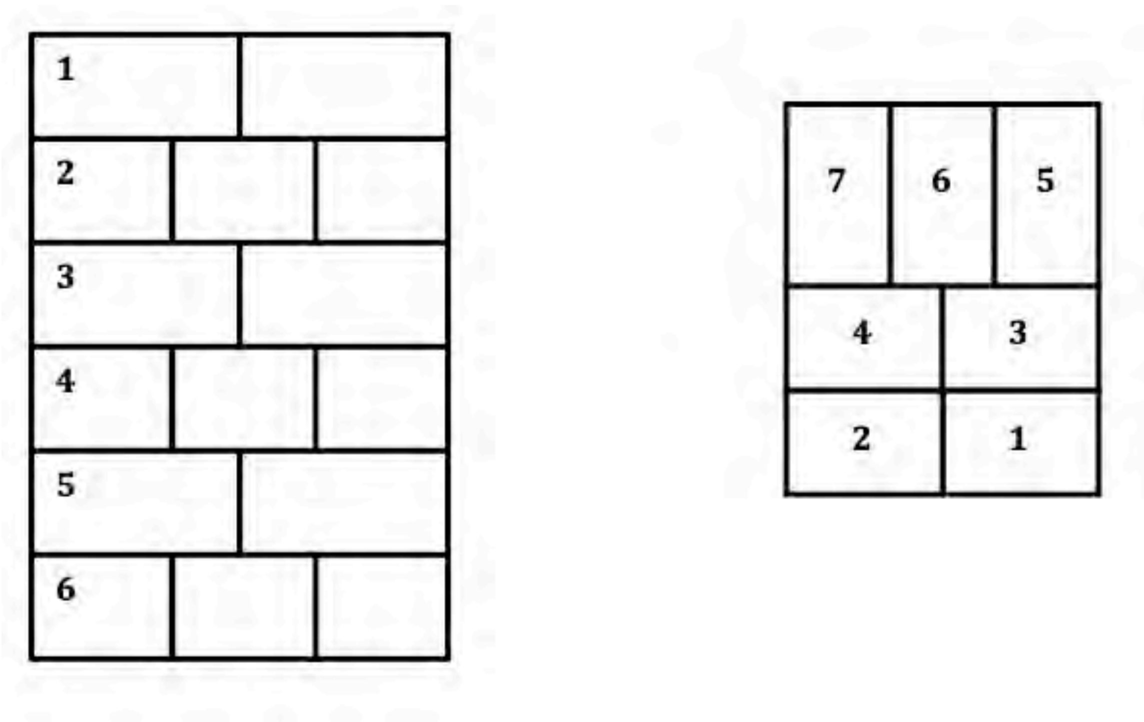

Figure 4: Pallet Layout with a) all levels (front view) and b) single layer (top view).

Figure 4a shows the front view of the pallet, while Fig. 4b shows the top view of a single pallet layer. One side of the pallet was rebuilt with the EPS trays (locations 1, 3, 5) and the other side with the molded fiber trays (locations 2, 4, 7) in an identical pattern. This was done to make sure that the cases with molded fiber trays were experiencing distribution hazards from cases only packed with molded fiber trays and that EPS trays were only experiencing hazards from EPS trays. Three cases were sampled from the top, layer 1, and the bottom, layer 6, while only one case was sampled per layer from the middle, layers 2-5. Prior to testing, the pallet was triple wrapped around the top and bottom two layers with 70% coverage in the middle to maintain load stability.

ISTA Procedure 3E was performed as a general simulation of the environment typical for a unitized load of the same product (ISTA 3E). This testing prescribes the following steps:

Atmospheric Preconditioning - 23°C, 50% relative humidity

Atmospheric Conditioning - 5.5-8.3°C

Shock - Inclined Impact - 1.1 m/s

Shock - Rotational Edge Drop - Drop Height = 2 m

Compression - Omitted

Vibration - Steel Spring Truck Profile - 4 hours

Shock - Rotational Edge Drop – Omitted

The static compression testing was omitted because the pallet would not typically be double stacked due to the vehicle height restrictions and the weight of the pallet. The cases would still experience dynamic compression during the testing cycle. The final rotational edge drop was omitted due to load instability. According to Hess brothers, a pallet of fresh apples with this weight and height would not normally be shipped; therefore, load instability would not be a typical concern. This is because fresh (unwaxed) apples would usually be shipped in smaller unit loads to local distribution centers. Therefore, this series of distribution testing performed on the apples was the most hostile environment that they would be exposed to. Fresh apples also bruise easier than waxed apples due to a faster respiration rate and loss of moisture. The results presented below could be an exaggeration of the normal bruising that would be seen in a typical distribution cycle, however, both trays experienced the same set of extreme hazards. Therefore, the data found can still be compared between the two materials.

Data Analysis

The objective of the data analysis was to determine the effects of both pallet layer and material type on the mean bruise number and mean bruise size. An Analysis of Variance was used to test for the overall effect of pallet layer and material on bruising. The specific effect of material, pallet level, and the material and pallet layer interaction were tested by a series of contrasts. The calculations were performed in JMP® software. It is important to note that the following assumptions were made regarding the statistical analysis of the data: random samples that are representative of the population, data follows a normal distribution, equal variation across groups, and the observations are independent from one another.

Results

The distribution environmental simulation testing resulted in no statistical difference between the protection that the EPS trays and the molded fiber trays provide. The average number of bruises per case was determined by taking the total of bruises per layer and dividing it by the number of cases sampled on that layer.

Table 1: The average number of bruises per case (standard deviation) by layer at 24 hours following testing

	Pallet Layer			
Material	**Top**	**Middle**	**Bottom**	**Mean**
EPS	14.0 (7.5)	7.0 (3.6)	10.3 (10.1)	10.4 (4.36)
Molded Fiber	15.0 (4.4)	7.3 (7.1)	9.3 (4.0)	10.5 (3.09)

The mean number of bruised apples per pallet layer in EPS trays (10.4) and the mean number of bruised apples per layer in molded fiber trays (10.5) were not significantly different (p-value = 0.9775), Table 1. Because all of the bruises were different shapes, the size of the bruise was calculated by measuring the maximum length and maximum width of the bruise to determine the square area that it created. In literature, it can be seen that other studies have measured the depth, shape, and surface color of the bruise (Mitsuhashi-Gonzalez). For the purpose of the experiment, it was only important to determine if damage occurred and not the extent or characteristics of the damage.

Table 2: The average size of bruises per case (standard deviation) by layer at 24 hours following testing

	Pallet Layer			
Material	**Top (mm^2)**	**Middle (mm^2)**	**Bottom (mm^2)**	**Mean (mm^2)**
EPS	168.52 (19.38)	233.54 (33.07)	267.99 (212.23)	233.35 (71.88)
Molded Fiber	124.74 (52.03)	216.44 (77.02)	175.14 (163.52)	172.20 (62.70)

According to the data in Table 2, the total mean size of the bruises on the apples in EPS trays (233.35 mm^2) and the total mean size of the bruises on the apples in the molded fiber trays (172.20 mm^2) were not significantly different (p-value = 0.3222). Even through the average size of the bruises were generally smaller for the molded fiber, the difference was not statistically different because the standard deviations were so large. Tests for unequal variance were performed and there was no statistical difference in the variation of the size of bruises.

A similar experiment was performed to determine the bruising of apples after vibration testing (Singh and Xu, 1993). Apples were packaged in four different types of inner packing using C-flute single wall corrugated shipping cases. In their study, apples were packed in inner partitions constructed of solid paperboard as well as EPS and molded fiber trays. Vibration testing simulated leaf spring and air ride suspension. Bruising of the apples was evaluated using sizes of bruises rather than number of bruises as performed in this study. They found that the EPS foam tray was best at protecting the apples with the smallest amount of bruising followed by the paperboard partitions and the molded pulp was the worst. Further, they found tests simulating that air cushion suspension produced lower damage to the apples than the leaf spring.

There are several reasons why there differences between the findings of our study and that of Singh and Xu, (1993). The type of apples used in each study was different as well as the vibration simulation method. In the Singh and Xu (1993) study, ASTM 4728-87, method A was used instead of ISTA 3E. The cases testing in the Singh and Xu (1993) study were not submitted to shock (inclined impact or rotational edge drop) testing or drop testing. The pallet configuration in the Singh and Xu (1993) study was column stacked while an interlocking pallet configuration was used in this study. The layout in the trays used in the Singh and Xu (1993) study was different from this one because their trays held 96 apples in columns and rows while ours held 80 apples with five rows that nested in one another. The difference in the number of apples per tray changes the weight of each case of apples. The main difference was the results from the physical handling testing of the trays. The Singh and Xu (1993) study did not examine how the trays would be handled in a retail environment and the level of protection the different material would provide at that stage in the distribution cycle.

Handling

The main purpose of this series of tests was to determine the difference between the two trays in their ability to protect apples when cases are handled and potentially dropped during manual palletizing and depalletizing.

Case Drop Testing

The main purpose of this portion of testing was to determine if there was a difference in the protection that the two different trays provided for the apples during free fall drops. Each case was only dropped once in a specified orientation, face or edge. The drop height for the drops was 60.96 cm. This height was used because it describes the worst-case drop height that an apple might undergo at an orchard (Lewis, 2008) and it is also the average height of the conveyors.

The trays and apples were preconditioned at refrigerated conditions (5.5-8.3°C) for 24 hours before testing. The same inspection process and sampling pattern, Fig. 3 was used for the drop testing as was for distribution testing. Three cases of each material were used for each drop orientation with a total of 120 apples per orientation. After the drops were performed, the apples were visually inspected for number and size of bruises immediately after and at 24 hours after testing.

Results

The drop testing proved that there was no statistical difference between the protection that the EPS trays and the molded fiber trays provide. There was, however, a difference between the visual appearances of the trays after the testing.

Table 3: The average number of bruises per case (standard deviation) by layer at 24 hours following testing			
Drop Orientation			
Material	**Edge Drop (mm^2)**	**Face Drop (mm^2)**	**Mean (mm^2)**
EPS	7.7(3.7)	5.7 (2.9)	6.7 (2.0)
Molded Fiber	8.0(4.3)	10.0(5.8)	9.0 (3.9)

Analysis of the data in Table 3 reveals that the mean number of bruised apples per case from EPS trays (4.1) and the mean number of bruised apple from molded fiber trays (5.0) were not significantly different (p-value = 0.2298). Similar results can be seen when describing the size of the bruises.

Table 4: The average number of bruises per case at 24 hours for each material regarding drop orientation and overall bruising			
Drop Orientation			
Material	**Edge Drop (mm^2)**	**Face Drop (mm^2)**	**Mean (mm^2)**
EPS	493.38	342.56	397.97
Molded Fiber	285.33	348.60	316.97

It was found that in data table 4, the mean size of the bruises on the apples per case in EPS trays (397.97 mm^2) and the mean size of the bruises on the apples per case in molded fiber trays (316.97 mm^2) were not significantly different (p-value 0.2309). Based on visual comparisons, the molded fiber trays did not damage as easily as the EPS trays did. For the edge drops, three out of twelve trays showed some small cracks for the edge on which they were dropped. The molded fiber trays, only two trays out of the twelve showed some minor tears on the edge on which they were dropped. The face drops provided completely different results.

Figure 5: Edge Drop Damage from 2.0 ft. a) EPS Tray b) Molded Fiber Tray.

All of the EPS trays shattered from the impact of the face drop because EPS is brittle at the refrigerated (5.5-8.3°C) conditions used. The molded fiber trays had four out of twelve trays show some minor tears in the trays. A visual comparison of the two trays can be seen in Fig. 5. Due to the fact that both trays provided the same physical protection for the apples in the drop testing, the only difference between the two trays are their appearances after the drops. The two materials absorbed the shock from the drops in different manners. The molded fiber trays were able to maintain their physical appearance after the drops while the EPS trays exhibited far more damage. Despite this, both trays protected the apples equally.

Tray Handling

There is no test standard or industry accepted testing sequence available for evaluation of the manual handling performance of the trays. Therefore, a test fixture needed to be designed and built to perform the testing.   The device needed to impart the forces that the trays would experience under a full load of apples. The final device is illustrated in Fig. 6 below.

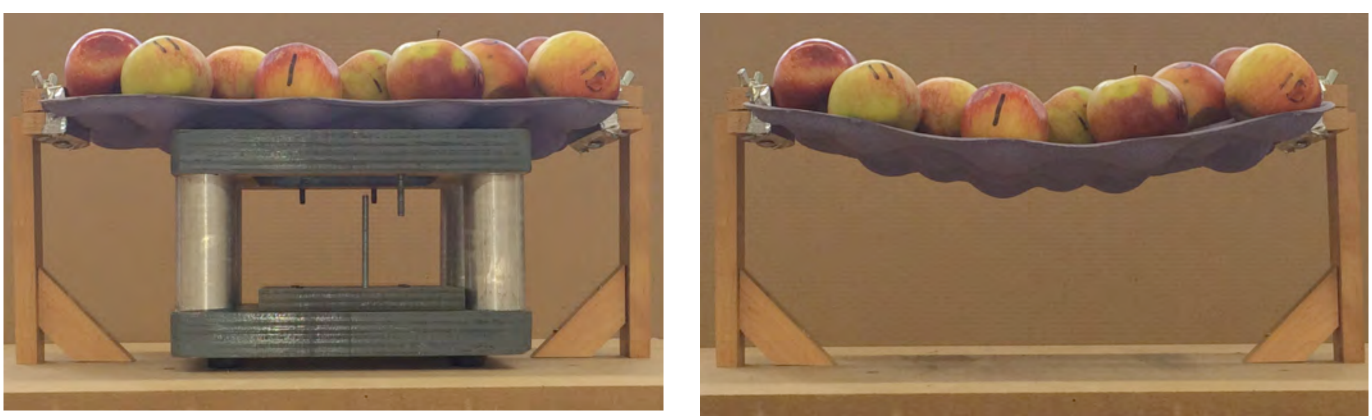

Figure 6: Handling Device a) with support and b) without support.

As seen in Fig 6, the two arms of the test fixture are held up by angle supports, which maintain constant force on the tray. The baseboard has five holes that align with the sampling pattern, Fig. 3, in order for deflection measurements to be taken with a depth gauge. A support was placed under the tray, Fig. 6a, while the apples were loaded, and then it was removed for deflection measurements, Fig. 6b.

Experimental Design

The trays were pre-conditioned at refrigerated conditions (5.5-8.3°C) and at tropical conditions (38°C, 85% Relative Humidity) for 24 hours prior to testing. For each environmental condition, thirty trays per material were tested. After a set of ten trays was tested for each material, the orientations of the apples within the cells of the trays was changed. For example, for the first testing set, apple 1 would be in cell one, apple 2 in cell 2, and so forth. For the second testing set, apple 1 would be in cell 7, and apple 2 would be in cell 18, and so on. The patterns were determined with a random number generator. This was done to eliminate the effects weight distribution of the apples in the deflection measurements of the trays. The same three orientations were used throughout testing.

The tray was placed in the clamps at the top of the arms as seen in Fig. 3 and secured. The support was placed underneath the tray, and the apples were loaded into the cells.

Once the apples were loaded in the tray, the support was removed, and deflections measurements were taken in the five specified locations as seen in Fig.3.

Results

Analysis of the tray handling data reveals significant differences between the two materials. The EPS trays did not deflect as much as the molded fiber trays Table 5.

Table 5: Average Deflection of Material (standard deviation) for refrigerated conditions

Deflection in cm				
Material	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Mean**
EPS	1.91 (0.05)	1.95 (0.03)	1.93 (0.07)	1.93 (0.05)
Molded Fiber	2.67 (0.08)	2.69 (0.07)	1.057 (0.09)	2.62 (0.12)

At the refrigerated conditions the EPS trays had a significantly lower (p value < 0.0001) mean deflection (1.93 cm) than the molded fiber trays (2.62 cm). The mean values for the separate orientations can be seen in Table 5. For each orientation, the deflection of the EPS trays was significantly lower than that of the molded fiber trays (p-value < 0.0001).

Table 6: Average Deflection of Material (standard deviation) for tropical conditions				
Deflection in cm				
Material	**Pattern 1**	**Pattern 2**	**Pattern 3**	**Mean**
EPS	1.94 (0.22)	1.98 (0.05)	1.96 (0.07)	1.96 (0.13)
Molded Fiber	2.38 (0.08)	2.51 (0.12)	2.62 (0.08)	2.50 (0.13)

At the tropical conditions, the EPS trays had a significantly lower mean deflection (1.96 cm) than the molded fiber trays (2.50 cm) ($p\text{-value} < 0.0001$). The mean values for the separate orientations can be seen in Table 6. For each orientation, the deflection in the EPS trays was significantly lower than the molded fiber trays ($p\text{-value} < 0.0001$).

Overall, the EPS trays had a significantly lower mean deflection (1.95 cm) than the molded fiber trays (2.56 cm) ($p\text{-value} < 0.0001$). Despite the differences in the deflection, both trays provided the same protection for the apples because they both held the apples in the tray through the process. Throughout the entire testing period, both materials held the apples; therefore, no damage occurred to the apples. For the purposes of this study, both materials provided the same protection for the apples during handling tests meant to simulate a retail environment.

The deflection differences between EPS and molded fiber trays can be explained by considering their material characteristics. The stress-strain response of the tray material to quasi-static tension was measured at tropical and refrigerated conditions, Figure 7. The results from the handling tests show that the average deflection of the Molded fiber trays is greater than the average deflection of the EPS trays. The EPS foam is clearly stiffer than the molded fiber resulting in a significantly higher slope of the stress-strain response. Figure 7 shows a dramatic difference between the stiffness of the two materials while the results from the handling tests follow the same trend but are not as dramatic. This can be explained by the construction of the handling device. The two posts that held the tray in place had some ability to deflect with the material, however, the posts still needed to be able to provide some resistance to prevent the whole devise from collapsing. Therefore, the results of the handling tests follow the trend that EPS trays are stiffer, but do not show as large as a difference that was seen in Figure 7.

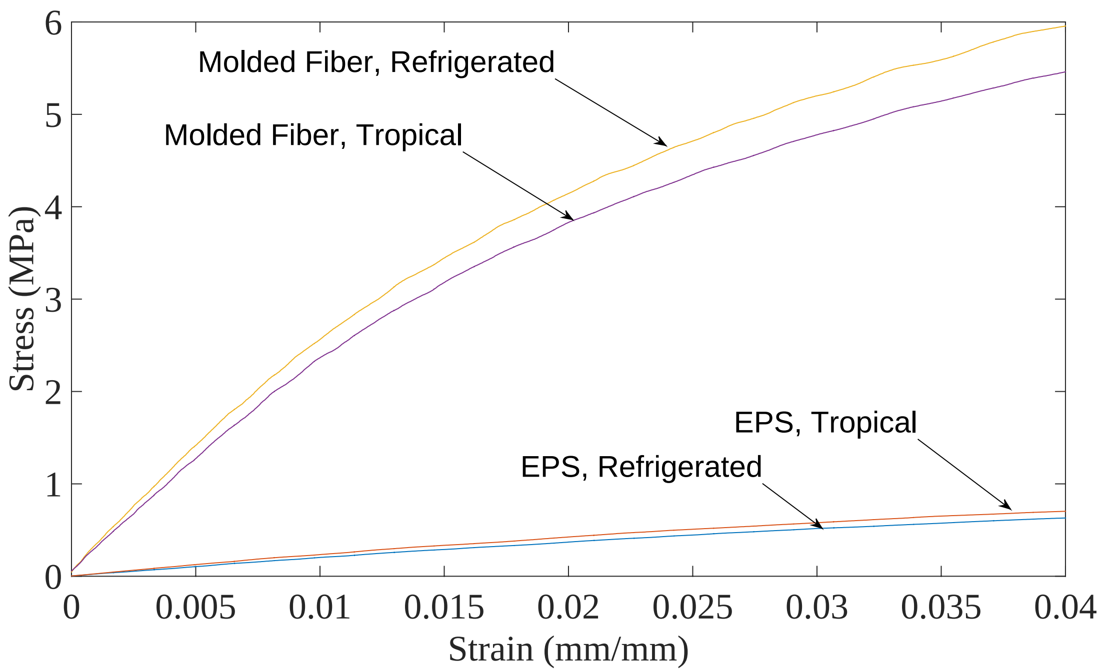

Figure 7: Samples representing the Stress-Strain behavior of EPS and molded fiber.

Figure 7 models the material behavior of EPS and molded fiber under refrigerated and tropical conditions. The molded fiber exhibits lower values than the EPS, therefore, it is expected that molded fiber will experience greater deflection values.

There results are supported by Gurav et al., (2003) where they performed experiments as well as models on additional variables used to measure cushion and strength properties of molded pulp. They included wall thickness, test duration, presence of impurities in the fiber slurry, tensile-strain analysis and rib design. Based on their findings, it appeared that the spread of the load across the surface of the material plays an important role in spread of the maximum product loading while thickness plays an even lesser role. However, in shorter test periods, wall thickness has a strong influence which the authors thought may have been due to local buckling during testing.

Microbial Analysis

The main purpose of performing a microbial analysis on the apples and the trays was to determine if one tray provides better microbial protection than the other.

Sample Collection

Fresh Wine Sap apples were picked by hand from a local orchard one day prior to testing. Eighty apples were packed in four trays of each material type. The eight trays, with the apples, were atmospherically conditioned in an environmental chamber at tropical conditions (38°C, 85% Relative Humidity) for one hour before the apples and tray samples were collected. Through prior testing, it was evident that the apples produced the maximum condensation after one hour in tropical conditions. After this time period, the core temperature of the apple is the same as the environmental chamber. Sterilized base pads were used to separate the tray and apples from the floor of the chamber.

The apples from the sampling locations Fig.3 on the third tray from the top were taken and placed in sterile stomacher bags. The condensation that was in the trays from the sampling areas was collected as well. For the molded fiber, a 1 gram sample (wet from condensation) was cut out with sterilized scissors. Any condensation, greater than 1 ml, was collected with a micro pipet.

Peptone (20 mL) was placed in the stomacher bag with the apples. The bags were closed and vigorously shaken for two minutes. A 1 ml sample was taken directly from the stomacher bag and placed onto the center of an Aerobic Plate Count petri film (APC). A second sample was taken to create a duplicate plate and instructions given with the APC petri films were followed for plating techniques. Dilutions were made using 1% peptone in a range from 10^{-2} to 10^{-4} for apples and up to a 10^{-5} for the condensation. Only plates that were within 20-200 colonies forming units (CFU/mL). If the colonies were greater than 200, two cells were counted, averaged, and multiplied by 20 to find the total number of colonies on the plate. This was done per the instructions of the APC petri films.

The 1 gram samples of the molded fiber with condensation was placed in sterile blender jar with 100ml of distilled water. The water and molded fiber were blended for one minute or until the molded fiber was completely blended into the distilled water. Any condensation that was collected from the EPS trays was sampled the same way the apples were. The condensation collected, however, was directly plated then the remaining dilutions were created from there.

For each material, five apples were sampled and their corresponding cell's condensation was sampled. For the molded fiber trays, five apples were sampled and four condensation areas were sampled. The EPS trays allowed for five apples to be sampled, but only one condensation area to be sampled because the condensation drained through the slots in the cells. After all of the plates were created, they were stored in an environmental chamber at 35°C for 48 hours.

Results

The aerobic plate count petri films were counted and the average populations for the raw apples and for condensation can be seen in Table 7.

Table 7: Total Aerobic Plate Count		
Material	Raw Apples (CFU/mL)	Condensation (CFU/ml)
EPS	9.16×10^{-4}	1.40×10^{-5}
Molded Fiber	4.17×10^{-4}	2.40×10^{-5}

There was a significant difference (p-value = 0.0413) between the microorganism populations on the raw apples taken from the EPS trays (9.16×10^{-4}) and the aerobic microbial populations on the raw apples taken from the molded fiber trays (4.17×10^{-4}). This result might show statistical significance, however, the aerobic flora population remains within 4 or 5 log CFU/mL for apples and condensation, respectively.

Initially it was believed that there could be a difference in microbial population due to the fact that condensation in the EPS trays would allow the possibility of moisture to remain close to the apples and provide an opportunity for growth to occur. Further, the molded pulp trays might not support microbial growth as easily since the moisture from condensation was expected to soak into the pulp and not remain close to the surface of the trays. However, EPS trays used in this study had a small drain slot in the bottom of each cell that held the apples, allowing condensation to drain away from the apples as with the molded pulp.

Previous studies have shown that an aerobic plate counts of 3.7 log CFU/mL on the surface of whole apples, similar to this study (Beauchat et al., 1998). Buchanan et al., (1999) found an aerobic plate population on the skin of apples to be 4 log CFU/mL. Other studies have found mold such as *Penicillium expansum* and *Botrytis cinerea*, typically found in bruised apples kept in storage (Barth et al., 2009). Since the apples in this study were tested in the typical orientation of being laid on their sides (cheeks), it was likely that microbial contamination from bacteria such as E. coli was not a likely possibility as researchers in previous studies have indicated that the bacterial point of entry is the calex or stem end where the apples are more porous and bacteria are able to penetrate into the flesh of the apple (Buchanan, et al., 1999). The apples are placed in the cells of the trays on their sides. Therefore, the stem end does not come in contact with the tray material.

Sustainability

Many companies are now beginning to examine the Life Cycle of materials they use due to recent environmental trends. A positive sustainable case can be made for both materials. The EPS trays have a developed recycling stream with a known recycling rate of 19%, while the molded fiber trays are made from post-consumer materials but the recycling rate remains unknown (EPS Recycling). On the other hand, EPS is produced using resin while Molded Fiber requires a much larger amount of energy to manufacture according to the a UK molded Pulp Study (PendlePace LTD, 2005). The EPS trays provide a premium look for the consumers and the molded fiber trays appeal to the environmentally friendly consumer. Therefore, the choice of which tray a company decides to should not be based on the protection that the material provides. Both trays provide equal protection for the apples so the company can decide to use the tray that is best in line with the company's initiative and goals.

Conclusions

The results from this study infer that both trays provide the same level of protection for the apples during the distribution cycle. There were differences seen in how they reacted to handling tests and microbial tests, however, those results did not provide insight that the protection they provided was different. The distribution tests proved that both trays provide apples with similar protection through the distribution cycle. The drop testing had similar results to the distribution testing, further proving that both trays provide the same protection for the apples. However, the drop testing demonstrated that the molded fiber trays were physically in tact and visually without damage after drop testing while the EPS trays had cracks. The handling testing exhibited that the EPS trays experienced less deflection from the same apples that the molded fiber trays did. Furthermore, the microbial analysis provided information that there were statistical differences in the aerobic microbial populations on the apples, but both populations remained within the spectrum of the natural flora of the apples. The series of testes provided information on the responses of the two trays to a distribution cycle. The responses of the trays were different in their physical appearance, but not in their ability to protect the apples through the distribution cycle.

RECCOMMENDATION FOR FUTURE WORK

Due to the nature of this research being broken into three main sections, recommendations for future work fall into the following categories; Distribution, Handling, and Microbial.

Distribution – The distribution tests can be repeated to determine if different stacking methods (interlocking and column), pallet height, and pallet weight can change number and size of the bruises on the apples.

Handling – In order to properly define the drop environment for cases of apples, warehouses and orchards could be studied. From these studies, drop tests could be preformed in different orientations and heights as well as single drop verses multiple drop to determine if the number and size of bruises on the apples changes. Try using round apples such as Macintosh rather than conical apples.

Microbial change sampling method or look at mold rates related to bruising and damaging., see if antimicrobial included into tray material could reduce mold or possibly pathogenic bacteria.

Recycle content – see if recycle content has any effect on molded pulp performance

Cost analysis – compare cost and weight (cost of shipping) for both materials.

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