

AN IN DEPTH LOOK AT E-COMMERCE FOOD PACKAGING: INFORMATION ON
CURRENT PACKAGING AND ITS CHALLENGES AS WELL AS A COMPARISON WITH
NOVEL PACKAGING

By

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ABSTRACT

Online grocery shopping is growing at an exceptional rate globally. Yet, little is known about the packaging in use that plays the key roles from protecting the food product to reducing food waste. The goal of this thesis was to contribute to advancing food packaging in the e-commerce channel by: (1) gathering information on e-commerce food packaging including resources and problems that can be used to design new packaging that enhances environmental sustainability while offering performance advantages and (2) comparing the performance of novel packaging materials against the current packaging materials in terms of extending the shelf life of food commercialized through the e-commerce channel. Information on e-commerce food packaging including resources and problems was obtained for different food product categories (liquids and produce) and using different data collection methods (a questionnaire administered to industry and packaged product analysis). The information gathered included package type, material, format, and defects, and the future of e-commerce food packaging. The comparison of monomaterial multilayer films as a primary package for produce in meal kits compared to both single-layer and polymaterial multilayer films by performing a shelf-life study demonstrated that monomaterial multilayer films are an alternative to package produce since they can extend produce shelf life equal or better than current meal kit films while homogenizing polymer type which could facilitate packaging material recovery. This thesis demonstrates the urgent necessity for improving e-commerce food packaging to enhance environmental sustainability and to reduce food waste.

Dedicated to my parents Douglas Spruit and Susanne Klarr-Spruit

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CHAPTER 1 INTRODUCTION

1.1 Introduction

In the last few years, the sales channel e-commerce has experienced significant growth compared to brick and motor retail (Nielson, 2017). E-commerce total U.S. retail sales has grown from 4.2% in the first quarter of 2010 to nearly 10% of total sales in the third quarter of 2018 (US Department of Commerce and US Census Bureau, 2019a). In last year alone, e-commerce retail sales have increased by 12.1% while total retail sales have grown only by 3.1% (US Department of Commerce and US Census Bureau., 2019b). Particularly, a subset of e-commerce known as online grocery, food items sold through e-commerce, has been increasing rapidly (eMarketer, 2018; Statista, 2020). Future trends indicate that 70% of U.S. consumers will be grocery shopping online by 2024 (Nielson, 2018b). As the online grocery channel pie continues to grow, industry will need to innovate and invest resources to compete in the market.

One area where industry should innovate is in package protection. Currently, unsuccessful deliveries are still a common problem in all e-commerce orders (Edwards et al., 2010; Florio et al., 2018). The rise in unsuccessful deliveries could be explained by the lack of protection the current package provides for these products in the new supply chain. There are reports that one in ten e-commerce packages arrive to consumers damaged (Dunn, 2013). Furthermore, experiments carried out by Bemis in 2016, reported a failure rate of nearly 70% for e-commerce packaging (cereal, chips, soda, soups, pet food, baby food, and dry goods) (Bemis, 2016). These failures could be a significant factor in why consumers are unsatisfied with their purchase and return e-commerce products more than 30% of the time (Donaldson, 2015) while brick and motor or traditional retail averages a modest return rate of 10% (National Retail Federation, 2018).

In addition to dissatisfaction with packaging performance, consumers care more about the impact their choices have on the environment which in turn leads to a want to have less packaging with the products they purchase. They place this responsibility of package reduction to industry by controlling the type of packaging for food that is released to market (Dilkes-Hoffman et al., 2019). Furthermore, increased carbon emissions and waste associated to packaging is attributed to the e-commerce supply chain compared with the traditional supply chain (Heard et al., 2019; Xiao and Zhou, 2020). The above-mentioned packaging failure, waste, and environmental emission impact as well as the consumer dissatisfaction which leads to returns has driven industry to look for innovative sustainable ways to package products for e-commerce shipment. However, due to the emerging nature of e-commerce as a supply chain for food the results are still in the early stages of evaluation (Heard et al., 2019; Song et al., 2018). Currently, there is limited information on resources (e.g., packaging materials) and performance (e.g., integrity failure) which would help in the estimates (e.g. carbon emissions from multilayer packaging) (Dahlbo et al., 2018), life cycle assessments (Ferreira et al., 2014), improvement of packaging waste collection (Tallentire and Steubing, 2020), and design of new generations of packaging for use by online grocers that can enhance environmental sustainability while offering performance advantages.

Packaging can extend the shelf life of food products by protecting these from the environment. Thus, the loss of package integrity has a negative impact on food shelf life. Package integrity failure can be caused by defects. Common defects occurring during package distribution include leaks, punctures, scratches, and deformations. These defects affect food shelf life differently. For example, leaks and punctures can expose the product to the outside environment including to undesirable oxygen and/or microorganisms. In contrast, deformations affect food shelf life only if they lead to product changes, but otherwise are only an aesthetic issue. The design of new

generations of packaging for online grocery shopping has to reduce defect presence since packaging that performs better during distribution can increase food shelf life and thereby can reduce food and packaging waste.

1.2 Objectives

The goal of this thesis was to contribute to advancing food packaging in the e-commerce channel.

To achieve this goal, the following objectives were proposed:

1. To gather information on food packaging in the e-commerce channel including resources and problems that can be used to design new packaging that enhances environmental sustainability while offering performance advantages.
 - a. The approach was to gather this information for different food product categories (liquids and produce) and using different data collection methods (a questionnaire where food manufacturers were directly asked about their products and packaging, and analysis of products and packages obtained by direct purchase).
2. To compare the performance of novel packaging materials against the current packaging materials in terms of extending the shelf life of food commercialized through the e-commerce channel.
 - a. The approach was to investigate the possible use of novel monomaterial multilayer films to package produce delivered in an e-commerce environment in order to improve aspects where current packaging materials fail.

1.3 Structure of Thesis

The first chapter of the thesis introduces the rationale of this research. A background on e-commerce, online grocery, and meal kits is reviewed in Chapter 2. The results from the performance of a market study covering the liquid food package materials, formats, and failures

in e-commerce are presented in Chapter 3. Chapter 4 examines the food and packages currently presented in meal kits. Chapter 5 compares the current meal kit packaging against novel packaging. The last chapter summarizes the findings and proposes future works.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Consistent with the scope of this study, a background and literature review on the how the changes in the logistical system are currently challenging the performance of food packaging is presented in this chapter. The review focuses on three specific packaging performance challenges: integrity, design, and waste and discusses how novel materials could address these challenges.

2.2 A New Logistical System

E-commerce is a recently growing distribution channel that integrates the internet interface to trades goods and services to consumers (Alberto et al., 2014). One proposed definition by Fraser et al. (2000) is any use of the internet for the exchange of information as value. Kalakota and Whinston (1997) viewed e-commerce in four distinct perspectives:

1. Communication perspective or e-commerce transmits information, products/services, and payments over computer networks or any other electronic means.
2. Business process perspective or e-commerce is the application of the internet towards the automation of workflows and other business transactions.
3. Service perspective or e-commerce is a tool helps firms, consumers, and management to cut service costs and improve the quality of goods and vastly increase the speed of service.
4. Online perspective or e-commerce provides the space to buy or sell products and information through online services

Hsiao & Chen (2013) further differentiate the e-commerce channel into two types: Manufacture-Operated and Retailer Owned channels. Manufacture-Operated channels are where the

manufacturer determines whether to introduce an online channel, offers the wholesale price to the retailer, and determines the price offered to the consumers, and the consumers decide which channel to purchase the products from. Retailer-Owned channels are where the retailer determines whether to introduce an online channel, the manufacturer offers the wholesale price to the retailer, and the retailer determines the price offered to the consumers, and the consumers decide which channel to purchase the products from. Within these two sub-channels, there are a multitude of online services that consumers can use to purchase products through e-commerce. For food products, there are two main modes consumers use to purchase goods online: home delivery and click and collect (Bauerová, 2018; Hübne et al., 2016).

2.2.1 Click and Collect

Click and Collect is one of the dominant delivery modes in online grocery (Hübne et al., 2016). Click and Collect can be described as a separate booth or area is installed inside a store, where customers can pick-up their online orders. This collection point located in-store is often the quick solution for a retailer that wishes to enter the online grocery channel quickly with low cost. In-store collection points can be less convenient than other fulfilment and delivery solutions for the consumer because the consumer still has to drive to the store and pick-up the order. The main benefit for the consumer is the lack of time spent on picking goods.

2.2.2 Home Delivery

Home delivery is another dominant mode consumer use to purchase groceries online (Nurfatiasari and Aprianingsih, 2017). Home delivery can be described as goods are delivered to a central hub (i.e. a brick and mortar store or distribution center) and customers perform the picking online and final delivery to their home themselves. Home delivery can be sub-divided into two categories: Shipped Consumer Staples and Meal Kit Delivery Services.

2.2.2.1 Shipped Consumer Staples

Shipped Consumer Staples can be defined as services that ship shelf stable products that consumers are likely to repurchased on a regular weekly or monthly basis (Nielsen, 2015). Shipped consumer staple products include food items such as cereal, nutritional supplements, soft drinks, and snacking items.

2.2.2.2 Meal Kit Delivery Services

This subscription based foodservice business model delivers portion-sized individually packaged fresh and partially prepared food to the consumer using corrugated boxes with gel packs and insulating material (Duffy, 2020).

2.3 Online Channel Packaging Challenges

The complexities of e-commerce delivery with many services and modes of distribution and the new demands of consumers has also greatly impacted the packaging in this channel (Alberto et al., 2014; Fisher & Lilienfeld, 2017). Alberto et al. (2014), indicates that packaging has five main requirements for businesses to be successful in e-commerce:

1. Protection: products contained in packages have to be protected (mechanical shock, vibrations, electrostatic discharge, compression, etc.). This is achieved using specific materials like bubble wrap. Korzeniowski (2005) explains that the primary role of packaging in e-commerce is to protect goods three types of damage: mechanical, chemical, and biological. Proper packaging materials, design, accessories can prevent the three types of damage.
2. Handleability/Usability: the ergonomic aspect or everything related to adaptations to the human interactions when using the product must be considered.

3. Security: packages must have shipping security. It could be necessary to install identification technologies such as RFID tags or barcodes in packages in order to reduce theft.
4. Environmental Considerations: E-commerce is known to produce more waste materials than traditional retail. To have a minimal environmental impact, it may be necessary for companies to try to recycle packages and minimize dangerous substances emitted when packaging waste is disposed of.
5. Re-use: minimizes both environmental impact and costs. Re-use of packages could also increase customer integration into e-commerce due to the lower level of environmental pollution produced.

Two of these five main points are further discussed below.

2.3.1 Package Protection

One area where industry needs to innovate is in package protection. Currently, unsuccessful deliveries are still a common problem in all e-commerce orders (Edwards et al., 2010; Florio et al., 2018). The rise in unsuccessful deliveries could be explained by the lack of protection the current package provides for these products in the new supply chain. There are reports that one in ten e-commerce packages arrive to consumers damaged (Dunn, 2013). Furthermore, experiments carried out by Bemis in 2016, reported a failure rate of nearly 70% for e-commerce packaging (Bemis, 2016). These failures could be a significant factor in why consumers are unsatisfied with their purchase and return e-commerce products more than 30% of the time (Donaldson, 2015) while brick and mortar or traditional retail averages a modest return rate of 10% (National Retail Federation, 2018).

2.3.1.1 Package Defects

When examining flexible and rigid food containers for package integrity there are many possible defects that can occur to the package during manufacturing to sale to the consumer. The Bacteriological Analytical Manual alone identifies 43 unique visual defects that can occur to packaging (Arndt, 2001). However, only not all defects occur or pose little risk during distribution, like false seams, crooked seals, delamination's, etc. (Lin et al., 2001). Also, many defects are similar in nature like crushed and deformed packaging (Arndt, 2001). Defects during distribution can be categorized into five distinct types: leaks, odor changes, punctures, scratches, and deformations. Leaks can be defined as package failures that relate to problems with the seal causing product or air within the package to leave the package or leak (ASTM F2338-09, 2013). Odor changes include issues where odors from the package and/or product transfer to an undesirable location prior to consuming the product (Fayoux et al., 1997). Punctures describe a failure of the package material to prevent a foreign object from penetrating the package exposing the product to the outside environment (Lin et al., 2001). Scratches or abrasions are defects that do not directly harm the product, but negatively impact the look of the package and possibly the barrier properties of the package material (ASTM F3300 – 18, 2018). Deformations are defects that are caused by compression and shock that change the shape of the package affecting its strength and possibly crushing the product within the package. All of these defects are associated with a loss of package integrity (Arndt, 2001). When package integrity fails the shelf life of the product is negatively impacted (Stauffer, 2020). The aforementioned defects can affect food shelf life differently. For example, leaks and punctures can cause air to enter into the package that results in the presence of undesirable oxygen and/or microorganisms. In contrast, deformations are more aesthetic issue and do not affect food shelf life if they do not lead to product changes.

2.3.2 Package Environmental Considerations

In addition to dissatisfaction with packaging performance, consumers care more about the impact their choices have on the environment which in turn leads to a want to have less packaging with the products they purchase. They place this responsibility of package reduction to industry by controlling the type of packaging for food that is released to market (Dilkes-Hoffman et al., 2019). Furthermore, increased carbon emissions and waste associated to packaging is attributed to the e-commerce supply chain compared with the traditional supply chain (Heard et al., 2019; Xiao and Zhou, 2020). However, due to the emerging nature of e-commerce as a supply chain for food the results are still in the early stages of evaluation (Heard et al., 2019; Song et al., 2018). Currently, there is limited information on resources (e.g., packaging materials) which would help in the estimates (e.g. carbon emissions from multilayer packaging) (Dahlbo et al., 2018), life cycle assessments (Ferreira et al., 2014), and improvement of packaging waste collection (Tallentire and Steubing, 2020).

2.3.2.1 Monomaterial Multilayer Films

Moving to single-layer films increases the probability of the recyclability as plastic recycling streams must be separated by type of plastic resin (Environmental Protection Agency, 2020). However, moving to single layer films reduces vital properties that multilayer, several layers of different types of plastics, films provide (Anukiruthika et al., 2020; Skoda, 2019). Multilayer films can help protect food better due to their superior barrier and physical properties (Wagner and Marks, 2016) but they have the downsides of poor recyclability (Horodytska et al., 2018). A possible way to bridge this gap is to utilize monomaterial multilayer films. Monomaterial multilayer films can be defined as a film that includes two or more layers made of the same base plastic resin, but the resins differ in chemical or physical properties. These are commonly created

by co-extrusion or lamination. Monomaterial multilayer films can provide the benefits of multilayer films on food shelf-life extension (Smart-LAM, 2020; Canadian Plastics, 2018; Termoplast, 2020) without the downsides of poor recyclability as the base resin can be recycled together.

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CHAPTER 3

A MARKET STUDY IN E-COMMERCE LIQUID FOOD PACKAGING

3.1 Materials and Methods

3.1.1 Survey Design

Qualtrics survey software (<https://qualtrics.msu.edu/>) was used to launch the online questionnaire and to collect data. The questionnaire was prepared, and this consisted of 79 questions that were separated into four blocks: (1) Traditional Supply Chain (TSC), (2) E-Commerce Supply Chain (ESC), (3) Future of Packaging Supply Chain (FPSC), (4) Demographics.

The TSC block asked the participants for the top three products in the traditional supply chain. Due to the nature of the questions the answers were open-ended. The participants were then asked about the package description which included information about the package type, package material, package style. For these questions, a mixture of fill-in-the-blank and multiple-choice questions were used to collect as much data due to the variety of possible answers. Following, the participants were asked to best estimate how often a specified defect occurs (%), and reason for type of defect for each of the three products. These questions were close ended, but if the participant could not find his/her answer he/she was able to fill in an answer in the other section. The five defects described are as follows: leaks, odor changes, puncture, scratching, and deformation. Next, the participants were asked for the causes of the above defects. For some defects, location was also investigated. These were multiple-choice questions that allowed for multiple answers.

Next, the participants completed the ESC section that was nearly identical to the TSC section. In some cases, the ESC section was shorter for participants due to how they answered

previous questions. Conditional programming statements, programming operators, and piped text were used to shorten the ESC section as much as possible for survey participant. This had no effect on survey results and reduced the completion time.

The participants then completed the FPSC section. This section included questions pertaining to the future trends of the E-commerce supply chain. This section included both close-ended and open-ended questions for the participants to answer. Demographics were asked immediately after this section and including questions pertaining to employee title, employee length at company, location of employee, length of company involvement in e-commerce, and annual sales of the company. This section contained only close-ended questions. UBE employees and other industry experts provided valuable feedback to ensure user-friendliness and to enhance the quality of the collected data prior to the launch of the questionnaire on June 3rd, 2018. The last survey reminder was released August 15th, 2018. The Appendix of this chapter contains a complete copy of the survey with survey flow.

3.1.2 Ethical Considerations

As required when conducting any research involving human subjects a consent statement was created and the study was reviewed by Michigan State University's Institutional Review Board (IRB) to approve of Market Study. The statement and study were approved April 30th, 2018. The Appendix of this chapter contains a copy of the consent statement and the IRB approval.

The consent statement was included prior to the survey and acceptance of participation was confirmed when the participant clicked the "next" button to start the survey. The consent statement was included prior to the survey and acceptance of participation was confirmed when the respondent clicked the "next" button to start the survey as previously indicated.

3.1.3 Survey Distribution

An initial email was sent over the Qualtrics Listserv due to the recommendation of the software. By using the Listserv possible mailing issues and software bugs are eliminated. However, after testing the Listserv it was found many of the emails to the recipients ended up in the junk folder. Further emails to recipients were then sent using the researcher's personal email to increase response rate. An example of this email can be found in the Appendix. Amcor Ltd was included as a promotional helper, since a large majority of the possible participant contact name and email was provided due to the work of a past MSU Alum employed by Amcor Ltd.

3.1.4 Sampling Method

Companies without liquid food products or dedicated packaging employees were excluded from the survey. It was necessary to have only dedicated packaging employees taking the survey to prevent uninformed answers related to packaging topics affecting results of the survey. The sample was selected from two sources: a list of companies provided by Amcor Ltd. and a list provided by the School of Packaging at Michigan State University (MSU). Lists were compiled, and any duplicate participant were removed.

3.1.5 Survey Participation

Table 3.1 provides survey participation results. The mailing list refers to the number of employees contacted to take the survey. Many employees within the same company were contacted during distribution to increase the response rate of the survey. This number should not be confused with the audience size or the possible number of company responses. The number of surveys opened refers to the number of employees who clicked on the link to the survey but decided not to proceed based upon the introduction and the consent statement. Surveys started refers to the total number of surveys started. Partially completed surveys refer to the number of

participants who failed to answer the 90% of the critical questions, blocks TSC and ESC of the survey. Completed surveys refer to the number of participants who answered more than 90 % of the critical questions.

Table 3.1 Survey participation results

Mailing List	Audience Size	Surveys Opened	Surveys Started	Partially Completed Surveys	Completed Surveys
195	49	19	13	3	10

Applying the results from Table 3.1, the completion rate and the response rate was calculated. Both completion rate and response rate were calculated using equations from the Encyclopedia of Survey Research Methods (Lavrakas, P. J., 2008). The completion rate (CR) was calculated using the following equation:

$$CR = \frac{\text{Completed Surveys}}{\text{Total Responses}} * 100$$

Past web survey research (Liu and Wronski, 2017) found an average web survey completion rate of 87 ± 10 % and imply poor completion rates fall below 60 %. The completion rate for this survey was 77.0 %. This completion rate was most likely due to the participants being promised a reward post completion of the survey. This reward being information about E-commerce from the final report. This completion rate implies that the participants received a survey that was not frustrating to complete, and the participants were able to complete most of the questions asked of them. Response rate (RR) was calculated using the following:

$$RR = \frac{\text{Completed Surveys}}{\text{Audience Size}} * 100$$

Duncan D. Nulty (2008) reported that the average response rate for an online survey can range from 20 % to 47 % with an average of 33 %. Saldivar (2012) stated that average response rate for online surveys is near 30 % as well. The response rate of this web survey was 20.9 %

which is on the lower normal range for online surveys. The lower response rate of this survey could be explained by the following factors:

- Sensitive product/brand information
- Sensitive damage information
- Sponsorship attachment to the study
- High risk for employee to take survey

3.1.6 Statistical Analysis

RStudio version 1.1456 using shiny version 1.2.0 (RStudio Inc., Boston, MA, USA) was used to perform statistical analysis. Hypothesis testing was performed for the categorical data to assess relationships. A chi-square test of independence was used ($p = 0.05$). If the categorical dataset tested contained less than 80% expected frequencies above five, the data was grouped; if grouping was not feasible, a Fisher's Exact Test ($p = 0.05$) was used as an alternative. For the investigated defects, Kruskal-Wallis ($p = 0.05$) was used as an alternative to ANOVA analysis due to the small sample size and non-normal dataset. Specifically, the test was used to compare the effect of supply chain (e-commerce or traditional), package format (rigid or flexible), package type (bottle, can, pouch, other), and package material (plastic, metal, other) on each of the investigated defects. If a p-value below 0.05 was produced, the non-parametric test Dunn's test for multiple comparisons was performed ($p = 0.05$). For the above statistical analyses, median values were calculated instead of mean values due to the non-normal distribution of the data.

3.2 Results and Discussion

3.2.1 Sample Demographics

Table 3.2 presents the results from the collected demographics. More than half of the companies involved in these surveys had annual sales between 1 billion dollars and 25 billion dollars. Three companies had annual sales over 50 billion dollars and only 1 company had sales less than 500 million.

Table 3.2 Demographics of survey participants

Variable	Category	Percentage (%)
Company annual sales (million)	< \$499	10
	\$500 - \$999	0
	\$1,000 - \$24,999	60
	\$25,000 - \$49,999	0
	> \$50,000	30
Time company active in e-commerce	< 3 years	0
	3 to 5 years	60
	5 to 8 years	10
	> 8 years	30
Company location*	Midwest	50
	Northeast	40
	N/A	10
Title at the company	Engineer	30
	Coordinator	10
	Category leader	10
	Manager	10
	Director	40
Time in current position	< 3 years	60
	3 to 5 years	0
	5 to 8 years	20
	> 8 years	20

*Company location was offered state-by-state basis and was then organized into United States census regions (Pacific, West, Midwest, Northeast, South) by researchers.

Most of these companies have only been involved in e-commerce for less than 5 years. This response is unsurprising, due to online grocery being relatively new compared to other sectors in e-commerce (Oliver Wyman, 2014). 3 companies have been involved for more than 8 years and

1 company between 5 and 8 years. All company participants were located within the Midwest and Northeast region of the United States. This is because most packaging engineers and directors are located at the headquarters of the company and most CPG headquarters are in the Midwestern and Northeastern United States (Wren, 2014). Participant titles varied with 80% having the title of either engineer or director. Most participant were employed with the company for less than 3 years. This is likely due to the fact than most food packaging companies have not been involved in e-commerce for more than five years and are recently creating e-commerce divisions within their company.

3.2.2 Current Liquid Food Product Market State

Participant were asked to identify their respective companies top three selling liquid food products in both the traditional supply chain and the e-commerce supply chain. Based on the answers from the participant a total of 52 liquid food products were analyzed. 19.2% of the products were top selling only through the traditional supply chain and 15.4% were top selling only through the e-commerce supply chain. 32.7% of the products were top selling in both supply chains. These differences allowed for data analysis in two different ways: (1) analysis of data from all liquid food products (100% of the collected data) and (2) analysis of data from liquid food products top selling in both supply chains (33% of the collected data).

3.2.2.1 Food Categories

The food products under study were grouped into food categories based on the nomenclature used by the Food and Agriculture Organization of the United Nations (FAO) Codex Alimentarius (FAO/WHO Codex Alimentarius Commission, 2019). This codex identifies 16 main food categories and a multitude of subcategories. For the purpose of this chapter, the subcategories were ignored. Table 3.3 contains these categories along with two new categories (Category 17.0

(pet food paste) and Category 0.0 (undetermined)). Table 3.3 shows the frequency of the top selling products through both supply chains in each food category.

Table 3.3 Food categories and frequencies (%) of the top selling liquid food products identified by industry (Adapted from the Codex GSFA's food category system)

Food Category	Category Number	Frequency through both (%)	Sold through TSC (%)	Sold through ESC (%)
Undetermined	0.0	1.6	0.0	100.0
Dairy products, excluding products of category 2.0	1.0	5.8	33.3	66.6
Fats and oils, and fat emulsions (type water-in-oil)	2.0	7.7	50.0	50.0
Edible ices, including sherbet and sorbet	3.0	0.0	0.0	0.0
Fruits and vegetables (including mushrooms and fungi, roots and tubers, pulses and legumes, aloe Vera)	4.0	0.0	0.0	0.0
Confectionery	5.0	0.0	0.0	0.0
Cereals and cereal products, including flours and starches from roots and tubers, pulses and legumes, excluding bakery wares of food category 07.0	6.0	0.0	0.0	0.0
Bakery wares	7.0	0.0	0.0	0.0
Meat and meat products, including poultry and game	8.0	0.0	0.0	0.0
Fish and fish products, including mollusks, crustaceans, and echinoderms	9.0	0.0	0.0	0.0
Eggs and egg products	10.0	0.0		
Sweeteners, including honey	11.0	3.8	50.0	50.0
Salts, spices, soups, sauces, salads, protein products	12.0	13.5	57.1	42.9
Foodstuffs intended for particular nutritional uses	13.0	23.1	50.0	50.0
Beverages, excluding dairy products	14.0	42.3	59.1	40.9
Ready-to-eat savories	15.0	0.0	0.0	0.0
Composite foods (e.g., casseroles, meat pies, mincemeat)	16.0	0.0	0.0	0.0
Pet food paste	17.0	1.6	0.0	100.0

42.3% of the products belong to category 14.0 (beverages). 59.1% of category 14.0 products were sold through the traditional supply chain while 40.9% of them were sold through the e-commerce supply chain. 23.1% of the products belong to category 13.0 (nutritional foodstuffs). Category 13.0 products were split evenly between traditional and e-commerce supply chains. 13.5% of the products belong to category 12.0 (salts, spices, sauces, and soups). 57.1% of category 12.0 products were sold through the traditional supply chain and 42.9% of category 12.0 products were sold through the e-commerce supply chain. 7.7% of the products were category 2.0 (fats and oils, and fat emulsions). Category 2.0 products were split evenly between traditional and e-commerce supply chains. 5.8% of the products were category 1.0 (dairy products). 33.3% of category 1.0 products were sold through the traditional supply chain while 66.7% of them were sold through the e-commerce supply chain. 3.8% of the products were category 11.0 (sweeteners). Category 11.0 products were split evenly between traditional and e-commerce supply chains. 3.8% of the liquid food products under study did not fall into FAO food categories. Thus, two new categories, Category 17.0 (pet food paste) and Category 0.0 (undetermined), were created to group these products. Both category 17.0 and category 0.0 products were sold only through the e-commerce supply chain. Based on the above results, the companies' popular food categories are similar whether the products are sold through traditional or e-commerce supply chains. The most popular food categories include beverages followed by nutritional foodstuffs and salts-soups regardless of the supply chain type (> 70%). Different amounts of these popular food categories are sold in each supply chain except for category 13.0, 2.0, and 11.0 products. It was observed that fewer category 14.0 and 12.0 products, but more category 1.0 and 17.0 products are sold through the e-commerce supply chain compared to the traditional supply chain. However, when the food categories were compared against distribution chains using chi-square test of independence (food

categories 14.0, 13.0, 12.0, and other foods (smaller categories were grouped)), the calculated p-value ($P = .6759$) does not provide sufficient evidence to claim a difference in e-commerce and traditional supply chain among food categories. This result is most likely due to analyzing all food categories together along with a larger proportion of food categories (13.0, 2.0, and 11.0 (~35%)) split evenly between traditional and e-commerce supply chains. Statistical analysis of each food category was not possible due to the nature of the chi-square test of independence and the data collected.

3.2.2.2 Package Format

Liquid food packaging formats were separated into two categories: rigid and flexible. This is a known way to split for food packaging formats (Coles, 2000; Selke et al., 2004). 88.5% of the liquid food products were rigid format packaged and contained many packaging types including bottles, cans, cartons, cups, and jugs. 56.5% of rigid formats were sold through the traditional supply chain while 43.5% of them were sold through the e-commerce supply chain. For the food liquid products packaged in flexible formats (11.5%), most of them were sold through the e-commerce supply chain (83.3%) and contained one packaging type the pouch. These results indicate that most package formats currently used to commercialize liquid food products are rigid. When the packaging formats were compared against distribution chains using there was not sufficient evidence to claim a difference in e-commerce and traditional supply chain package formats ($p > 0.05$). A plausible reason for this result was that most of the liquid food products were rigid format packaged and closely split between traditional and e-commerce supply chains (56.5% vs. 43.5%) and most of the liquid food products were rigid format packaged (94%). Comparing the same liquid food products in both supply chains, their package formats did not differ ($P > 0.05$).

3.2.2.3 Package Type

Package types for liquid food products were divided into 6 categories: bottle, can, carton, pouch, cup, and jug which are the most common types of packages used to commercialize liquid food products (Robertson, 2009). Figure 3.1 (Appendix) provides the frequency (%) of each package format type used for liquid food products across supply chains. 50% of the package type used to sell liquid food products was the bottle type package. This agrees with the current understanding that bottles are widely used to package beverages including water, carbonated drinks, fruit drinks, juices, and sport drinks (Newhart, B., 2019). 61.5% of these bottled products were sold through the traditional supply chain (Figure 3.1). Cans were the second largest package type category with 15.4%. More canned products were sold through the traditional supply chain (62.5%) than through the e-commerce supply chain (37.5%) (Figure 3.1). Carton type packages and pouch type packages did not differ in amount (11.5%); both were found to be the third largest package type category. 66.7% and 83.3% of liquid food products were sold in carton type packages and pouch type packages through the e-commerce supply chain (Figure 3.1). 7.7% of the package type used to sell liquid food products were cup type packages. Cup type packages were split evenly between traditional and e-commerce supply chains. 3.9% of the package type used to sell liquid food products were jug type packages. Jug type packages were split evenly between traditional and e-commerce supply chains. These results indicate that fewer bottle type packages and can type packages and more carton type packages and pouch type packages are used to sell liquid food products through the e-commerce supply chain and vice-versa for the traditional supply chain. In contrast, cup type packages and jug type packages were split evenly between traditional and e-commerce supply chains. When the package types were compared against distribution chains using chi-square test of independence (bottle types and others (can, carton, cup, jug, and pouch categories

were grouped together), there was not sufficient evidence ($P = 0.2669$) to claim an association in e-commerce and traditional supply chain among package materials. This result is most likely due to analyzing all package types together. Statistical analysis of each package type was not possible due to the nature of the chi-square test of independence and other statistical tests. Comparing the same liquid food products in both supply chains, their package types did not differ. Most of these liquid food products were sold in bottle type package (53%) and can type package (18%).

3.2.2.4 Package Material

Liquid food packaging materials were divided into five categories: glass, metal, paper, paperboard, and plastic. These are the main packaging material used for liquid food products (Beverage Industry, 2018) and other food types (Almenar et al., 2012) by the food industry. Packages can be made of many different materials, however, for the purpose of this research the responses include only the primary material contained within the package. 63.5% of the packages were primarily made of plastic. 51.5% of plastic packages were sold through the traditional supply chain (Figure 3.2 (Appendix)). This agrees with the fact that plastics are the main packaging material for food products due to their many advantages including cost-performance ratio (Almenar et al., 2012). Furthermore, the American Chemistry Council's IHS Markit attributes an increased demand for plastics packaging in 2018 to the rapid growth of food delivery (IHS Markit, 2019). The use of more plastic than other packaging materials in online grocery has been related to higher packaging emissions (Heard et al., 2019). The second most frequently used packaging material was metal which contributed to 13.5% to the total. This is supported by the fact that key food segments for cans include liquids (e.g., soups, sauces, and shelf-stable milk products) (Almenar et al., 2012). 71.4% of metal packages were sold through the traditional supply chain (Figure 3.2). 11.5% of the packages were primarily made of paperboard. 66.7% of paperboard

packages were sold through the e-commerce supply chain (Figure 3.2). Glass and paper did not differ in amount (5.8%) and thus, both of them were found to be the least used packaging material. 66.7% of the packages primarily made of glass were sold through the traditional supply chain; the same percent of packages primarily made of paper were sold through the e-commerce supply chain (Figure 3.2). These results indicate that plastic is the packaging material mainly used across both supply chains. These results also show that packages sold through the traditional supply chain are more likely to be primarily made of metal or glass than packages sold through the e-commerce supply chain. In contrast, packages sold through the e-commerce supply chain are more likely to be primarily made of paperboard or paper than packages sold through the traditional supply chain. When the package materials were compared against supply chains there was not sufficient evidence ($P = 1$) to claim an association in e-commerce and traditional supply chain among package materials. This is most likely due to 63.5% of the packages primarily made of plastic and these were almost split evenly between traditional and e-commerce supply chains (51.5% vs. 48.5%). Liquid food products were mainly sold in plastic packages regardless of the supply chain type (65-71%). The largest package material identified in Figure 3.2, plastic materials, was divided based upon their capacity of deformation or format. Two types of plastics were identified as flexible plastics and rigid plastics. When they were compared against supply chains, there was sufficient evidence to claim a significant difference ($p = 0.0445$) between supply chains. Rigid plastics were distributed fairly equally between e-commerce (41.4%) and traditional (58.6%) chains while all of the flexible plastics were located in the e-commerce supply chain (Table 3.4).

Table 3.4 Percentage distribution of the plastics identified in liquid food packaging in terms of amount, type of package (single-layer or multi-layer) and supply chain (traditional or e-commerce)

Plastic	Frequency (%)	Type of package		Supply chain	
		Single-layer (%)	Multi-layer (%)	Traditional (%)	E-commerce (%)
PET	32.2	73.7	26.3	47.4	52.6
PP	25.4	40.0	60.0	60.0	40.0
HDPE	20.3	16.7	83.3	66.7	33.3
EVOH	10.2	0	100	33.3	66.7
Others (LLDPE, LDPE, and Nylon)	11.9	0	100	30.8	69.2

3.2.2.4.1 Plastic Material

Plastic materials were divided based upon their plastic components. Two types of plastic materials were identified: multi-polymer packages and single-polymer packages. 61.1% of plastic packages were single-layer packages. This amount is less than the reported “monotype” plastic present in the Municipal Solid Waste of Finland (Dahlbo et al., 2018). Nearly half of single-polymer (45.5%) and multi-polymer packages (53.8%) plastics were sold through the e-commerce supply chain. Plastic materials were further subdivided, and each polymer component was identified. Seven different components of plastic packaging materials were identified. Three components were used in both single-polymer and multi-polymer packages: polyethylene terephthalate (PET), polypropylene (PP), and high-density polyethylene (HDPE). The other four components: ethylene vinyl alcohol (EVOH), low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), and Nylon were only used in multi-layer packages. This agrees with the literature that lists EVOH, LDPE, LLDPE, and nylons among the plastics most commonly

used to produce multi-layer packages (Kaiser et al., 2018; Maes et al., 2018). PET was the material most frequently used to package liquid food products regardless of the type of supply chain (Table 3.4. Specifically, 32.2% of plastic packages contained PET; 73.7% of PET packages were single-layer. 52.6% of PET plastics were used to sell liquid food products through the e-commerce supply chain. Multi-layer PET and single-layer PET were nearly distributed equally among supply chains. Marsh and Bugusu (2007) also reported that PET is the packaging material of choice for many food products, particularly beverages. The second most frequently used plastic packaging material was PP followed by HDPE. 25.4% of plastic packages contained PP (60% of PP packages were multi-polymer) and 20.3% of plastic packages contained HDPE (83.3% of HDPE packages were multi-polymer). 60.0% and 66.7% of PP plastics and HDPE plastics, respectively, were used to sell liquid food products through the traditional supply chain. Marsh and Bugusu (2007) reported PE and PP as the two most widely used plastics in food packaging. This still holds today (Dahbo et al., 2018). According to the American Chemistry Council's HIS Markit, released in August 2019, PP followed by HDPE were the two polyolefins that represented the largest plastic share globally in 2018 (HIS Markit, 2019). 10.2% of plastic packages contained EVOH. 66.7% of EVOH plastics were used to sell liquid food products through the e-commerce supply chain. Maes et al. (2018) reported that EVOH is one of the most commonly used gas barrier materials in multilayer food packages. The final 11.9% of plastic packages contained either LLDPE, LDPE, or Nylon. These results indicate that PET is the material most frequently used to package liquid food products regardless of the type of supply chain. Similarly, Song et al. (2018) identified PP as one of the two topmost frequently used plastic packaging materials for Chinese food delivery packaging in 2017. The second most frequently used plastic packaging material is PP. These results also show that packages sold through the traditional supply chain are more likely to contain PP and HDPE than

packages sold through the e-commerce supply chain. Packages sold through the e-commerce supply chain are more likely to contain EVOH, LDPE, and LLDPE than packages sold through the traditional supply chain. Nylon plastics were split evenly between traditional and e-commerce supply chains. Life cycle analyses associated to the aforementioned packaging materials should be performed to compare environmental impacts between supply chains. To have a fair comparison, the way the different plastics can protect the food product from mechanical damage and extend food shelf life should be taken into consideration. Comparing the same liquid food products in both supply chains, their plastic materials did not differ in polymer type ($p > 0.05$) except for the presence of LLDPE in the e-commerce supply chain ($p < 0.05$). The same amounts of all materials except LLDPE were used in both supply chains.

3.2.3 Defects

Defects were categorized into five types: leaks, odor changes, punctures, scratches, and deformations. These are the most common defects found in food packages (Arndt, 2001; Lin et al., 2001). These defects go from simple aesthetic issues to significant impacts on food shelf life that result in important amounts of food and packaging waste. 13.5% of the products reported by the companies recorded a zero value for each of the defect types specified above in both supply chains. The rest of the products were recorded with defects ranging between 0.1% and 3.0% in occurrence. Holloway et al. (2003) reported 1.6% purchase damage during online delivery when examining consumer's perspective of online failures.

3.2.3.1 Defect Rates

To decrease variability, the results were further analyzed excluding the companies reporting a zero value for a specific defect and further divided into two groups: low defect rate (0.1 to 1.4) and high defect rate (1.5 to 3.0). Table 3.5 provides the median percent of liquid food

product packages that experienced a specified defect in each defect rate group and each supply chain. The median of the low defect rate ranged between 0.3-1.0, with most of the defects being rated at approx. 0.5% occurrence regardless of the distribution channel. For low defect rate, no significant differences were found for leaks ($P = 0.431$), odor changes ($P = 0.9111$), punctures ($P = 0.8602$), and scratches ($P = 0.8012$).

Table 3.5 Median defect (%) per defect rate group and supply chain

Defect rate	Supply chain	Median defect (%)				
		Leaks	Odor Changes	Punctures	Scratches	Deformations
Low	E-Commerce	0.60	0.45	0.50	0.50	0.30
	Traditional	0.40	0.40	0.60	0.50	1.00
High	E-Commerce	N/A	N/A	1.70	1.95	2.40
	Traditional	2.00	N/A	1.50	2.10	2.20

Significant differences were found for deformations ($P = 0.0013$). Packages sold through the traditional supply chain present more deformation than the ones sold through the e-commerce supply chain. For high defect rate, no significant differences were found for any defect. These results indicate that the investigated defects at high rate are the same in both supply chains. The no differences between supply chains could be attributed to the combination of different materials (e.g., plastic, metal, paperboard), package formats (e.g., rigid, flexible), and package types (e.g., bottle, can). The results also show that odor changes only occur at low rate in both supply chains and that leaks only occur at low rate in the e-commerce supply chain. Further analysis was performed by splitting each of the defects in each supply chain among three factors: package format, package type, and package material and comparing the results between supply chains. Figure 3.4 (Appendix) provides the median percent of liquid food products that experience specified defect in each package format between supply chains. The highest observed median defect (%) for the rigid package format was scratches (0.45%) occurring in the traditional supply

chain. The flexible package format median defect (%) was highest among leaks (0.40%) in the traditional supply chain. Leaks occurring in flexible packages in the traditional supply chain was observed to be the second highest median. Medians for odor changes and punctures were observed to be 0.0% for both formats and supply chains. Median scratches were 0.0% for packages traveling through the e-commerce supply chain. No significant differences were found for leaks ($P = 0.9665$), odor changes ($P = 0.6474$), punctures ($P = 0.8708$), scratches ($P = 0.2778$), or deformations ($P = 0.2663$). The no significant differences can be attributed to the combination of different materials (e.g., plastic, metal, paperboard) and package types (e.g., bottle, can). Figure 3.5 (Appendix) provides the median value of the percent of liquid food products that experience specified defect in each package type between supply chains. Package type was grouped into four categories (bottle, can, pouch, and other (cups, jugs, and cartons were grouped together)). Can packages distributed through the e-commerce supply chain were observed to have the highest median leaks (0.80%). Bottle packages scratches (0.65%) and deformations (0.6%) were observed to be the highest medians in the traditional supply chain. Pouches were observed to have similar median leaks to bottles (0.40%) in the traditional supply chain but they had less leaks (0.20%) in the e-commerce supply chain. Medians for odor changes and punctures were observed to be 0.0% for both formats in the traditional supply chain, however, punctures were experienced by both bottles (0.1%) and cans (0.4%) in the e-commerce supply chain. No significant differences were found for leaks ($P = 0.2377$), odor changes ($P = 0.7008$), punctures ($P = 0.3909$), scratches ($P = 0.1107$), or deformations ($P = 0.2657$). For package types within the traditional supply chain, there was no difference between package types and defects within the traditional supply chain. According to Kamei et al. (1991), there should be more opportunities for breach of seal integrity for flexible and semi-rigid packaging than for cans due to the fact that flexible and semi-rigid

packages undergo temporary shapes caused by abuses incurred during storage and distribution. The difference could be that the current supply chain differs from the 90s' supply chain in terms of package abuse. Statistical analysis of each package type was not possible due to the limitations of statistical tests to small sample sizes.

To continue decreasing variability, package type defect data were analyzed within the e-commerce supply chain and within the traditional supply chain. For package types within the e-commerce supply chain, no significant differences were found for odor changes ($P = 0.3025$), punctures ($P = 0.1259$), and deformations ($P = 0.07605$). Significant differences were found for leaks ($P = 0.0013$) and a Dunn's post hoc test was used to test pairwise comparisons. Bottles, cans, and pouches were not significantly different to another ($P > 0.05$), but bottles were significantly different to other types of packages ($P=0.03732$). Significant differences were also found for scratches ($P = 0.02709$) and a Dunn's post hoc test was used to test pairwise comparisons. Bottles, cans, and pouches were not were not significantly different to another ($P>0.05$), but bottles were significantly different to other types of packages ($P=0.0257$). These results indicate that bottles experience scratches and leaks more than other type packages within the e-commerce supply chain. For package types within the traditional supply chain, no significant differences were found for leaks ($P = 0.7593$), odor changes ($P = 0.8917$), punctures ($P = 0.6688$), scratches ($P = 0.7477$), or deformations ($P = 0.5348$). Indicating there was no difference between package types and defects within the traditional supply chain. Figure 3.6 (Appendix) provides the median percent of liquid food products that experience specified defect in each package material between supply chains. Package material was grouped into three categories by grouping smaller categories into one category. Metal packages distributed through the e-commerce supply chain were observed to have the highest median leaks (0.80%). Plastic packages were observed to have the highest median

deformation in the traditional supply chain (0.80%). Other packaging materials (paper, paperboard, and glass) median leaks values were like plastic packages (0.4%), however, other types of packages had a median of (0.0%) in the e-commerce supply chain. Medians for odor changes and punctures were observed to be 0.0% for both formats in the traditional supply chain, however, punctures were observed by cans (0.4%) in the e-commerce supply chain. No significant differences were found for leaks ($P = 0.7909$), odor changes ($P = 0.2271$), punctures ($P = 0.2297$), scratches ($P = 0.2023$), or deformations ($P = 0.05913$). No differences were observed because the Kruskal-Wallis test used all material types to compare each defect between supply chains and the data shows large variations among material types caused by package type (e.g., 0.8 vs. 0.0 for deformations in traditional supply chain). Statistical analysis of each package material was not possible due to the limitations of statistical tests to small sample sizes.

3.2.3.2 Defect Rationale

For each defect type, participants were asked to provide a rationale for why the defect is occurring in the liquid food product package. For the defect leaks, the location of the leak was also asked to the participants. Table 3.6 compiles the responses from the participants. The low frequency responses were combined into one category, which is showed as “other” in Table 3.6. The rationale given most frequently for leaks was seal breakage in both e-commerce (24%) and traditional (30%) supply chains. This rationale was distributed similarly between supply chains. Leak location was similar between supply chains, too. Most leaks (20-30%) occurred either at the cap/closure of the package or among the seals of the package for both e-commerce and traditional supply chains. Similarly, Keller (1998) reported that flexible and rigid packages are susceptible to various imposed defects, such as burst defects and seal creep, due to abuses via shock and vibration

during product storage and distribution. Temperature abuse was the most frequently provided rationale for odor changes between both supply chains.

Table 3.6 Overview of participants' rationale for each defect

Defect Rationale	Frequency (%)	
	E-Commerce Supply Chain	Traditional Supply Chain
Reason for Leaks		
Broken Seal	24.0	30.0
Pinholes	8.0	14.0
Other	10.0	14.0
Location of Leaks		
Seal	18.4	21.1
Cap/Closure	28.9	23.7
Other	5.3	2.6
Reason for Odor Changes		
Package Material	9.5	19.0
Surrounding Packaged Foods	9.5	4.8
Temperature Abuse	19.0	28.6
Other	0.0	9.5
Reason for Punctures		
Sharp Package Edges	9.5	9.5
Other	0.0	23.8
Unknown	33.3	23.8
Reason for Scratches		
Interactions w/ Different Packages	18.9	10.8
Interactions w/ Identical Packages	24.3	45.9
Reason for Deformations		
Impact	12.3	10.5
Shock	19.3	10.5
Vibration	12.3	8.8
Static Load	12.3	10.5
Other	0.0	3.5

According to the literature, temperature abuses above or below the optimal food product- specific temperature range occur frequently (Ndraha et al., 2018). Package material (9.5%) and surrounding packaged foods (9.5%) were provided equally as a reason for odor changes in

e-commerce while package material (19.0%) was provided more than surrounding packaged food (4.8%) in the traditional supply chain. Gas movement through the packaging material, a.k.a. permeation, reduces the shelf life and quality of the packaged food product (Almenar and Auras, 2010). Furthermore, gas movement can occur through seams via channel leakers, through the body wall of the container via pinholes, through the bound polymer layers in multi-layer plastics, etc. (Placencia et al., 1988; Reich, 1985). The reason packages were being punctured was relatively unknown in both supply chains (e-commerce supply chain (33%) and traditional supply chain (23.8%). However, other reasons were noted by participants as much as the unknown reasons in the case of the traditional supply chain. These reasons included top load shipping hazards and other shipping hazards. The rationale given most frequently for scratches was interactions with identical packages for both e-commerce (24.3%) and traditional (45.9%), however scratches due to interactions with different packages occurred only slightly lower (18.9%) in the e-commerce supply chain. Among the all defect rationales only deformations occurred at a higher frequency in the e-commerce supply chain ($p < 0.05$). The primary rationale given for deformations in the e-commerce supply chain was shock (19.3%); all other identified rationales occurred at the same frequency. Impact, shock, and static load were provided as a reason for deformations equally in the traditional supply chain (10.5%)

3.2.4 Future of E-commerce Packaging

3.2.4.1 *A Change in the Food Product Landscape*

According to a MyWebGrocer's study published in 2015, the most popular food categories purchased online were dairy, produce, beverages, frozen food, and sweets & snacks (Watt, 2016). This list has changed a bit during the last years. According to participants, there are many food categories with increasing presence in e-commerce. Category 8.0 (meat and meat products) was

chosen by participant 21.4% of the time. In agreement, the 2017 Nielsen Total Food View reported a growth for fresh meat in e-commerce (Staff, 2018). Category 4.0 (fruits and vegetables), 13.0 (nutritional foodstuffs), and 14.0 (beverages) products were each chosen 14.3% of the time. Similarly, the 2017 Nielsen Total Food View highlighted the growing e-commerce opportunity for fresh perishables (Staff, 2018) and Amazon reported beverages as their most popular grocery category (Danziger, 2018). Category 1.0 (dairy products), 2.0 (fats and oils, and fat emulsions), 12.0 (salts, spices, sauces, and soups), and 15.0 (ready-to-eat products) were each chosen 7.1% of the time. 10% of the participant observed increasing presence in pet food products (not included in FAO food categories). All in all, these results correlate with those from the Nielsen's consumer trend reports that indicate more online purchases of perishable grocery (Nielson, 2018a; Nielson, 2018b).

3.2.4.2 A Change in Package Materials and Formats

All participants believe that liquid food products sold through e-commerce require different packaging than traditional retail, however, they differ in how the packaging will change. Most participants claim flexible plastic containers (60%) perform best over other types of containers (i.e., rigid plastics containers, aseptic cartons, glass containers, metal containers) for liquid food products shipped to consumers through e-commerce. From participants who prefer flexible plastic containers, they believe on average that 39% of their respective company's products will move towards flexible plastics. Companies moving towards flexible liquid food packaging are looking into three packaging styles: pouch (41.7 %), stand-up pouch (33.3%), and bag (25%). Therefore, pouches were observed to be preferred over bags for commercialization of liquid food products through e-commerce supply chain. In contrast, companies are not looking to move to skin, shrink-wrap, or other styles of flexible packaging ($p < 0.05$). Rigid plastics and glass containers are

preferred by 30% and 10% of the participants, respectively. Participants who prefer rigid plastics believe 45% of their liquid food products will move towards rigid plastics. Participants who prefer glass container believe all of their products will continue to use glass containers. Metal containers and aseptic cartons are not preferred. According to a 2019 e-commerce study by PMMI's Business Intelligence, 39% of brand owners that are active in e-commerce are looking to change their primary packaging for the e-commerce channel. About a quarter (27%) of these brands will develop a new primary packaging specific for the e-commerce channel while the other quarter (25%) will develop a new primary packaging for both e-commerce and retail (omnichannel package design). It is worth mentioning that only 8% of the responses came from beverage brand owners (Reynolds, 2019). According to our participants, most predicted changes for liquid food products are packaging changes whether it will be changes to the packaging material (42.9%) or packaging format (42.9%). Other possible change is product changes (10%). Similarly, the aforementioned study by PMMI's Business Intelligence found that 72% of brand owners are looking for new materials with greater durability to prevent product damage (Reynolds, 2019).

3.2.4.3 Reasons for Changes

Participants described expected material changes as changes in selection to increase food product shelf life and to reduce package damage. Examples of specific comments (paraphrased for readability) are “the need to move away from cans towards more lightweight packaging to decrease damage” and “more robust packaging to survive the e-commerce market”. Packaging format changes were conflicted with some adding multiple sizes (single serve, family, and variety) while others believe in consolidation of multiple SKUs into one package. Some other packaging format changes involved adding tamper-evidence and involving different configurations, overpacks, or dunnage to decrease damage rates. Therefore, decreasing damage rates seems to be the top current

need for change in the food packaging field and participants plan to address that need by changing both packaging material and packaging format. Similarly, the study by PMMI's Business Intelligence found that the top areas where companies are concentrating their e-commerce efforts and budgets are new produce/package development (29%), optimized or right-sizing package for contents, DIM weights, etc. (23%), new primary package design (14%), and addressing sustainable solutions (reuse, recycle) (18%) among others (Reynolds, 2019). All of the above point to the reduction of both food waste and packaging waste with the development of more sustainable packaging.

3.2.4.4 E-commerce Economic Effects

75% of participants have lower profit margins in e-commerce compared to traditional retail ranging from 5% to over 50% lower margins in this distribution channel. The 25% with higher profit margins only see at most 10% larger margins. One reason for companies experiencing lower profit margins could be the penalizations from e-commerce retailers. Most companies (80%) are penalized by the e-commerce merchants when the package fails to protect the product. The penalization varies from chargebacks, loss of demand for their products, or overpacking of their products. In general, the penalization hurts the company's credibility with the merchants and issues are expected to be solved quickly. For most participants (44.4%), it is unknown what is done for the consumer if their primary package leaks affecting other products within the secondary package. For some participants (22.2%), the issue is resolved by the e-commerce retailer and reimbursement is passed to the brand owner. One participant noted that by using ISTA Amazon-6 Overbox testing the brand owner is protected from liability. The above may be one of the reasons why this study and the study by PMMI's Business Intelligence (Reynolds, 2019) report that companies are concentrating their efforts in decreasing damage rates. These efforts should lead to an increased

protection of the food product and thereby less food and packaging waste by resulting to the less food packages thrown away.

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APPENDIX

Figures

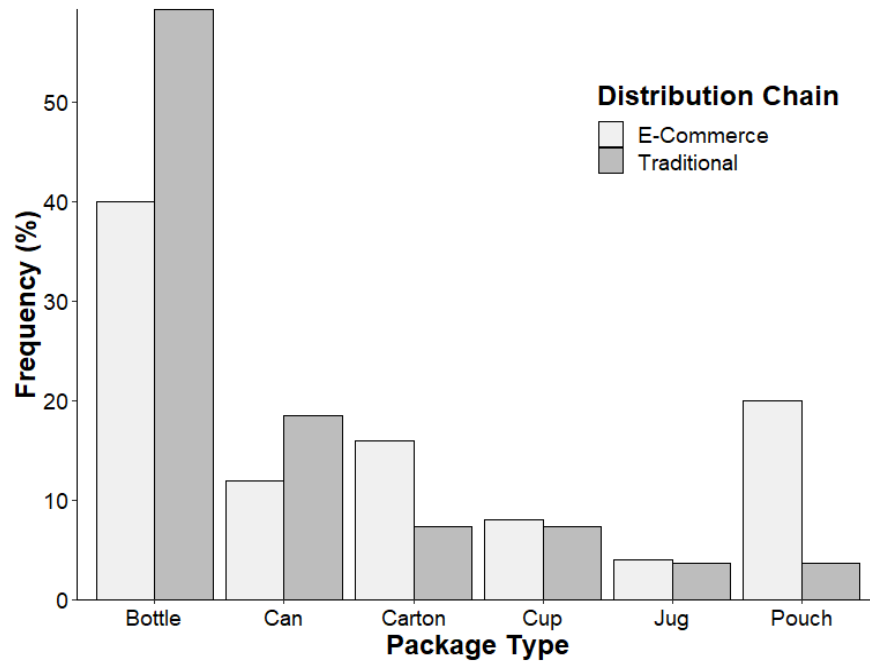


Figure 3.1 Frequencies (%) of packaging type between e-commerce and traditional supply chains

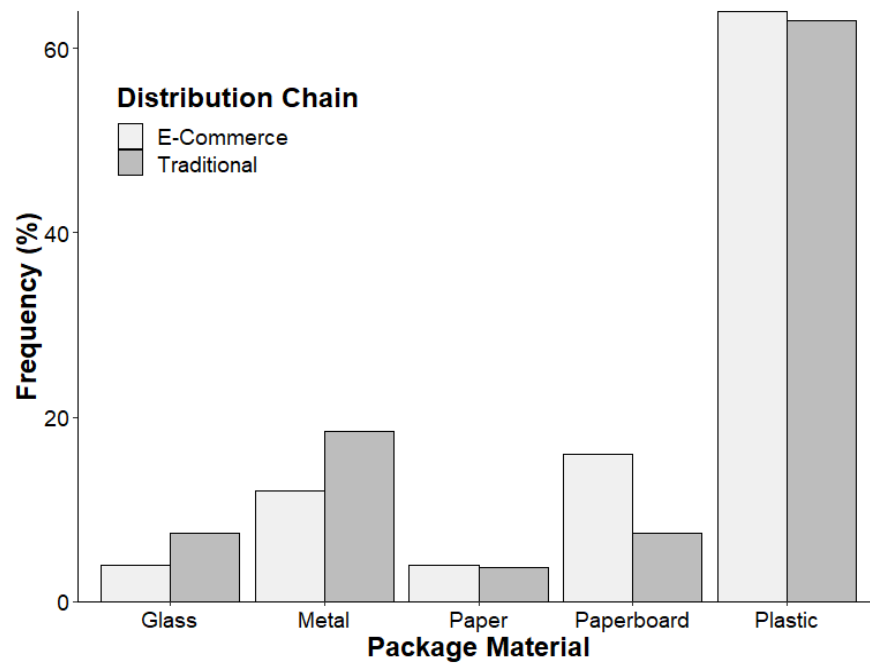


Figure 3.2 Frequencies (%) of packaging material between e-commerce and traditional supply chains

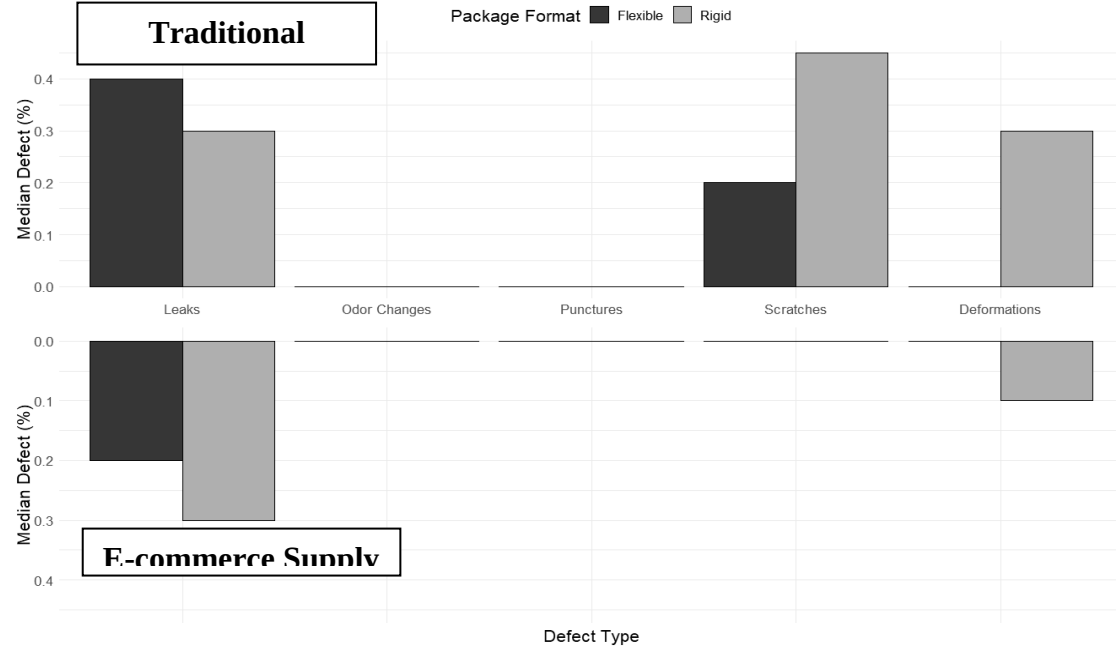


Figure 3.3 Median defect (%) of package format between both e-commerce and traditional supply chains

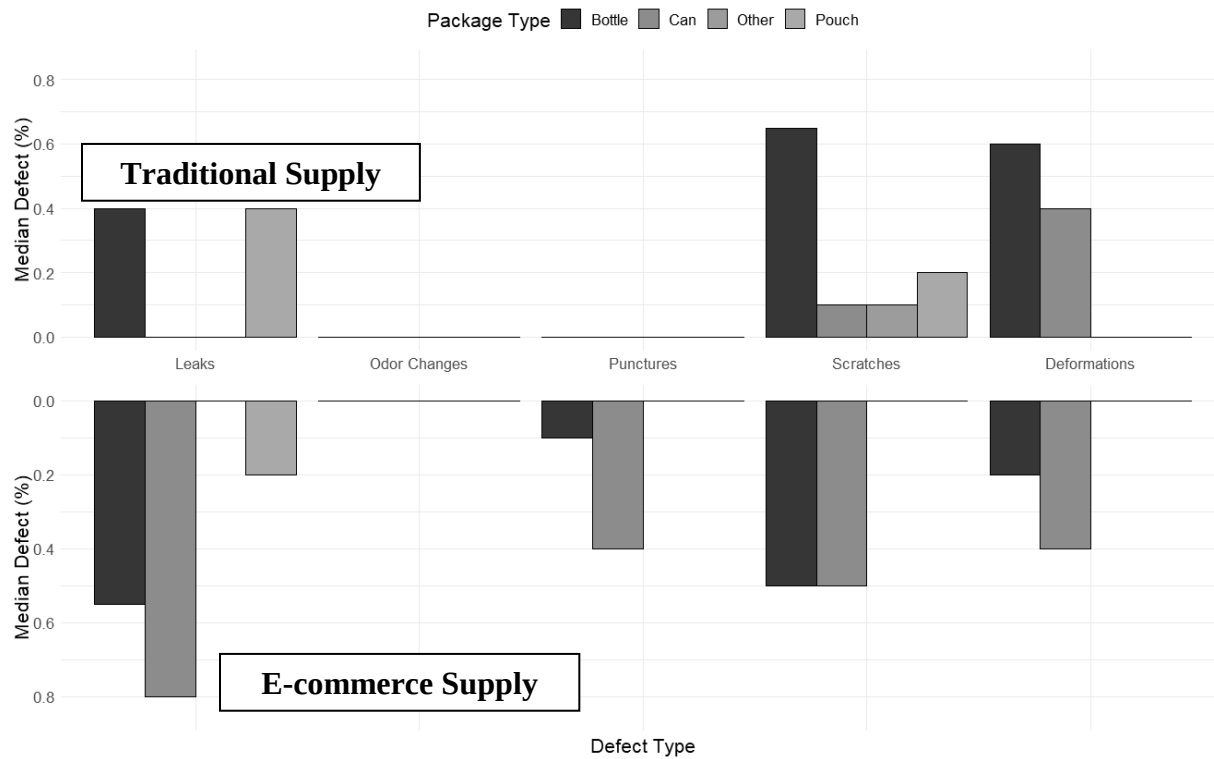


Figure 3.4 Median defect (%) of package type between both e-commerce and traditional supply chains

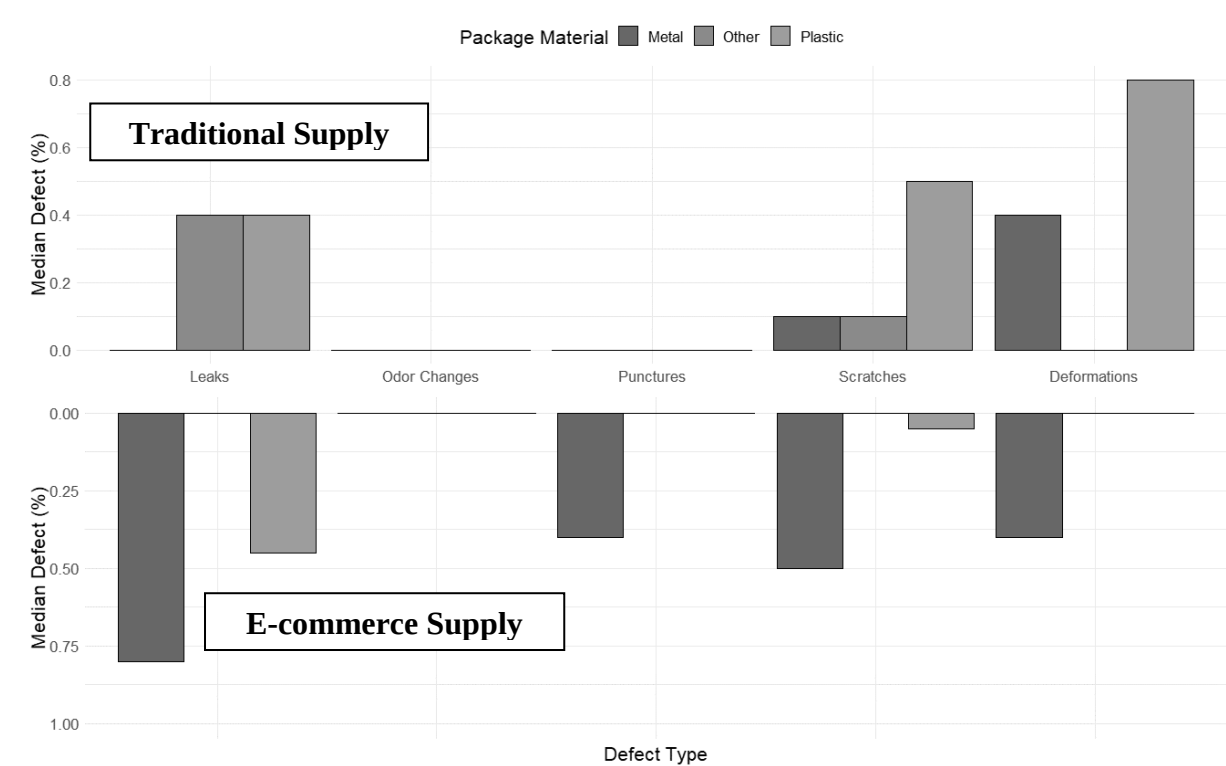


Figure 3.5 Median defect (%) of package material between both e-commerce and traditional supply chains

Consent Statement

You are being asked to participate in a research study. The purpose of the study is to understand current packaging for food packaging for E-commerce, the major failure modes of these packages, and potential improvements that can be done. You will be asked to answer questions about packaging used for specific products, damages related to the packaging you use for these products, and the current and future trends within your company that relate to packaging.

It will take about 20 minutes to complete the survey. All answers you provide will remain anonymous to protect you and your organization. Your participation is voluntary. You can skip any question you do not wish to answer; some questions require an answer to continue the survey simply enter “N/A” if you wish not to answer that question. You may also withdraw at any time. You must be 18 or older to participate.

You will receive the results of the survey once the research is completed. If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researchers Dylan Spruit by phone at 248-974-9098 or by email at spruitdy@msu.edu or Dr. Eva Almenar by phone at 517-355-3603 or by email at ealmenar@msu.edu.

By clicking on the button below, you indicate your voluntary agreement to participate in this online survey.

MICHIGAN STATE UNIVERSITY

EXEMPT DETERMINATION

April 30, 2018

To: Eva Maria Almenar Rosaleny

Re: **MSU Study ID:** STUDY00000799

Principal Investigator: Eva Maria Almenar Rosaleny

Category: Exempt 2

Exempt Determination Date: 4/30/2018

Title: Food Packaging E-Commerce Market Study

This project has been determined to be exempt under 45 CFR 46.101(b) 2.

Principal Investigator Responsibilities: The Principal Investigator assumes the responsibilities for the protection of human subjects in this project as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Continuing Review: Exempt projects do not need to be renewed.



**Office of
Regulatory
Affairs
Human Research
Protection Program**

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Lansing, MI 48910

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Fax: 517-432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the project is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Change in Funding: If new external funding is obtained for an active human research project that had been determined exempt, a new initial IRB submission will be required, with limited exceptions.

Reportable Events: If issues should arise during the conduct of the research, such as unanticipated problems that may involve risks to subjects or others, or any problem that may increase the risk to the human subjects and change the category of review, notify the IRB office promptly. Any complaints from participants that may change the level of review from exempt to expedited or full review must be reported to the IRB. Please report new information through the project's workspace and contact the IRB office with any urgent events. Please visit the Human Research Protection Program (HRPP) website to obtain more information, including reporting timelines.

Email

Hi [First_Name] [Last_Name],

MSU School of Packaging needs your help. Please take our survey on e-commerce food packaging to help us understand ways to improve and fortify the packaging for the online retailer environment.

You are part of a select group of people we are asking to provide insight into e-commerce packaging needs. As a thank you, after analysis of the survey, you will receive exclusive early access to a complete report and a possibility to discuss the results with the research team. Your responses will be anonymous and published results will not include information that could be related to any of the participating companies.

This important survey will help us understand the differences in primary package damage between e-commerce and the traditional supply chain. Additionally, it will identify which materials are best suited for e-commerce shipments. Please complete the survey by [Specified Date].

Follow this link to the Survey:

https://msu.co1.qualtrics.com/jfe/form/SV_6o2JnVW5xJbXnyl?Q_DL=3OsSWjIhZrBE1hz_6o2JnVW5xJbX

If you are not the correct person to be speaking with about packaging for e-commerce, can you please assist us with an introduction to your team member who is responsible for the emerging market space?

Thank You!

Dylan Spruit, Graduate Researcher, Michigan State University
Dr. Eva Almenar, Associate Professor, Michigan State University

This research project was made possible by the generous sponsorship of UBE America Inc. Additionally, the promotional efforts of Amcor Ltd. helped increase survey participation.

CHAPTER 4

ASSESSING THE CURRENT FOOD PRODUCTS AND PACKAGING WITHIN E-COMMERCE MEAL KITS

4.1 Materials and Methods

4.1.1 Categorization of commercial meal kits

Sixteen meal kits with three meals each were collected from four separate companies over the course of four weeks. The companies chosen were leading in market share in the United States during the time of the study (2019). They are referred as meal kit companies throughout this chapter. Upon arrival, the meal kits were photographed, unpacked, and information regarding the company week of arrival was logged. The food contents within each kit were then separated according to the meal recipe that they belonged to. Packaged food products were photographed and removed from their primary packages. Data corresponding to each food product including company ID, product name, product amount, primary package type, secondary package type, primary package material, and secondary package material was logged.

The food products were grouped into food subcategories based on the nomenclature presented in the Codex GSFA's food category system by the Food and Agriculture Organization of the United Nations (FAO)/ World Health Organization (WHO) (FAO/WHO, 2019). This codex identifies 16 main food categories and a multitude of subcategories and of sub-subcategories. In this paper, food subcategories and food sub-subcategories are only presented. They are first named and then followed by their corresponding codex number between parentheses. The codex number of the food subcategories consists of 2 integers separated by a hyphen where the first integer indicates category and the second integer subcategory (e.g. 1-1). The codex number of the food sub-subcategories consists of 3 integers separated by two hyphens where the first two integers indicates the same as states above and the third integer indicates sub-subcategory (e.g. 1-1-1).

The primary package type and package material(s) for each of the food products were identified and classified. These packaging data were also logged. If the primary package contained a plastic, this was identified using the technologies differential scanning calorimetry (DSC) and Fourier-transform infrared (FTIR) spectroscopy. DSC was performed using the differential scanning calorimeter Discovery DSC 25 (TA Instruments®, New Castle, DE, USA), which utilized the TRIOS software v5.0.0 (TA Instruments®, New Castle, DE). Samples of $5 \text{ mg} \pm 1.5 \text{ mg}$ were cut using a fixed-blade utility knife or a circular sample cutter. Using tweezers, the samples were then placed in aluminum Tzero pans (TA Instruments®) and were sealed using a Tzero Press (TA Instruments®). Each sample was placed onto the DSC auto-sampler tray and had its position recorded. Samples were heated at a rate of $20 \text{ }^{\circ}\text{C}/\text{min}$ to $300 \text{ }^{\circ}\text{C}$ and an isothermal condition was set to 5 minutes. Samples were then cooled at a rate of $20 \text{ }^{\circ}\text{C}/\text{min}$ to an equilibrium state at $23 \text{ }^{\circ}\text{C}$ and an isothermal condition was set to 5 minutes. This cycle was repeated. The first cycle removed residual solvents and erased the thermal history of the polymer. The second cycle was used to identify the polymers in the sample. Melting point and glass transition temperature peaks were identified using the TRIOS software. The values were compared with values found in the literature (Selke et al., 2004). FTIR spectroscopy was conducted using an Alpha Series FTIR spectrophotometer (Bruker Co., Billerica, MA, USA) and the curves were produced using the OPUS software (OPUS Software Inc., San Francisco, CA). Prior to use, the FTIR was wiped using Kimwipes™ (Kimberly-Clark, Irving, TX, USA) dabbed with Klean Strip™ Acetone (W.M Barr & Co Inc., Memphis, TN, USA). When conducting tests with the FTIR both sides of the plastic film/sheet were tested providing two FTIR graphs. Prior to testing each sample, each sample ID and side ID was logged using the OPUS software. The sample was placed onto the machine and the test was ran using the OPUS software. Prior to analysis, the spectrum produced by the machine

was total reflection (TR) converted. Analysis was conducted using an internal library supplied by UBE Corporation Europe, S.A.U. (Castellon, Spain). The results from the DSC and FTIR curves were then compared and if discrepancies were found the DSC graph was preferred over the results from FTIR.

4.1.2 Data Analysis

RStudio version 1.1456 (RStudio Inc., Boston, MA, USA) was used to organize and represent the data. This included the following: restructuring the collected data into a long format, creating proportion tables in R to identify data distributions, and developing an application to clearly reveal as much as the results as possible. Graphical data was produced using the ggplot2 version 3.1.0.9000 (tidyverse.org).

4.2 Results and Discussion

4.2.1 Food Products in Meal Kits

Each of the 16 meal kits contained 3 meals and each of the 48 meals contained a mean of 9.46 ± 1.96 food products. Meals differed in combination of food products among them. When the 459 food products were grouped into food subcategories based on the nomenclature presented in the Codex GSFA's food category system, the subcategories found in meals with the highest frequency were vegetables (4-2) and fruits (4-1) that represented 30.9% and 15.7% of the total of food products, respectively. Following fruits were herbs and spices (12-2) (9.6%) and sauces (12-6) (9.2%). Next was cheese (1-6) and meat (8-1) both containing about 5% of the food products. The rest of the 18 subcategories each contained less than 4% of the total food products. Similarly, Fenton (2017) found that vegetables are the largest share food product type by weight (24.93 ounces vs. 39.84 ounces) in meal kits in USA and Gibson et al. (2019) found vegetables to have the highest number servings in meal kits in Australia (pooled mean 2.68 vs 7.78). Fenton (2017)

did not include sauces or spices as a category, which could have contributed to the overwhelming share of product by weight being vegetables (62.6%). Furthermore, vegetables in Fenton (2017) included dark green, red orange, starchy, and legumes rather than the FAO category groupings. It must also be noted that Fenton (2017) looked weight of products while this study focused on package-product units. Fenton (2017) also found fruits (2.54 ounces), meat (2.27 ounces), and dairy (2.50) to be in the top 5 share of food products.

The identified top FAO subcategories were divided into sub-subcategories to better understand the more specific food products that were popular among the meal kits. The two most common sub-subcategory products were fresh vegetables (4-2-1) and fresh fruits (4-1-1), which contained 26.4% and 12.9% of products, respectively. Next was non-emulsified sauces (12-6-2) and herbs and spices (12-2-1), which both contained 6.75% of the products. Fresh meat (8-1) was unchanged (5%) due to not splitting into other sub-subcategories. When the dairy category was split into the following sub-subcategories: pasteurized cream (1-4-1) (3.1%), unripened cheese (1-6-1) (1.3%), and ripened cheese (1-6-2) (3.5%), the category made less of an impact than other popular categories. The sub-subcategories 4-2-1, 4-1-1, 12-6-2, 12-2-1, and 8-1-1 alone accounted for 57.6% of the total products in the meal kits. The other sub-subcategories that were considered each contained less than 5% of the products. Due to this, the section about package types and package materials (3.1.2) in meal kits focuses on the top 5 sub-subcategories only.

4.2.2 Package Types and Materials in Meal Kits

Figure 4.1A (Appendix) shows the types of primary packaging across the five top sub-subcategories and their frequencies. Primary package types fell into 10 categories: bag, bottle, can, carton, cup, jar, pouch, tray, wrap, and not applicable (NA; product not contained in package). The pouch was the most frequently used primary package type (48.3%). This corresponds with data

presented at the 2011 Global Pouch Forum indicating that one of the major drivers in recent pouch growth being due to meal kits (Packaging Strategies, 2011). The next most common was for products to not be included in a primary package at all (27.9%). Then trays and bags were used for 7.5% and 6.0% of the products, respectively. All other primary package types were used for less than 5% of the products each. Similar results were obtained when the primary package types specific to each of the top food sub-subcategory were analyzed (Figure 4.2 (Appendix)). The pouch was the most common primary package type for fresh vegetables (4-2-1, 58.7%), herbs and spices (12-2-1, 51.6%), and non-emulsified sauces (12-6-2, 35.5%). Fresh fruits (4-1-1) was dominated by the lack of primary packaging with 62.7% of the fruits without a package. The pouch was still second in this food sub-subcategory, but only contained 11.9% of the products. Bags followed pouches very closely (10%). Both resulted in 22% of the primary package type used for fresh fruits. Four out of the five top food sub-subcategories are included in Figure 4.2 since the fifth top food sub-subcategory, fresh meat (8-1-1), was always contained in pouches.

Figure 4.1B (Appendix) shows the materials used to produce the aforementioned primary packages across the five top sub-subcategories and their frequencies. Plastics were the most frequently used material (97.3%) while all together non-plastic materials contributed to (2.7 %) to the primary packages, which corresponds with past literature finding high plastic use in meal kits (Fenton, 2017; Heard et al., 2019). PE was the most frequently used packaging material contained within 34.2% of the food products from the five top FAO sub-subcategories. Similarly, Fenton (2017) reported LDPE as the predominating plastic in meal kits and attributed its use to plastic bags. PP and PET were also popular materials among all products contained in 18.4% and 13.5%, respectively. Similarly, Song et al. (2018) identified PP as one of the two topmost frequently used

plastic packaging materials for Chinese food delivery packaging in 2017. In contrast, Fenton (2017) reported that PET but not PP is a plastic used in meal kits in US.

Specific package materials for pouches were identified (Figure 4.1C (Appendix)) due to their large use in meal kits. They are in descending frequency: PE (47.0%), PP (25.5%), PA (11.5%), PET (9.5%), EVOH (5.0%), and paperboard (1.5%). In contrast, Fenton (2017) reported that plastic bags are made of LDPE and rigid bottles of PET in meal kits. The discrepancy could be due to the fact that Fenton (2017) did not use equipment for plastic identification. EVOH and PA were strictly used in multilayer packaging usually combined with a PE layer. Other authors also list EVOH, LDPE, LLDPE, and PA among the plastics most commonly used to produce multilayer packages (Maes et. al., 2018; Kaiser et. al. 2018). Splitting pouches by sub-subcategories shows that 35.1% of the fresh fruits (4-1-1) were mainly packaged in single-layer plastic made of PE (15%). 47.9% of the fresh vegetables (4-2-1) were also packaged in single-layer plastic made of PE with the remainder packaged in either PP (17.4%) or PET (4.1%). Fresh meats (8-1-1) were packaged only in multilayer plastic pouches and have a variety of plastics. 63.0% of the meats were packaged in multilayer materials containing either PA or PE with the majority of the remainder (28.8%) packaged in PP, too. Herbs and spices (12-2-1) were mainly packaged in PET as a part of a multilayer while non-emulsified sauces (12-6-2) were mainly packaged in PE used as single or as a part of a multilayer.

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APPENDIX

Figures

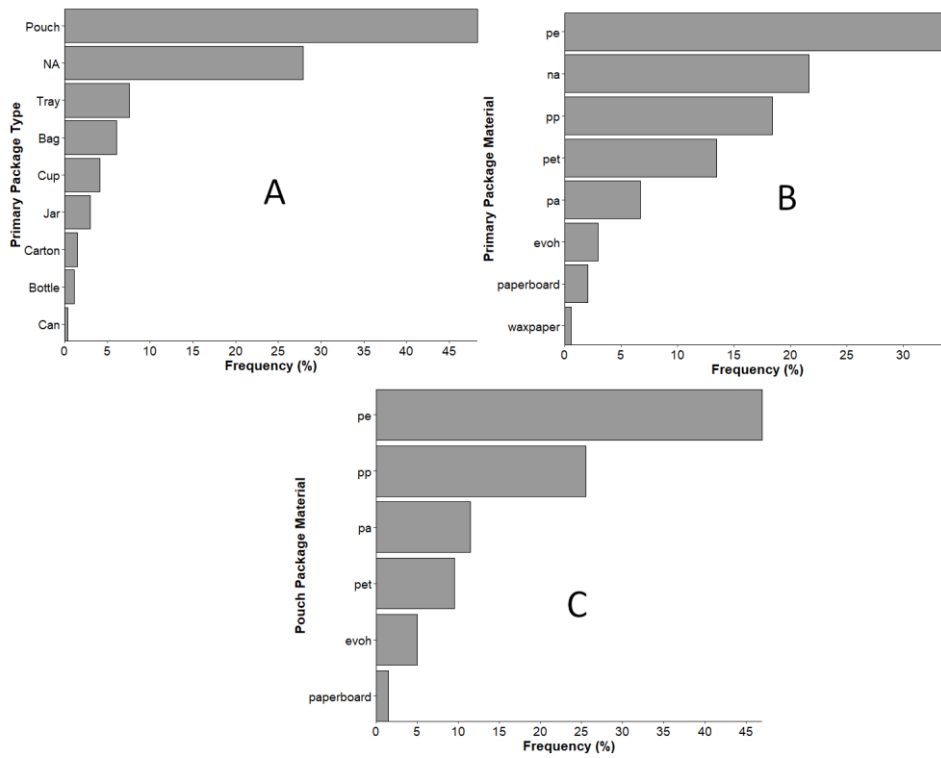


Figure 4.1 Frequency of Primary Package Type (A) and of Primary Package Material (B) as well as of Pouch Package Material (C). NA is used when products were not contained in a primary package

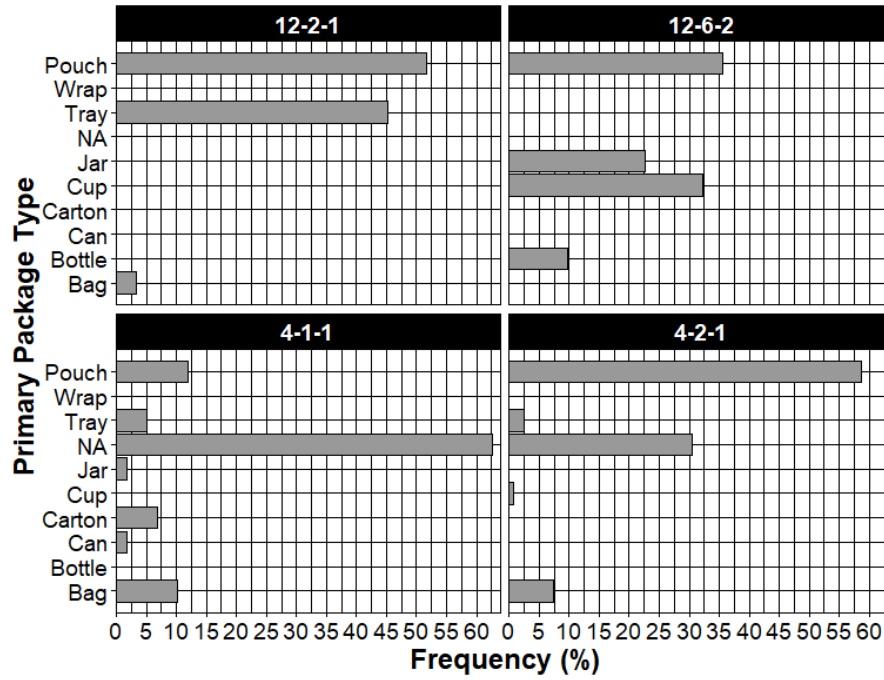


Figure 4.2 Frequency of primary package type of top food sub-subcategories excluding 8-1

CHAPTER 5

PERFORMANCE AND COMPARISON OF CURRENT E-COMMERCE MEAL KIT PACKAGING WITH NOVEL MULTILAYER PACKAGING MATERIALS

5.1 Materials and Methods

5.1.1 Choosing products for novel meal kit packaging

The popularity of fresh vegetables (4-2-1) in the meal kits and the fact that most of them are packaged (section 4.3.1) make fresh vegetables an ideal candidate for research into novel primary packaging for meal kits. The most used fresh vegetables in meal kits in descending frequency are garlic, leafy greens, shallots, scallions, onions (bulb), carrots, and potatoes (Figure 5.1 (Appendix)). Garlic, leafy greens, scallions, and carrots were chosen because shallots, onions, and potatoes are rarely packaged in primary packaging in the meal kits. The different factors that shorten the shelf life of garlic, leafy greens, scallions, and carrots or other fresh vegetables lead to different packaging requirements for shelf life extension. When fresh vegetables are packaged with plastics, put together inside a closed box like a meal kit and exposed to an uneven cold chain, vapors (i.e., aroma, water) and gases (i.e., ethylene, oxygen) can permeate in and out through the plastics and affect the quality and safety of the fresh vegetables. Furthermore, these two can be seriously compromised if package integrity fails (e.g., broken seal, material rupture) during meal kit delivery. Based on the literature, polyamide (PA) film has a better barrier to aroma (Nielsen et al., 1992), oxygen (Del Nobile et al., 2006; Lange and Wyser, 2003), and ethylene (Awalgaonkar et al., 2020) but not to water vapor (Del Nobile et al., 2003) than PE film. PA film also has higher tensile and impact strength than PE film (Peters, 2017). Furthermore, PA film performance can be improved by the co-extrusion of PA layers differing in properties creating a desired monomaterial multilayer PA. This makes this novel material an ideal candidate to investigate its performance as

primary packaging material against PE, the top plastic used for vegetables in meal kits, in its two forms: monolayered PE and multilayered PP-PE.

5.1.2 Preparation of meal kits

5.1.2.1 *Packaging materials*

Packaging that mimics current meal kit packaging was put together. The secondary packaging of the meal kits was produced at the School of Packaging (East Lansing, MI, USA). The dimensions of the corrugated box of the meal kit were obtained from the meal kit companies. These dimensions were used to design a dieline of the secondary package using the ArtiosCad version 18.1 (Esko, Ludlow, Massachusetts, USA). This dieline was used to create twelve 43.18 cm x 33.02 cm x 27.94 cm C-fluted (32 lbs/in ECT) corrugated boxes at the School of Packaging. Each of the corrugated boxes was manually filled with three 1.36 kg freezer packs (Uline, Pleasant Prairie, WI), one 34.29 cm x 29.21 cm C-flute corrugated board also created at the School of Packaging, and one 40.64 cm x 30.48 cm x 30.48 cm insulated box liner (Uline, Pleasant Prairie, WI, USA). A single sheet of corrugated board (34.29 cm x 29.21 cm), as it is used in current production of meal kits, to separate the cold packs and the meat packages from the other food products contained in the meal kit.

The primary packaging for the food products was obtained from two sources: meal kit companies and UBE Corporation Europe, S.A.U. Meal kit company packaging was reused after the packages were opened, emptied, and cleaned with 70% alcohol prior to reuse. UBE Corporation Europe, S.A.U. provided the experimental packaging under study, which consisted in monomaterial multilayer PA. Four different monomaterial multilayer PA were investigated. These were identified as the following: 4.1, 4.2, 5.1, and 5.2. ID 4.1 and 4.2 were seven-layer coextruded nylons with a lower melting point coPA on the inner layer to improve sealing capabilities and

another coPA as the core layer to maximize water vapor transmission. ID 4.1 and 4.2 had a thickness of 100 μm and 50 μm , respectively. ID 4.1 had higher barrier to oxygen and aroma than ID 4.2. ID 5.1 and 5.2 were seven-layer coextruded nylons with a lower melting point coPA on the inner layer to improve sealing capabilities and an PA12 as the core layer to reduce water vapor transmission. ID 5.1 and ID 5.2 had a thickness of 100 μm and 50 μm , respectively. ID 5.1 had higher barrier to water vapor than ID 5.2. The two films had higher barrier to water vapor than ID 4.1 and 4.2.

5.1.2.2 Food products

Food within the meal kits was obtained and prepared differently depending upon the use. The food products in the meal kits that were not assessed were obtained from the meal kit companies (reuse) (Chicago, IL) and a grocery chain (purchase) (Meijer, East Lansing, MI, USA). Perishable food obtained from the meal kit company and Meijer was stored in a fridge to stay as fresh as possible until use within 24 hours. Food obtained from Meijer was purchased to replicate other foods contained in meal kits and to make sure all food products except the assessed products were identical within the meal kits. The food products obtained from Meijer were cherry tomatoes, canned tomato paste, canned chickpeas, vacuum-packaged beef, potatoes, lime, and onion bulbs). The food products assessed in this study, carrots, garlic, Romaine lettuce, and scallions, were purchased from three separate grocery chains (Meijer; Whole Foods, East Lansing, MI, USA; and Fresh Thyme, East Lansing, MI, USA) to increase the variability present in each food product and thus to strengthen statistical results. Three of the above four food products were processed to obtain peeled garlic cloves, fresh-cut lettuce, and shredded carrots. The garlic cloves were peeled, the green leaf lettuce was chopped, and the carrots were cut using a manual spiral cone shredder. Produce processing occurred inside of a class II AC2-4E2 safety cabinet (ESCO, Singapore) using

cutting devices sanitized with 70% isopropyl alcohol prior to cutting produce. The reason why these food products were selected among the rest of food products contained in a meal kit is explained in section 3.1.3 under Results and Discussion.

5.1.2.3 Packaging

Some of the food products purchased in Meijer were packaged although they were not assessed to simulate the current content of the meal kits used by companies. Cherry tomatoes were packaged in vented clamshell containers. Limes were contained in a “knick knack” plastic pouch along with three to four other simulated meal kit company products. These products included vinegar in a bottle, random spices in a pouch, and heat-sealed cups of guacamole. The “knick knack” plastic pouch also contained one of the tested foods, the peeled garlic cloves. Furthermore, the four food products assessed in this study were also packaged. A total of twelve primary packages were created for each of them. Six packages were made from the material currently used by meal kit companies (treatment #1) and the other six packages were made from monomaterial multilayer PA (treatment #2). Packages mimicked the shape and dimensions of the packages used by meal kit companies regardless of the material. Food products from separate grocery chains were not packaged together, thus each treatment had two packages with food products from the same store chain. The peeled garlic cloves were packaged in a 30- μm thick multilayer fin-sealed pouch made of polypropylene and polyethylene (PP-PE) with dimensions 7.62 cm x 5.08 cm. The shredded carrots and fresh-cut lettuce were packaged in a 50- μm thick 4-sided low-density polyethylene (LDPE) pouch with dimensions 15.24 cm x 12.70 cm and 15.24 cm x 21.59 cm, respectively. The pouch was macroperforated in the case of the fresh-cut lettuce to mimic current meal kit primary packaging for fresh-cut lettuce. The scallions were packaged in a macroperforated 40- μm thick 3-sided LDPE pouch with dimensions 29.21 cm x 8.89 cm. The PA packages

produced for peeled garlic cloves, shredded carrots, fresh-cut leafy greens, and scallions were made of IDs 4.1, 5.1, 5.2, and 4.2. All the food products were packaged under the sterilized safety cabinet mentioned above and sealed with a tabletop impulse sealer (Technopack, Sunrise, FL, USA).

The meal kits were assembled inside a temperature-controlled chamber (Environmental Growth Chambers, Chagrin Falls, OH, USA) at 3 °C for 1 hour. Treatment #1 contained the current packaging used for every food product contained within the meal kit including the investigated food products. Treatment #2 contained the current packaging used for non-tested food products along with the tested food products packaged with the several monomaterial multilayer PA. Both of the aforementioned treatments consisted of six meal kits, each with two meal kits with assessed food products from one of the three grocery stores. Figure 5.2 (Appendix) shows an example of the assembly for the meal kits.

5.1.3 Distribution simulation

The ISTA 6-AMAZON.COM-SIOC for Type A Packaged-Products (International Safe Transit Association, 2018) was conducted to simulate the 16 to 24-hour delivery of a meal kit from its distribution center located in Chicago (IL) to a house located in East Lansing (MI). The test type A was selected because of the weight of the meal kit being less than 23 kg. The transportation time period lasted 17 hours, which effectively mimics transportation time from Chicago distribution center to a consumer home in East Lansing. Sequence 1 of ISTA 6-AMAZON.COM-SIOC for Type A Packaged-Products requires a package to be conditioned at ambient laboratory environmental conditions for 12 hours. However, sequence 1 was modified to obtain timing conditions closer to the ones the meal kits are exposed to during their stays at the distribution center. This was done to prevent unnecessary thawing of the cool packs that would have affected

food shelf life including unintentional microbial growth in the food products. Thus, the meal kits were stored for 6.5 hours at 23 °C and 50 % RH. This time period was selected taking into consideration storage of meal kits at two distribution centers as identified based on transpiration tracking from Chicago to doorstep (East Lansing). Sequence 3 complied with the apparatus sections of ASTM D5276 - 19 (ASTM D5276, 2019). Sequence 4 complied with the apparatus section of ASTM D4728 - 17 (ASTM D4728, 2017). Due to the area limitation of the vibration table six packages instead of twelve packages were placed on the table per profile. Consequently, two profiles had to be done. Sequence 5 complied with the apparatus sections of ASTM D5276 - 19 (ASTM D5276, 2019). Sequence 2 was used for the last period of distribution, doorstep. The hot and humid conditions (38 °C and 85% ± 5% RH) outlined in the ISTA 6 SIOC Test for Type A Packages was selected to be applied for four hours to simulate the worst-case scenario of a package being delivered to the consumer's doorstep.

5.1.4 Package assessment

5.1.4.1 Package temperature

Temperatures inside four out of the twelve meal kits were recorded using remote temperature monitors (AcuRite, Lake Geneva, Wisconsin). The devices were placed on top of the primary packages in the meal kits. These devices were not placed near the cooled gel packs.

5.1.4.2 Integrity failure

Assessed primary packages were examined for integrity failures right after the simulated doorstep period was over and the meal kits were open. Integrity failures were identified visually looking for a variety of defects including the following: pinholes, cuts, minor seal ruptures (product could not leave the package (< 1-inch width)), and major seal ruptures (product could leave the package (> 1-inch width)).

5.1.4.3 Aroma barrier

A method to compare the aroma barrier of some of the investigated packaging materials was created. Packaged peeled garlic cloves were placed inside 495-ml glass jars (Ball Co., Broomfield, CO, USA). The jars were closed with screw lids modified for withdrawing of volatiles from the jar headspace (Awalgaonkar, 2018). To avoid leaks the jars were sealed using 1.27 cm wide thread seal tape wrapped thoroughly around the thread of the jars. A silicon sealant was spread around the rubber stoppers on the top of the lids to further prevent leaks. After 24 hours, the volatiles present on the jar headspace due to permeation through the pouch material were trapped into a 50/30 μm divinyl-benzene/carboxen/polydimethylsiloxane solid phase microextraction (SPME) fiber (Supelco, Bellefonte, PA, USA) for 5 minutes. The trapped aromas were desorbed into the injection port of a Flame Ionization Detector - Gas Chromatograph (FID-GC; Hewlett Packard 6890 Series, Palo Alto, CA, USA) for 2 minutes. The GC was equipped with a HP-5 column ((5% phenyl)methylpolysiloxane, 30 m $\times$ 0.32 mm, 0.25 μm ; Hewlett Packard, Palo Alto, CA, USA) and set to an oven temperature of 40 $^{\circ}\text{C}$ with an initial time of 5 minutes. The injector and detector were set at 220 $^{\circ}\text{C}$. The temperature increased at a rate of 10 $^{\circ}\text{C}/\text{min}$ to end on a final temperature of 220 $^{\circ}\text{C}$ after 30 minutes. Chromatograms were overlapped and compared. A total of 3 jars per material type and 3 blanks (empty jars) were analyzed.

5.1.4.4 Ethylene barrier

A method to compare the ethylene barrier of some of the investigated packaging materials was created. Empty 7.62 cm x 7.62 cm plastic pouches were created using a table style impulse sealer (TechnoPack, Sunrise, FL, USA). These pouches were then injected with 2 mL of 500 ppm ethylene gas mixture (balance N_2) from a gas cylinder (Airgas, Radnor, PA, USA) using a 10-mL syringe (SGE Analytical Science, Ringwood, Victoria, Australia). The pouches were then placed

inside the 495-ml glass jars described in section 5.2.3.3 The jars were closed with the screw lids modified for withdrawing of volatiles from the jar headspace described in section 5.2.3.3 After 24 hours, some of the gas present on the jar headspace was withdrawn using a 100- μ l syringe (SGE Analytical Science, Ringwood, Victoria, Australia). The gas was injected into the injection port of a Carboxen®-1010 PLOT fused silica capillary column (30 m x 0.53 mm) that the above-mentioned FID-GC was equipped with as well. The oven, injector and detector temperatures were set a 150, 220 and 220 °C, respectively. A total of 3 jars per material type were analyzed. Chromatograms were overlapped to compare ethylene permeation through different film types.

5.1.5 Food assessment: shelf-life study

After recording damages (section 5.2.3.2), the peeled garlic cloves, fresh-cut lettuce, and shredded carrots, and scallion packages were placed into a 0.405 m³ refrigerator (Whirlpool, Benton Harbor, MI, USA) for 7 days to simulate the maximum duration that the products could be stored within the consumer's home before use due to the three meals contained in a meal kit. The rest of the refrigerator was filled with non-tested food products from the meal kits and some water bottles in order to create the conditions of a real household refrigerator. The temperature ($4\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$) and relative humidity ($34.5\text{ \%} \pm 18.5\text{ \%}$) of the refrigerator were recorded using a digital indoor temperature and humidity monitor (AcuRite, Lake Geneva, WI, USA). The packages were only removed from the refrigerator to be analyzed. Specific methods and procedures were identified and/or developed to evaluate the packaged food products depending on their main spoilage mechanisms and package limitations (e.g., headspace analysis was not performed for the perforated packages (fresh-cut lettuce and scallions)).

5.1.5.1 Package headspace analysis

The concentrations of oxygen (O₂), nitrogen (N₂), and carbon dioxide (CO₂) present in the peeled garlic cloves and shredded carrots packaging was measured after the eight-day shelf-life period. Prior to data collection, an adhesive septum was placed on the bag of each tested package. The package headspaces were determined using a Thermal Conductivity Detector - Gas Chromatograph (TCD-GC; ThermoScientific West Palm Beach, FL, USA). The TCD-GC was equipped with a Carboxen®-1010 PLOT fused silica capillary column (30 m x 0.53 mm). 100 µL of headspace gas mix was collected from each package using an airtight 100 µL syringe (SGE Analytical Science, Ringwood, Victoria, Australia) and injected into the splitless injection port of the GC. The oven temperature was set to 45 °C for 4 min and then increased to 190 °C at rate of 60 °C/min. The injector temperature was 125 °C and for the thermal conductivity detector the block temperature was 200 °C and the transfer temperature was 190 °C. Six peeled garlic cloves packages and a minimum of one shredded carrots package were analyzed per type of material because only packages without integrity failures were analyzed. Results are expressed as percentages of O₂, N₂, and CO₂.

5.1.5.2 Color analysis

Changes in the color of the peeled garlic cloves and shredded carrots were monitored using a spectrophotometer (HunterLab XE Spectrophotometer, Reston, VA). The L* (lightness from black to white), a* (green to red), and b* (blue to yellow) values of the peeled garlic cloves were determined on day zero and day eight of the study. These values were then used to calculate the browning index (BI) values of the peeled garlic cloves using the following equations (Subhashree et al., 2017):

$$BI = \frac{100(x - 0.31)}{0.17}$$

$$x = \frac{a + 1.75L}{5.645L + a - 3.012b}$$

The L*, a*, and b* values of the shredded carrots were recorded as well. These values were used to calculate the chrominance (chroma) of the shredded carrots using the equation (McGuire, 1992):

$$Chroma = (a^2 + b^2)^{\frac{1}{2}}$$

Three areas on the peeled garlic cloves and shredded carrots were analyzed per treatment. Six peeled garlic cloves packages and six shredded carrot packages were analyzed per type of material.

5.1.5.3 Weight loss

The weight losses of all the tested food products were determined using a precision balance (DHAUS Adventure, Saginaw MI). At day 0, packages were weighed before and after they were filled with the tested food products. Both weights were recorded. After eight days, the packages were weighed a second time and the weights were recorded. These weight values were used to calculate produce weight loss. The results are presented as percentage. Six peeled garlic cloves packages, six scallions' packages, a minimum of five fresh-cut lettuce packages, and a minimum of three shredded carrots packages were analyzed per type of material.

5.1.6 Statistical analysis

RStudio version 1.1456 (RStudio Inc., Boston, MA, USA) was used to perform statistical tests. The MICE () package was used to perform Multivariate Imputation by Chained Equations to manage the missing data. One-way ANOVA analysis was performed to compare the headspace concentrations (O₂, CO₂, N₂) between treatments and planned contrasts were performed to detect mean differences of these concentrations between materials. Mixed ANOVA was used to compare the following: weight loss between materials, and color results (L*, a*, b*, browning index (%), and chroma) between days and between materials. The use of Mixed ANOVA was due to

unbalanced design and missing values due to package integrity issues and statistical outliers. If there was no interaction present between day and treatment, Type II ANOVA was performed, however, if an interaction between day and treatment was observed Type III ANOVA was performed. Planned contrasts were performed to detect differences within the factor treatments to identify differences between materials. Estimated marginal means are presented in the paper instead of descriptive means due to the unbalanced nature of the experiments.

5.2 Results and Discussion

5.2.1 Package assessment

5.2.1.1 Package temperature

Table 5.1 presents the data recorded from the four remote temperature monitors placed in the first replication of each of the 2 treatments (two meal kits with the monomaterial multilayer PA (treatments 2A and 2B) and two meal kits with the material currently used by meal kit companies (treatments 1A and 1B)).

Table 5.1 Temperature profiling of the meal kits during distribution simulation

Treatment	Event (hours)						
	Warehouse (0)	ISTA 6 initial (6.5)	ISTA 6 mid 1 (12.5)	ISTA 6 mid 2 (15)	ISTA 6 Doorstep initial (17)	ISTA 6 Doorstep mid (19)	ISTA 6 Doorstep final (21)
Treatment1A	13 °C	17 °C	15 °C	19 °C	19 °C	29 °C	30 °C
Treatment1B	10 °C	14 °C	14 °C	18 °C	19 °C	29 °C	30 °C
Treatment 2A	13 °C	15 °C	14 °C	18 °C	19 °C	29 °C	30 °C
Treatment 2B	12 °C	12 °C	17 °C	17 °C	17 °C	26 °C	26 °C

The average temperature of the meal kits at the beginning of warehouse conditioning (0 hour) was 12 °C with little variance between treatments. During the distribution simulation (ISTA 6), the temperatures increased to a mean temperature of 15.8 °C $\pm$ 2.1 °C after 12.5 hours and of 18.5 °C

± 1.0 °C after 17 hours (arrival at doorstep). Similarly, Flynn (2017) reported that meal kits packed with gel packs have about half of their food products with a surface temperature near 23.9 °C. During the doorstep phase of the distribution simulation, three of the meal kits shared the same temperatures during initial, midpoint, and final times (19 °C, 29 °C, and 30 °C, respectively). Treatment four, however, presented lower temperatures of 17 °C, 26 °C, and 26 °C during initial, midpoint, and final times, respectively. This could be due to movement of the thermometer within the meal kit due to shock and vibration since it has been noted that meal kits do not regulate temperature well (Flynn, 2017).

5.2.1.2 Package integrity failures

Primary packages made of the materials currently used by meal kit companies experienced more package integrity failures (39%) than the primary packages made of the monomaterial multilayer PA (22%) (Table 5.2). The latter packages had one major seal rupture (Figure 5.3 (Appendix)), two minor seal ruptures and one pinhole compared to the current package system which contained two major seal ruptures, four minor seal ruptures and one pinhole. Thus, the multilayer monomaterial PA demonstrates to have a better sealing capability and consequently performance as a packaging material for sealed pouches in meal kits. Package integrity failures were only observed in the case of shredded carrots and fresh-cut leafy greens. This could be attributed to the larger headspace of the packages containing shredded carrots and fresh-cut lettuce compared to the other heat-sealed package (peeled garlic cloves). The larger headspace allowed for interaction with more products and thus for more damage.

5.2.1.3 Aroma analysis

Overlapping chromatograms indicate that the two multilayered materials (PP-PE and PA 4.1) allow some permeation for some aroma compounds. Furthermore, the two materials have

different barriers to the different aroma compounds that contribute to the aroma profile of garlic. The empty jars used as blanks had some aroma per se that could be attributed to the rubber ring of the lid and contributed to the aroma profile of the multilayered materials. A more detailed analysis using an MS-GC and calibration curves would be needed to get a deeper understanding of the barriers to different aroma compounds of the two materials. In agreement with the above results, Nielsen et al. (1992) reported that films commonly used in food packages including PP, LDPE, PA and PET differ in permeability to different aroma compounds.

5.2.1.4 Ethylene analysis

The overlapping of the three chromatograms was used to compare ethylene permeation through LDPE, a common film in meal kits, and the monomaterial multilayer PA 5.1. The chromatogram showing the ethylene standard peak was used to determine the retention time of ethylene (4.1 minutes). A peak around 4.1 minutes was observed when LDPE was used to produce the pouches containing ethylene while there is no peak in the case of using the monomaterial multilayer PA 5.1. The peak indicates that ethylene moved from the pouch made to LDPE into the jar headspace but not from the pouch made of the monomaterial multilayer PA. These results prove the better barrier property of the monomaterial multilayer PA 5.1 to ethylene compared to LDPE and consequently, in principle, the better protection of the shredded carrots from external ethylene present in the meal kits (e.g., tomatoes) when packaged in the monomaterial multilayer PA 5.1. Similarly, Awalgaonkar et al. (2020) reported a better ethylene barrier for PA 6 compared with LDPE. Further studies should be performed for longer time periods to get an ethylene permeability value for the monomaterial multilayer PA.

5.2.2 Food assessment

5.2.2.1 *Weight loss*

The weight losses of the packaged peeled garlic cloves, fresh-cut lettuce, shredded carrots, and scallions after 1 day of distribution followed by 7 days of refrigeration are presented in Table 5.2 . The peeled garlic cloves had a higher ($P < 0.05$) weight loss when they were packaged in the monomaterial multilayer PA 4.1 ($2.6\% \pm 0.4\%$) than in the polymaterial multilayer PP-PE ($0.6\% \pm 0.1\%$). Similarly, Sothornvit and Tangworakit (2015) reported a weight loss of $\sim 1\%$ for fresh-cut garlic cloves in polyolefin bags after 8 days of storage. The difference between the two packaging treatments can be attributed to the higher barrier to water vapor of the components of the polyolefin multilayer (PE and PP) compared to those of the PA-based multilayer that was designed to have an intermediate barrier to water but a good barrier to aroma and O_2 . In general, polyolefins are better barrier to water vapor than nylons (Del Nobile et al., 2003; Awalgaonkar et al., 2020). Fresh produce generally shows symptoms of freshness loss with 3-10% weight loss (Ben-Yehoshua, 1987). Taking this into account, peeled garlic cloves in the monomaterial multilayer PA packages looked as fresh as peeled garlic cloves in the polymaterial multilayer PP-PE packages on day 8. For all other vegetables, there was not a significant ($P > 0.05$) difference in weight caused by material type. Shredded carrots lost 1.1% of weight over eight days. This loss is lower than that reported in the literature for shredded carrots packaged in monolayer PE for similar storage periods and temperatures (Izumi and Watada, 1994; Izumi et al., 1995). The package failure “pinhole” did not impact weight loss significantly, however, the other package failures like “seal rupture” did. Minor seal rupture resulted in shredded carrots losing from 1.5 to 10% weight depending on the width of the rupture. The impact of the package failure “major seal rupture” was greater since the product was exposed to air once it came out from the bag (data not

measured). Packaged scallions and fresh-cut lettuce had much higher ($P < 0.05$) weight losses than the other vegetables due to the macroperforations in their packaging, which increased surface exposure to air. This high moisture loss greatly affected the visual appearance of the two vegetables. As discussed above, symptoms of freshness loss in fresh produce are generally shown with 3-10% weight loss (Ben-Yehoshua, 1987) and packaged scallions and fresh-cut lettuce loss more than 10% moisture.

5.2.3 Package headspace gas composition

The headspace gas compositions of the packages containing peeled garlic cloves and shredded carrots after 1 day of distribution followed by 7 days of refrigeration are presented in Table 5.2.

Table 5.2. Weight losses and headspace gas compositions of packaged vegetables in meal kits along with the integrity failures of their packages

Product	Treatment	Primary package material	Weight loss (%)	O ₂ (%)	CO ₂ (%)	Integrity Failures (n)
Peeled garlic cloves	1A	PP-PE	0.6a**	0.7a	54.7a	0
	1B					0
	2A	PA 4.1	2.6b	0.8a	57.0a	0
	2B					0
Scallions	1A	LDPE	26.1a			0
	1B					0
	2A	PA 4.2	25.5a			0
	2B					0
Shredded carrots	1A	LDPE	1.1a	N/A*	N/A*	3
	1B			13.3*	6.5*	2
	2A	PA 5.1	1.1a	2.5*	45.4*	2
	2B			4.8*	43.8*	2
Fresh-cut lettuce	1A	LDPE	15.8a			1
	1B					1
	2A	PA 5.2	12.9a			0
	2B					0

**Products sharing the same lowercase letter in the same column indicates no significant ($P > 0.05$) difference between primary package materials.

*Multiple replications in this column suffered from package integrity failures and prevented statistical analysis due to too few replications.

The concentrations of O₂, N₂, and CO₂ within the peeled garlic cloves packages were the same regardless of the material type ($p = 0.89$, $p = 0.54$, $p = 0.55$ respectively). The O₂ content was low ($0.73\% \pm 0.10\%$) and the CO₂ content was high ($55.85\% \pm 6.37\%$) among all packages. Low O₂ (1%) combined with high CO₂ (10% and up) reduces loss of shelf life and quality in peeled garlic cloves (Cantwell et al., 2003; Kang and Lee, 1999). The observed low O₂ can be attributed to several factors including the high respiration rate of the peeled garlic, the use of packaging with a good barrier to O₂, and the high temperatures that the meal kits are exposed prior to and at the

doorstep (section 3.2.1.). The respiration rate of garlic increases significantly when cloves are peeled and chopped, specifically if stored above 5 °C (Cantwell and Suslow, 2002). In fact, there is an exponential decrease in shelf life of peeled garlic cloves with increasing temperature due to increased respiration rate (Veríssimo et al., 2010). Furthermore, produce respiration changes more with temperature than film permeability does (Almenar, 2020). This is more evident in the case of good barrier materials. Nylon is known to be a strong barrier to O₂ (Del Nobile et al., 2006; Lange and Wyser, 2003) and the coextrusion of PP and PE results in a decent barrier to O₂ (González-Buesa et al., 2014). Previous work done with packaged peeled garlic has shown a similar effect of temperature on package headspace gas composition. Peeled garlic packaged in LDPE presented <1% O₂ after 15 days of storage at 25 °C (Singh et al., 2019). The high CO₂ content among all packages could be the reason for the lack of sprouting since high CO₂ atmospheres reduces sprout development (Kang and Lee, 1999). Due to the damages during shipment, statistical analysis could not be performed for the headspace composition of shredded carrots, however, observed O₂ values were higher in LDPE packages corresponding with lower CO₂ values. More packaging (replications) for both materials would be needed to verify the headspace compositions reported in Table 5.2. The macroperforated packages exposed the fresh-cut lettuce and scallions to air, which does not align with current commercial practices aimed to extend the shelf life of these two vegetables. The reason for macroperforated packaging could be to avoid possible anaerobic conditions resulting from the high temperatures that the meal kits are exposed to and thereby safety issues. Anaerobic microorganism that can compromise human health can grow in leafy greens and scallions under anaerobic conditions (Garcia-Gimeno et al., 1996; Saltveit, 2003).

5.2.3.1 Color

The color results for packaged peeled garlic cloves and shredded carrots after 1 day of distribution followed by 7 days of refrigeration are presented in Table 5.3. Past studies on peeled garlic cloves have described color using L* and b* on day zero at 84 and 25, respectively (Sothornvit and Tangworakit, 2015).

Table 5.3 L*, b*, a*, BI (%) and Chroma mean differences (Δ) from day 0 for packaged peeled garlic cloves and shredded carrots in meal kits

Product	Treatment	Day 0 L	Δ L	Day 0 b	Δ b	Day 0 a	Δ a	Day 0 BI (%)	Δ BI (%)	Day 0 Chroma	Δ Chroma
Peeled garlic cloves	1A	89.2	0.7	11.5	-1.5			13.1A	-1.9		
	1B	A	Aa	A	Aa				Aa		
	2A		0.7		-0.4				-0.8		
	2B		Aa		Aa				Aa		
Shredded carrots	1A	62.4	-5.1			29.2	-1.0			37.9 A	1.2
	1B	A	Ba			A	Aa				Aa
	2A		-5.2				-0.7				1.6
	2B		Ba				Aa				Aa

*Columns containing day zero values were reported using the estimated marginal mean value. Columns containing delta values were reported using estimated difference between the day zero marginal mean and day eight mean.

*Products sharing the same lowercase letter in the same column indicates no significant ($P > 0.05$) difference between materials after eight days of storage.

*Rows sharing the same uppercase letter in the same row between paired day 0 and Δ columns indicate no significant ($P > 0.05$) change in color parameter after eight days of storage.

The peeled garlic cloves of this study were lighter (higher L* values) and less yellow (lower b* values) most likely due to the use of a different garlic cultivar. There were not significant changes in the color of packaged peeled garlic cloves (L*, b*, and BI (%)) after 8 days ($p = 0.23$, $p = 0.40$, $p = 0.14$, respectively), indicating color retention (Table 5.3). As such, there was also no difference between the monomaterial multilayer PA 4.1 and the polymaterial multilayer PP-PE after 8 days (Table 5.3). These results could be attributed to the low O₂ content and small weight loss in all packages regardless of the material that did not allow browning to happen throughout storage. Changes in color in peeled garlic cloves have been attributed to enzymic and non-enzymatic browning (Kang and Lee, 1999). In agreement, Sothornvit and Tangworakit (2015)

reported a decrease in L* value and an increase in b* value for peeled garlic cloves packaged in LDPE bags at 25 °C as storage time increased, which was caused by the poor O₂ barrier of the monolayer LDPE bags. Furthermore, Akan et al. (2019) reported that weight losses lower than 3% better keep the color of peeled garlic cloves.

Past studies on carrot have described its color using L*, a*, and chroma values on day zero at 56, 24, and 54 (Xylia et al., 2019). This study found slightly higher L* and a* values but lower chroma values indicating brighter desaturated orange carrots on day zero. This can be attributed to the use of a different carrot cultivar. The L* value for shredded carrots decreased by ~5 units ($p < 0.05$) for both the monomaterial multilayer PA 5.1 and the monolayer LDPE ($p > 0.05$) (Table 5.3) meaning the shredded carrots darkened equal amounts over the eight days. However, the chroma value of the shredded carrots was maintained for eight days ($p > 0.05$) regardless of the packaging material ($p > 0.05$) indicating no change in orange color (Table 5.3). This could be due to the different conditions the shredded carrots were exposed to that resulted in differences in both chroma and weight loss. Some packages burst during distribution (minor seal rupture) and consequently the shredded carrots were exposed to air that resulted in oxidation and high weight losses. β -carotene is the reason for the orange color in carrots and thus, its oxidation results in less orange color in shredded carrots (Chervin and Boisseau, 1994; Falconer et al., 1964). The fading of the orange color of shredded carrots has been associated with a decrease in chroma values (Izumi et al., 1995). In contrast, other packages continued sealed or had pinholes and those shredded carrots were exposed to high CO₂ levels and had little weight losses. Good retention of the orange color of acidified sliced carrots has been previously reported when this were packaged in high CO₂ (Juliot et al., 1989). Whitening, which depend on lignin formation and has been partially attributed to surface dehydration (Cisneros-Zevallos et al., 1997), was not observed in the packaged shredded

carrots due to the little weight loss (1.1%) of the shreds. The color of the fresh-cut lettuce and scallions was not measured due to the expected darkening and browning, respectively, caused by the weight loss and exposure to air resulting from the use of macroperforated packaging.

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APPENDIX

Figures

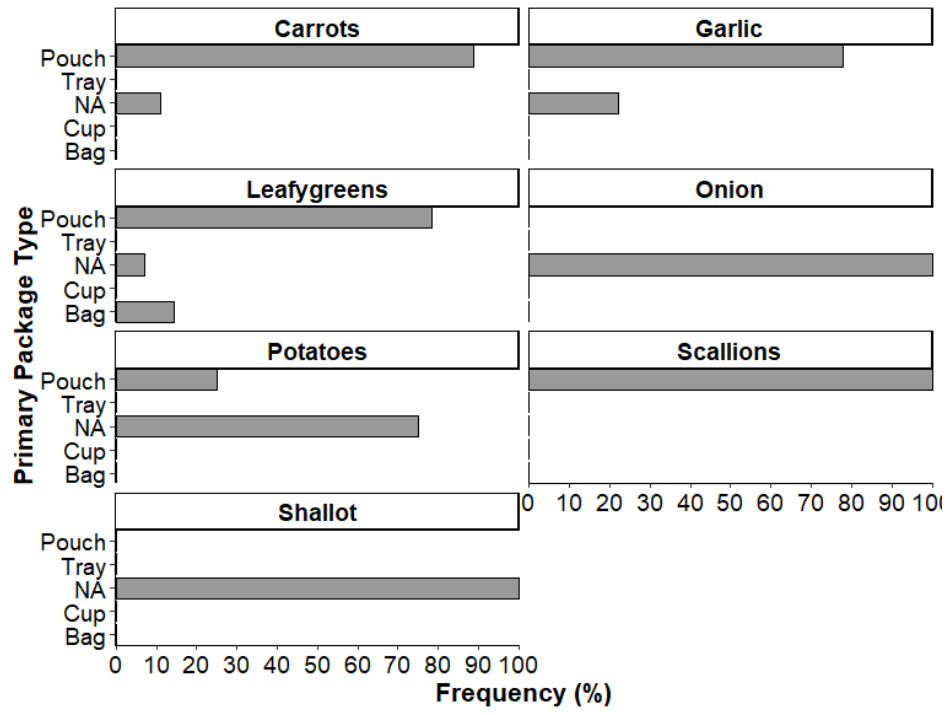


Figure 5.1 Frequency of primary package types for 4-2-1



Figure 5.2 Creation of meal kits



Figure 5.3 Example of major seal failure

CHAPTER 6

CONCLUSIONS

6.1 Conclusions

The majority of the package formats used to commercialize liquid food products in the USA, which are mostly the FAO food categories 14.0, 13.0, 12.0, are rigid regardless of the supply chain type. Most of these rigid packaging formats result from bottles and cans being the largest package types. Plastics are the most frequent material used to package liquid food products. They are present as flexible and rigid in the e-commerce supply chain, but only as rigid in the traditional supply chain. Seven plastics are used in liquid food product packaging, with PET and PP being the top ones in both supply chains and LLDPE having higher presence in e-commerce. The above makeup of packaging leads to 86.5% of the liquid food product packages to experience defects, which can have a maximum rate of occurrence of up to 3%. The two supply chains differ in the level of packaging deformation and within the e-commerce supply chain, bottles differ from cups, jugs, and cartons in the percent of scratches and leaks. Deformation is mainly attributed to shock in e-commerce while to impact, shock, and static load equally in the traditional supply chain. Leaks are mainly attributed to seal breakage occurring either at the cap/closure or among the seals of the package for both supply chains, while scratches are mainly caused by interactions with identical packages in the traditional supply chain and with both identical and different packages in the traditional supply chain. Thus, this study collects and compares the most common defects found in food packages in both e-commerce and the traditional supply chain including their rationales for the first time. The desire for packaging damage reduction and its resulting food shelf-life extension and food and packaging waste reduction lead to the packaging changes required for e-

commerce that the survey participants expressed including the preference for flexible plastic containers (with pouches being rated top) over other types of packages for liquid food products.

Meal kits were found to contain a range of food products and packaging structures. Of the wide range of food products, it was found that fresh vegetables (4-2), fresh fruits (4-1), non-emulsified sauces (12-6-2), herbs and spices (12-2-1), and fresh meat (8-1-1) were the most frequently used products. Of these food categories fresh vegetables, specifically, peeled garlic cloves, scallions, sheered carrots, and fresh-cut lettuce were identified as a food product that could be extended using monomaterial multilayered films. Both the new material and the control exhibited package integrity failures in shredded carrots and fresh-cut lettuce, but less failures were found from the new material. Results from the aroma analysis suggest that both materials allow for some permeation for some aroma compounds; a more detailed analysis would be needed to identify the type of compounds. Ethylene analysis suggest that the new material performs better than the control as an ethylene barrier. Between both materials, weight losses of the food products were similar except for peeled garlic cloves where the new material exhibited higher weight loss. For the peeled garlic, there was no difference in headspace between both materials. Color changes of peeled garlic cloves and sheered carrots were similar both materials as well. In total, these results suggest that these novel monomaterial multilayer materials could be used as an alternative which would contribute to reducing food and packaging waste.

The above information should help industry and academia better understand the differences or lack thereof of the makeup of packaging and packaging damage between the two supply chains as well as current packaging trends to develop more sustainable packaging for online grocery.

6.2 Future Work

This study being one of the first academic studies in both packaging and e-commerce prompted many new questions and research interests. The survey developed for this study was limited in scope and could only provide insight on liquid food packaging in e-commerce. There are currently many other food categories outside of liquid foods that are growing and in need of study. Also, surveying the damage rates of other food categories would provide greater insight into other areas packaging could be improved. Categorization of meal kits should be further investigated. The meal kits were categorized over the course of four weeks in the same spring season. More research should be investigated to identify if the packaging materials and food items change depending on the seasons. Further ethylene and aroma investigation is needed as preliminary only indicate similar performance between the current and novel material. Also, shelf life studies and distribution tests for other popular food categories such as fresh meats, herbs and spices, and non-emulsified sauces should be investigated to identify problem areas.