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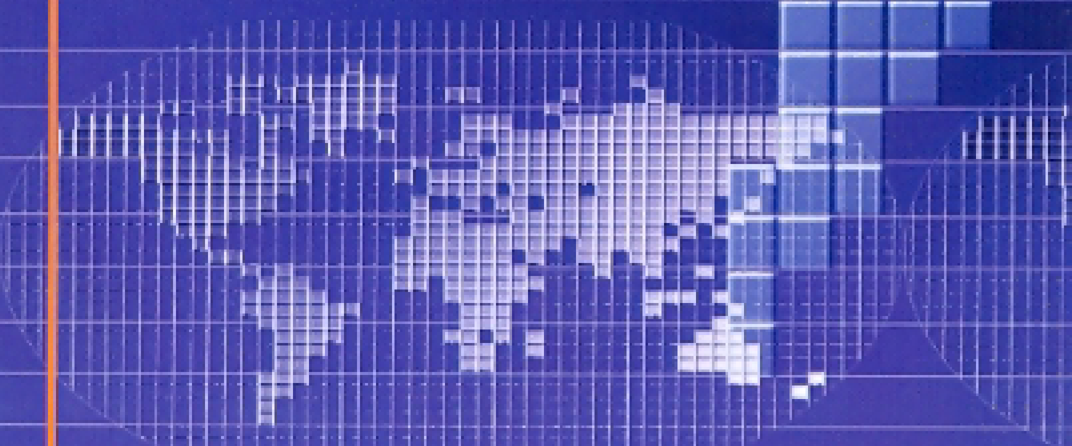

Aim and Scope

The *Journal of Applied Packaging Research* is an international forum for the dissemination of research papers, review articles, tutorials and news about innovative or emerging technologies for the packaging industry. The journal is targeted towards the broad packaging community including packaging scientists and engineers in industry or academic research and development, food scientists and technologists, materials scientists, mechanical engineers, industrial and systems engineers, toxicologists, analytical chemists, environmental scientists, regulatory officers, and other professionals who are concerned with advances in the development and applications of packaging.

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CONTENTS

A Quantitative Study of the U.S. Wood Pallet Industry Based on Supply Chain Management Practices

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ABSTRACT: Pallets play an important role in the movement of goods from place to place. They are not only used in warehouses or distribution centers, but also in all those activities that require an efficient and effective method of transportation. To better understand business practices and external factors that impacts supply chain management (SCM), a survey of 1,500 U.S. wood pallet manufacturers was conducted. Main results focus on the identification of critical aspects affecting purchasing decisions, supplier relationships, internal business practices, customer satisfaction levels, and external uncertainties.

INTRODUCTION

ONE of the major business developments of the last decade is the emergence of supply chain management [1], [2], and [3]. A supply chain is a system constituted by materials, suppliers, facilities, and customers, connected by the flow of materials and information [4]. Globalization, advances in transportation of goods, information technology, and increasing sophistication of customers are all drivers of supply chain management, as companies no longer compete as individual entities but as part of complex networks [4]. Successful companies realize the need to work in close relationship with their suppliers and customers, pursuing the same objective: customer satisfaction [5]. Research has demonstrated that collaboration between supply chain members provides a significant competitive advantage [3]. Typical benefits from supply chain management practices are shortened lead time, reduced costs, improved design, and overall im-

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proved customer satisfaction [5]. Researchers found that an efficient supply chain begins with customer and supplier collaboration and information sharing, and with the use of advanced technology such as Electronic Data Interchange (EDI), where the appropriate information can improve companies' operations.

The U.S. wood pallet industry faces several challenges to its competitiveness; among these, the competition for wood fiber with other users [6]; competition from substitute products such as plastic and steel pallets [7]; lobby from competitors to limit their use for food safety reasons [8]; downturn in the economy, which reduces the demand for goods transported on pallets; and the fragmented nature of the industry. The industry could benefit from adopting better supply chain management practices in their strategic planning and operations, both to ensure supply of raw materials and ensure better service to customers [4].

Goal and Objectives

The goal of this paper is to identify and understand current business practices affecting the US wood pallet industry. Specific objectives are:

- Understand the main demographics characteristics of the U.S. wood pallet industry.
- Identify what factors affect purchasing decision of raw materials.
- Compare perceptions of the U.S. wood pallet industry regarding customer service activities.
- Identify what business management practices are being used today in the U.S. wood pallet industry.
- Define the most important external uncertainties that U.S. wood pallet firms face today.

METHODOLOGY

Figure 1 shows the various steps that were conducted to collect, analyze, and present data. Data was collected through a large survey that was designed and validated using secondary sources, case study research, and expert's opinions. Secondary sources were used to find production volumes, types of pallets manufactured, species of raw materials, imports, and channels of distribution in the wood pallet industry.

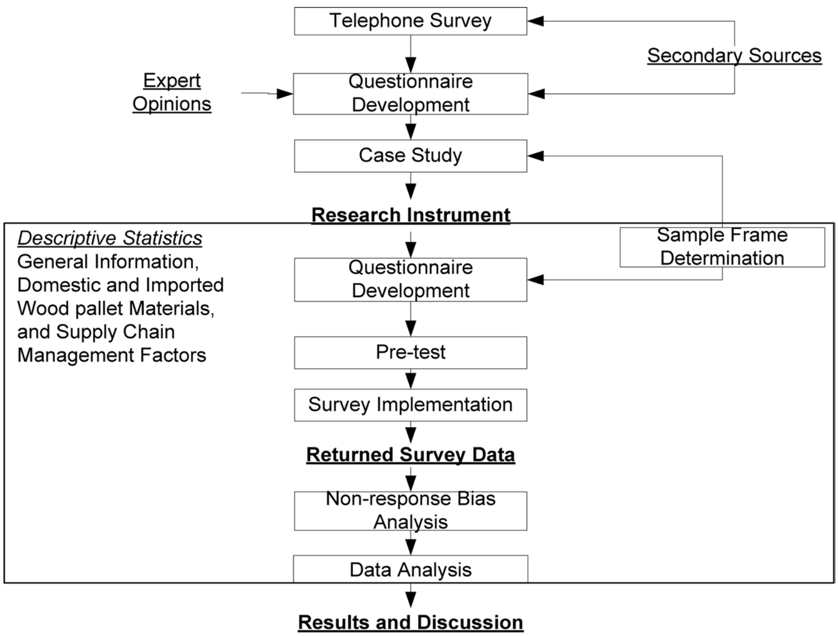

Figure 1. *Survey research methodology.*

This information was complemented with phone interviews and case study research conducted in three wood pallet industries following suggestions by Yin [9] in order to better understand factors affecting business processes in wood pallet industries.

A questionnaire was designed based on the previous inputs and it contained five main sections: (1) general information, (2) raw materials, (3) customer service, (4) business management, and (5) external uncertainties (Table 1). Questions included in the general profile and the wood pallet material sections are standard demographic questions included in similar surveys by Bush and Araman [10], Buehlmann *et al.* [11] and Hammett, Naka, and Parsons [12]. Questions included customer service, business management, and environmental uncertainties and were built considering results of interviews and case studies mentioned earlier and in addition to that, an extensive literature review was conducted as indicated (sources shown in Table 1). In a previous publication [13], the authors have validated the data using statistical techniques such as the alpha coefficient of internal reliability and exploratory factor analysis techniques.

A first draft was subject to review by experts in the academic world and industry. Their feedback was used to improve the questions, elim-

Table 1. List of Constructs and Their Items.

Section	Questions	
1. General profile	1. Type of business 2. Major products 3. Type of Customers 4. Number of employees	5. Average pallet production 6. Annual average gross sale
2. Wood Pallet Materials	1. Domestic wood pallet materials factors 2. Purchasing raw materials factors 3. Monthly raw material input 4. Average supplier's order lead time 5. Major customers 6. Wood pallet materials from overseas	7. Environmentally certified wood pallets 8. Barrier imports factors 9. Imported wood pallet materials factors 10. Comparison of domestic and overseas suppliers 11. Wood species and origin
3. Customer service [14], and [4]	1. Our company keeps track of customer needs and asks their feedback on quality/service 2. Our company asks customers about their expectations 3. Our company makes it easier for the customers to look for assistance 4. Our company can deliver the required wood pallet quantities to the customers on time 5. Our customers are happy with the quality of the products that we offer (CS5) 6. Our products are only focused on the customer's needs	
4. Business Management [15], [16], [17], [18], [19, [20], [21], [22] and [23]	1. Our company forms leader groups from diverse areas for the planning and developing of the strategic business plan 2. Our company develops strategic operation plans with suppliers 3. Our company has reduced manufacturing processes cost in the last 3 years 4. Inventory costs have been reduced in the last 3 years 5. Our company offers competitive wood pallet prices 6. Our company offers lower prices than our competitors	

(continued)

Table 1 (continued). List of Constructs and Their Items.

Section	Questions
4. Business Management [15], [16], [17], [18], [19, [20], [21], [22] and [23] (continued)	7. Our company works with a differentiation strategy (produces unique products for different customers)
	8. Our company works with a segmentation strategy (categorizes its customers in groups with similar needs, and makes products to satisfy those needs)
	9. Our company produces only against firm customer orders or uses the "pull" production system
	10. Our company produces for stock replenishment
	11. Our company places emphasis on the benefits of our product compared to our competitors'
	12. Our company offers wood pallets directly to the customer
	13. Our marketing team has a lot of experience
	14. Our company invests resources in new processes and products
	15. Our company usually hires some experts in the pallet field for improving processes and products
5. Environmental Uncertainties [24], [25], [26], [27], and [28]	1. Our company works with more than 3 suppliers
	2. Our company trusts its suppliers
	3. Our company involves suppliers when planning strategic goals
	4. Our company is open to work with suppliers from other countries
	5. Competition in the wood pallet sector is strong
	6. There is a high level of communication and coordination with our suppliers
	7. Our company uses certified wood for manufacturing pallets
	8. Our company is informed by the government about important aspects that can affect our business
	9. Our company would like to work with suppliers who have availability of resources and consistency of supply
	10. Our company thinks that logistics and transportation is the number one criterion when selecting suppliers
	11. The delivery of imported wood pallet materials can easily go wrong
	12. Our company does not want to work with countries from overseas, because they tend to have a lot of social and political issues that would affect our production

inate redundancies and errors, and include some items that were considered appropriate to the objectives of the research. A second version was pre-tested, and results from this pre-test were used to further improve the questionnaire. Before mailing out the questionnaires, a pre-test was conducted. A pre-test is an indispensable part of the research process when carrying out research [29], [30] to find potential inconsistencies or errors, questions that need clarifications, and get expert's feedback to improve the research instrument. To conduct the pre-test, a representative from a major trade publication, entrepreneurs, and professors were appointed to review the questionnaire and provide feedback. Once the questionnaires were improved based on the results of the pre-test, the mailing was conducted. Along with the questionnaire, a cover letter (explaining the purpose of the survey and the potential benefits for the industry), and a prepaid return postage code were mailed as well. Two questionnaires were mailed to 1,500 wood pallet manufacturers during fall 2010 with a four week-separation between each mailing [31], [32].

Data collected is presented and analyzed using nonparametric techniques and statistics. The sample was stratified by industry size following a similar procedure indicated by Mangun and Phelps [33]and all analysis was performed using the statistical software SAS. Table 1 shows only the sections of the questionnaire that are analyzed and reported in this article.

The survey management was conducted using procedures recommended in Dillman's Tailored Design Method [32] as shown in Figure 2. According to the U.S. Census Bureau, there were about 2,600 companies in the U.S. that produce wood pallets and containers in 2006 [34]. However, due to budget limitations, the sample frame was reduced to 1,500 representing approximately 57% of the total wood pallet and container companies in the U.S. To access the sample size, a list of companies was provided by a trade journal publication that specializes in the pallet industry and the mailing process was performed through a third party firm. Rea and Parker [35] recommended that the minimum of 94 respondents is necessary for a population of 3,000 (95% confidence level).

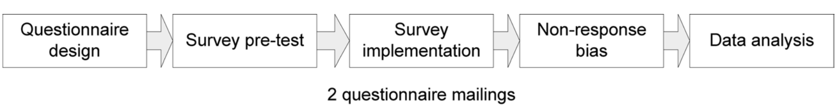

Figure 2. *Survey process.*

RESULTS AND DISCUSSION

The survey response rate was 14% (Table 2). A total of 249 questionnaires were returned but only 202 were in good shape for further analysis. Given that two mailings were made, a non-response bias analysis was carried out to evaluate if respondents tend to have different characteristics than non-respondents. To accomplish this, company characteristics of early respondents were compared to those who returned the questionnaire later [36]. Results from the non-response bias assessment appear to show that medium and large companies were more likely to respond to this survey. However, the data is grouped and analyzed by industry size in order to make the results applicable to all type of industries in this sector.

General Profile of the Industry

Results from the questionnaire indicated that firms are involved in multiple business activities. A 93% out of the 202 firms who responded to the questionnaire were manufacturers of new wood pallets, followed by 45%, which corresponded to a pallet recycler or repairer (see Table 3). Pallet broker, lumber broker and pallet material importer accounted for 8%, 5%, and 3% of respondents respectively. "Other" type of business accounted for 11%, this group included activities such as dunnage, mulch, pallet parts, wood crates, specialty boxes, survey stakes, cut stocks, grade lumber or run their own sawmill.

When companies were asked to report their more important products for year 2009, new wood pallet production was pointed out as their lead activity, followed by recycled/repaired wood pallets in small and large industries (Table 4). The third most important activity for small and large industries is lumber production. Recycle/repaired wood pallet

Table 2. Response Rate.

Description	Quantity
Initial mailing	1,500
Returned questionnaires, and useful for data analysis	202
Returned questionnaires, but were out of business	5
Returned questionnaires, but declined to fill out	1
Undeliverable	41
Non-respondents	1,251
Adjusted response rate	14%

Table 3. Industry Type of Respondents.

	Frequency by Type of Business			
Type of Industry	**0 < Employees < 20 (total of 109)**	**20 ≤ Employees < 100 (total of 78)**	**100 < Employees (total of 15)**	**%**
Manufacturer of new pallets	102	71	15	93%
Pallet material importer	4	1	0	2%
Pallet recycler or repairer	36	46	9	45%
Lumber broker	4	5	0	4%
Pallet broker	6	9	2	8%
Other type	13	8	2	11%

production is the lead activity for medium size firms. Similar results were obtained in the research conducted by Bush and Araman ([10] and [37]) where 57% of companies reported new wood pallet production as their primary activity.

In terms of wood pallet production (Table 5), results indicate that small, medium, and large industries produced 135,276, 982,707, and 4,134,888 units respectively during 2009. Bush and Araman [10] indicated in their 2008 report that production per firm was 512,533 units for 2006 (as an aggregate for all industries).

Annual average gross sale for 2009 indicates that 43% of respondents reported having gross sales from 1 to 5 million dollars, followed by 35% indicating less than 1 million dollars in revenue, and 12% between 5 to 10 million dollars. Eight percent reported to have annual revenue between 10 to 20 million dollars, and 3% reported more than 20 million dollars in the same category. Surveyed firms were also asked

Table 4. Most Important Products by Companies.

	Most Important Products (7 most important, 1 less important)		
Type of Industry	**0 < Employees < 20**	**20 ≤ Employees < 100**	**100 < Employees**
New wood pallets	7	7	7
Wood pallet parts	4	6	1
Recycle/repaired wood pallets	6	5	6
Lumber	5	3	5
Railroad ties	3	2	2
Wood containers	2	4	3
Others	1	1	4

Table 5. Pallet Production in Units.

Type of Material	**Frequency by Type of Business**			**Kruskall-Wallis test**
	0 < Employees < 20	**20 ≤ Employees < 100**	**100 < Employees**	**p-value**
Pallet production in units (sample size)	135,276 (90)	982,707 (69)	4,134,888 (11)	< 0.0001

to report back their sales by type of customers (Table 6). On average, small, medium, and large firms reported that 84%, 75%, and 79% of their sales come from manufacturers in that order. Second most important customer for small wood pallet firms are retailers and pallet brokers with 49% of sales in both cases. For medium size and large wood pallet firms, the second most important customer is distributors. A nonparametric test was conducted to compare the mean percentage of each group with a 0.05 significance level. The mean percentages were statistically significant for retailers, pallet brokers, and for manufacturers as indicated in Table 6.

Wood Pallet Materials

Data about species used was also collected in order to learn about the wood pallet market (see Table 7). Approximately 50% of respondents answered this question (no comparison between groups is presented here). Mixed hardwoods had the highest percentage in the mix (27.3%), followed by oak and southern pine, with around 16% each; spruce-pine-fir followed with 12.7%, yellow poplar with 8.1%, maple with 4.7%, and Douglas fir with 4.3%. “Other” species (4%) included aspen, larch, ponderosa pine, black ash, lodgepole pine, cottonwood and cedar. This

Table 6. Type of Customers.

Industry Size	**Distributor**	**Retailer**	**Pallet Broker**	**Government (GSA, DOD)**	**Manufacturer**	**Other**
	Mean (as % of total sales)					
0 < Employees < 20	30%	49%	49%	26%	84%	24%
20 ≤ Employees < 99	23%	14%	18%	11%	75%	12%
100 < Employees	16%	7%	9%	4%	79%	10%
Kruskall-Wallis test (p value)	0.83	0.03	< 0.0001	0.77	0.004	0.63

Table 7. Species and Source of Wood Pallet Materials.

		Source (percent of respondents)		
Species	**% in mix**	**Domestic**	**Canada**	**Other Countries**
Mixed Hardwoods	27.3%	87%	13%	
Oak (red or white)	15.8%	92%	8%	
Southern Pine	15.5%	100%		
SPF (Spruce-Pine-Fir)	12.7%	27%	73%	
Yellow-Poplar	8.1%	92%	8%	
Maple	4.7%	79%	21%	
Douglas-Fir	4.3%	60%	40%	
Others	4.0%	55%	45%	
Hemlock-Fir	3.3%	82%	18%	
Red Alder	1.2%	86%	14%	
Eucalyptus	0.4%			100%
Radiata Pine	0.2%			100%

hardwood/softwood split compares quite well to 63.6 percent (by volume) hardwood and 36.4 percent softwood material in 2006 reported by Araman, Bush, and Hager [38]. It was also found that some companies import SPF from Canada as well as eucalyptus and radiata pine from South American countries like Chile, Brazil, and Uruguay. The amount of pallet wood imported from Canada is very impressive.

When industries were asked about the percentage of new or recycled materials for the production of recycled pallets, results show that small and large industries use more new materials than recycled ones (see Table 8). The opposite trend was found in medium size industries where it was indicated that a majority of recycled material is preferred over new materials. According to Bush and Araman [10] and Brindley [39], the production of recycled wood pallets has shown an increase due to their advantages in cost, and technical characteristics compared to new wood pallets.

Supply of pallet materials is an important issue for wood pallet man-

Table 8. Type of Materials Used for Production of Recycled Pallets.

	Percentage (sample size)			Kruskall-Wallis Test p-value
Type of Material	**0 < Size < 20**	**20 ≤ Size < 100**	**100 < Size**	**p-value**
New wood materials	68.1% (37)	47.3% (46)	57.6% (11)	0.04
Recycled materials	54.5% (40)	62.5% (50)	46.6% (10)	0.42

Table 9. Perceptions Regarding Local Supply of Wood Pallet Materials.

	Mode (sample size)			
Perceptions Regarding Local Wood Pallet Materials Supply	**0 < Employees < 20**	**20 ≤ Employees < 100**	**100 < Employees**	**Kruskall-Wallis Test p-value**
Domestic wood pallet materials supply is not consistent	Agree (96)	Agree (78)	Agree (14)	0.91
Domestic wood pallet materials supply is not delivered on time	Disagree (96)	Disagree (77)	Disagree (13)	0.16
Transportation is a problem when acquiring wood pallet materials	Disagree (95)	Disagree (77)	Disagree (13)	0.89
Suppliers cannot give us information about where wood pallet materials are located when transported	Disagree (87)	Disagree (74)	Disagree (14)	0.53
Domestic wood pallet materials are of high quality	Agree (97)	Undecided (78)	Agree (14)	0.41

ufacturers. Respondents were asked to rate in a Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Undecided, 4 = Agree, and 5 = Strongly Agree) their perceptions in factors related to the supply of local materials for pallet manufacturing (Table 9). All groups seem to agree that supply of pallet materials is not consistent. However, all groups agree that local suppliers deliver on time, provide good means of transportation and material traceability features. In general, respondents believe that the quality of the materials provided by suppliers is of high quality. Comparisons across groups were not statistically significant (using a nonparametric test with a 0.05 significant level), meaning that answers by group can be treated as the same.

It is also critical to understand what factors affect purchasing decisions of pallet raw materials. A total of 16 questions in this regards were asked to the survey participants in a Likert format scale as shown in Table 10. In some of the cases responses were statistically significant across groups (by industry sizes) after conducting an independent sample test comparison using the nonparametric Kruskall-Wallis test (significant level of 0.05). A comparison across items was not conducted in order to statistically compare each item against others. However, the mode will be used to rank the level of importance across the items.

Cost, quality, reliable supplier, delivery on time, and availability of materials received the highest scores among all the factors (comparing the modes with no statistical test across items). The wood pallet industry is very sensitive to these factors, specially to cost, quality, and material availability given the impact on manufacturing costs and to the end product quality. Supplier reliability has become an important issue while reliable transportation and delivery on time are also critical issues that impact not just the manufacturing cost but also customer satisfaction issues. In this specific case, industries were also asked to report on their supplier's delivery time. Small companies indicated that on average it takes 7.26 days, 7.44 days for medium size firms, and 7.57 days for large firms as the time it takes their suppliers to receive an order. The nonparametric test indicates no difference between the mean responses of each group (using a 0.05 significance level and group sizes of 89, 73 and 13 for small, medium, and large industries respectively).

In second place (comparing by the mode, not statistically test) factors were ranked machinability, mechanical properties, durability, strength, stiffness, density, logistics and transportation, workmanship, and species. These factors are mostly technical aspects related to the physical properties of the raw material which is different from the pre-

Table 10. Rating of Factors Affecting the Materials Purchasing Decision Process.

Factors Affecting Purchasing Decisions of Raw Materials	**Mode* (group size)**			**Kruskall-Wallis test**
	0 < Employees < 20	**20 ≤ Employees < 100**	**100 < Employees**	**p-value**
Machinability	Agree (87)	Agree (69)	Agree (13)	0.35
Mechanical properties	Agree (77)	Agree (62)	Undecided (12)	0.42
Durability	Agree (94)	Agree (74)	Agree (14)	0.43
Strength	Agree (97)	Agree (74)	Agree (14)	0.17
Stiffness	Agree (90)	Agree (72)	Agree (14)	0.88
Density (specific gravity)	Agree (89)	Agree (71)	Agree (14)	0.07
Environmental certified	Undecided (87)	Undecided (71)	Strongly disagree (13)	0.07
Cost	Strongly agree (103)	Strongly agree (77)	Strongly agree (14)	0.23
Availability	Strongly agree (101)	Strongly agree (76)	Strongly agree (14)	0.43
Quality	Strongly agree (102)	Strongly agree (76)	Strongly agree (14)	0.93
Reliable Supplier	Strongly agree (102)	Strongly agree (76)	Strongly agree (14)	0.88
Delivery on time	Strongly agree (100)	Agree (75)	Agree (14)	0.31
Logistics and transportation	Agree (93)	Agree (75)	Agree (14)	0.55
Workmanship	Agree (95)	Agree (74)	Agree (13)	0.21
Species	Agree (93)	Agree (73)	Agree (13)	0.49

*Measured using a five point interval Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

vious factors that more closely related to business aspects. It would be interesting to conduct an item reduction procedure, such as principal component analysis (PCA), to be able to compare business and technical factors affecting purchasing decisions. However; this potential test falls outside of our objectives.

The results of the industry perception on the importance of environmental certified raw materials when making purchasing decisions is very interesting given the attention that sustainability and environmental issues are receiving today. Small and medium size firms seem to be undecided on this item but large size industry responded that environmental certified products is not a factor affecting purchasing decisions. Survey participants were specifically asked if they believe their customer will pay more for environmentally certified products (a nominal question, Yes or No) and the aggregate answer was 86% No and 14% Yes. Respondents indicated that the main reasons given by their customers for not purchasing these types of products are price (70.7%) and low demand (10.5%). In contrast, the most important driver for demanding environmentally certified products is when certified products is a requirement. It is not a requirement and this will (or may) not change until pallet customers demand environmentally certified pallet materials.

Although the majority of respondents purchased raw material from domestic suppliers, surveyed firms who imported raw materials (cants, lumber or pallet parts) were asked to rate barriers to the import process as shown in Table 11. Price, tariffs, paperwork, government policies,

Table 11. Rating Barriers Affecting the Imports of Cants, Lumber, and Wood Pallet Parts.

Factors Affecting Purchasing Decisions of Raw Materials	Mode* (group size)			Kruskall-Wallis test
	0 < Employees < 20	20 ≤ Employees < 100	100 < Employees	p-value
Price	Agree (41)	Strongly agree (56)	Strongly agree (10)	0.04
Tariffs	Agree (40)	Undecided (52)	Strongly disagree (9)	0.01
Paperwork	Agree (39)	Undecided (53)	Disagree (10)	0.05
Quality	Undecided (41)	Agree (56)	Disagree (9)	0.18
Language	Undecided (40)	Undecided (53)	Disagree (9)	0.13
Delivery on time	Agree (42)	Agree (56)	Agree (9)	0.21
Logistics and transportation	Agree (41)	Agree (53)	Agree (10)	0.83
Production capacity	Undecided (39)	Undecided (54)	Undecided (9)	0.73
Government policies	Agree (40)	Undecided (54)	Undecided (9)	0.005
International treaties	Undecided (38)	Undecided (53)	Strongly disagree (9)	0.005
Past experiences	Undecided (31)	Undecided (51)	Disagree (9)	0.75
Phytosanitary requirements	Undecided (38)	Undecided (53)	Undecided (9)	0.04
Payment methods	Undecided (40)	Undecided (54)	Agree (9)	0.37

*Measured using a five point interval Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

and international treaties seem to be different for each group. Large and medium size firms believe that price is a strong barrier. Medium and large size firms perceive tariffs as a barrier while medium size firms are undecided in this item. It is interesting to see that large industries did not perceive paperwork as a barrier as is the case of small firms. This leads one to believe that large firms have more experience with international suppliers than small and medium large firms. Other factors such as government policies, international treaties, and phytosanitary requirements were also statistically significant. While small companies believe that government policies have an impact on the import of raw materials, large and medium companies are not clear about this item. However, large firms clearly indicate that international treaties are not a barrier and it might be perceived as an opportunity to source materials from overseas with competitive conditions. Surveyed firms were also asked to compare (Kruskall Wallis test with a 0.05 significance level) local and international suppliers in a few categories but in any of the four categories (technical performance, better customer service, meeting technical specifications, and easier to do business with) there were no statistical significances. In summary, none of the groups (small, medium and large) perceived international suppliers as better than local suppliers in the four categories mentioned above.

Business Management

Wood pallet companies were asked about their perception on a series of items (see Table 1, Section 3, 4 and 5) categorized as customer satisfaction, business management, and external factors. A balanced-five-point Likert scale was designed to capture the companies' perception. Given that Likert scales are in nature ordinal, nonparametric techniques are used to analyze and present the data [40]. As a measure of central tendency, the mode is used and for each item the frequency for each score is calculated as well. Data is segmented by industry size following a similar procedure by Mangun and Phelps [33]. The Kruskal Wallis statistic (a nonparametric test) is used to test for item differences by company size and the mean scores of the Wilcoxon Scores test (not shown) are used to break the ties when differences are detected (see Table 12).

Survey firms were asked their perception on 15 items related to general business management aspects including strategy, operating planning, marketing, investments, and inventory management. In terms of

Table 12. Perceptions on Business Management Issues.

Business Management Issues	Mode* (group size)			Kruskall-Wallis test
	0 < Employees < 20	20 ≤ Employees < 100	100 < Employees	p-value
1. Our company forms leader groups from diverse areas for the planning and developing of the strategic business plan	Disagree (64)	Neutral (64)	Agree (13)	0.09
2. Our company develops strategic operation plans with suppliers	Agree (78)	Agree (68)	Agree (13)	0.02
3. Our company has reduced manufacturing processes cost in the last 3 years	Agree (91)	Agree (73)	Agree (15)	0.007
4. Inventory costs have been reduced in the last 3 years	Agree (91)	Agree (75)	Agree (15)	0.05
5. Our company offers competitive wood pallet prices	Agree (97)	Agree (74)	Agree (15)	0.70
6. Our company offers lower prices than our competitors	Neutral (95)	Neutral (76)	Agree (14)	0.03
7. Our company works with a differentiation strategy (produces unique products for different customers)	Agree (90)	Strongly Agree (73)	Agree (15)	0.16
8. Our company works with a segmentation strategy (categorizes its customers in groups with similar needs, and makes products to satisfy those needs)	Agree (79)	Neutral (68)	Agree (14)	0.93
9. Our company produces only against firm customer orders or uses the “pull” production system	Agree (88)	Agree (70)	Agree (14)	0.73
10. Our company produces for stock replenishment	Agree (84)	Agree (72)	Agree (13)	0.34
11. Our company places emphasis on the benefits of our product compared to our competitors’	Agree (91)	Agree (73)	Agree (14)	0.5
12. Our company offers wood pallets directly to the customer	Strongly Agree (99)	Strongly Agree (76)	Strongly Agree (15)	0.05
13. Our marketing team has a lot of experience	Agree (82)	Agree (72)	Agree (15)	0.3
14. Our company invests resources in new processes and products	Agree (86)	Agree (74)	Agree (15)	< 0.0001
15. Our company usually hires some experts in the pallet field for improving processes and products	Disagree (78)	Neutral (96)	Strongly Disagree (15)	0.31

*Measured using a five point interval Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

strategy (items 1, 2, 7, and 8 in Table 12), there was statistical significance only for item 2 in this category. The Wilcoxon score for item 2 shows that large firms have better strategic planning than small and medium firms related to supplier practices. Item 1 (not statistically significant) shows low perceptions for small and medium enterprises, indicating perhaps that large firms are most used to strategic planning.

In regards to the manufacturing category (items 3, 9, and 15) only one item was found statistically significant between groups. By looking at the Wilcoxon scores to break this tie, it shows that large corporations are more sensitive of cost reduction than small and medium size corporations. The item pull production system is ranked equally in three groups (ranked as "agree") and the item consulting services for process improvement is the same in three groups but received low perception rankings (ranked "strongly disagree" in large firms, "undecided" in medium firms, and "disagree" in small firms). This result might indicate that wood pallet industries do not hire many consultants to help them with process improvement projects. These results in terms of manufacturing are consistent with the results obtained from a study by Buehlmann *et al.* [11] in the hardwood industry (a supplier to the wood pallet industry), where manufacturing issues such as quick delivery and just in time delivery were the highest rated services in the sector.

The items related with the category marketing are items 6, 11, 12, and 13. In this category, only items 6 and 12 were found statistically significant. It appears that large size industries perceive their product offerings are a lower price than competitors. The other difference was found with item 12, direct selling to customers. By looking at the Wilcoxon scores to break the tie, it appears that medium size firms perceive their capabilities to offer direct marketing of higher rank compared to small and large size firms. Finally, the three groups all agree that they all place emphasis in marketing their products as superior than their competitors.

Regarding investments (item 14), the nonparametric test shows statistically significant among the three groups. Large firms have the highest Wilcoxon scores, followed by medium size and small size firms. This indicates that large firms have better tendencies to invest in improvement of products and processes. The last category in Business management (Table 12) is inventory management (items 4 and 10), Item 4, inventory cost reduction, was found statistically significant. The Wilcoxon scores show that large firms put more attention on this issue followed by medium and small firms in that order. Item 10, stock replenishment production, was perceived equally by all three groups where they all ranked it as agree. This might be an indication that wood pallet firms manufacture their products following a make-to-stock traditional scheme with little involvement in just in time strategies.

Customer Service

In terms of the items grouped under the category customer service, results show that there is no statistically significance in the perception of the items by industry size (Table 13). For all items, the mode is greater than 4, indicating that all industries at least agree with the statement in each item. Customer service was also identified as the most critical aspect in research by Marwaha *et al.* [41] and Jeffrey and Wesley [42] with quality as the crucial element to achieve customer satisfaction. Also, Dunn *et al.* [43] indicated that customer service is one of the most important manners to achieve company success. Buehlmann *et al.* [11] also found that manufacturers are looking to improve customer service and have realized that orders are no longer in large quantities of the same material, but they are increasingly requiring small quantities of a variety of materials or products. Results on the perceptions of the industry related to customer satisfaction indicate in general that the industry have a good relationship with their customers, they understand customer requirements, and the industry is committed to continue focusing on the customer's needs to increase their performance.

External Factors or Uncertainties

An understanding on external factors affecting the wood pallet industries is also necessary. Table 14 presents a list of items that were asked to the surveyed firms. Items were grouped by company size and a nonparametric statistics test (Kruskall Wallis with a 0.05 significance level) was used to compare the responses among the groups. The mode was used to present the rankings by group and in the case of ties when there is statistical significance, the Wilcoxon scores are used to find the ranking order.

Items in external uncertainties were categorized in supply chain management, competitiveness, policy and government, environmental issues. Items grouped in the category supply chain management are items 1, 2, 3, 4, 6, 9, 10, and 11. In this category items 1, 3, 4, 9 and 10 were found statistically significant. By looking at Wilcoxon scores,

Table 13. Comparison by Industry Size of Items in the Section Customer Service.

Customer Service Items	0 < Employees < 20		20 ≤ Employees < 100		100 < Employees		Kruskal-Wallis statistic (p value)
	Group Size	Mode (freq)	Group Size	Mode (freq)	Group Size	Mode (freq)	
1. Our company keeps track of customer needs and asks their feedback on quality/service (CS1)	98	Agree (50)	75	Agree (51)	15	Agree (47)	0.46
2. Our company asks customers about their expectations (CS2)	100	Agree (56)	76	Strongly Agree (49)	15	Agree (60)	0.18
3. Our company makes it easier for the customers to look for assistance (CS3)	92	Agree (46)	76	Agree (45)	15	Strongly Agree (47)	0.63
4. Our company can deliver the required wood pallet quantities to the customers on time (CS4)	101	Strongly Agree (63)	76	Strongly Agree (74)	15	Strongly Agree (53)	0.23
5. Our customers are happy with the quality of the products that we offer (CS5)	101	Strongly Agree (60)	76	Strongly Agree (55)	15	Agree (67)	0.19
6. Our products are only focused on the customer's needs (CS6)	99	Strongly Agree (50)	76	Agree (46)	15	Agree (73)	0.24

*Measured using a five point interval Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

it was found that large companies rank higher (strongly agree) than medium and small size firms in regards of having multiple suppliers (item 1). The involvement of suppliers in developing strategies (rank as agree) and an openness to work with international supplier (rank as agree) were also items that rank higher for large size industries than for the other two. A similar outcome was found for item 9, partnership with consistent suppliers, where large size industries have the largest score (rank as agree). Item 10 (all “disagree,” statistically significant) is an indication that industries in the wood pallet industry consider other factors than transportation and logistics aspects to select suppliers. In this particular case, small firms rank the highest (using the Wilcoxon scores) than medium and large in that order.

Items 2 and 6 (trust and communication with supplier) in the supply chain management category were ranked by each group as “Agree” with no statistical significance among the groups. These results might be an indication that in the wood pallet industry there is a strong sensitivity to partner and collaborate with suppliers. Also, the lower ranks in the supply chain management items found in small and medium firms (where statistical significance was found) might be due to the fact that supply chain management is a complicated matter as its concepts are better understood and practiced in large size industries. In this category, it was interesting to see that small and medium firms rank item 11 (inconsistency with delivery of import materials) as undecided and the large group ranked as Disagree. Although there was not statistical significance found for this item, this could be an indication that large firms have more experience with imports than the other two groups.

In terms of the category of competitiveness (item 5) groups large and medium strongly agree with the statement that competition in the wood pallet sector is strong. The group small firms ranked this statement as “agree.” However, statistical significance was not found in this item. Regarding the category policy and government where items 8 and 12 are grouped it was found that item 8, government communications, is not statistically significant. In all cases, this item is ranked as “disagree” indicating that the wood pallet industry has the perception that the government does a poor job in communicating important information to the industry. Item 12, overseas political conflicts, reflect that large size firms have more experience in working with suppliers in other countries than small and medium size industries (significant at 0.05 significance level).

The last category, certified products (item 7), reflects earlier findings (Table 10) where there is little interest in the sector for the use of en-

Table 14. Comparison by Industry Size of Items in the Section External Factors.

	Mode Response (group size)			Kruskall-Wallis test (p value)
External Uncertainties	**0 < Employees < 20**	**20 ≤ Employees < 100**	**100 < Employees**	**p-value**
1. Our company works with more than 3 suppliers	Agree (97)	Strongly agree (73)	Strongly agree (14)	0.002
2. Our company trusts its suppliers	Agree (99)	Agree (73)	Agree (14)	0.74
3. Our company involves suppliers when planning strategic goals	Agree (89)	Agree (71)	Agree (14)	0.05
4. Our company is open to work with suppliers from other countries	Agree (88)	Agree (71)	Agree (12)	< 0.0001
5. Competition in the wood pallet sector is strong	Agree (104)	Strongly agree (73)	Strongly agree (15)	0.15
6. There is a high level of communication and coordination with our suppliers	Agree (4)	Agree (4)	Agree (14)	0.25
7. Our company uses certified wood for manufacturing pallets	Disagree (92)	Agree (68)	Strongly dis-agree (12)	0.75
8. Our company is informed by the government about important aspects that can affect our business	Disagree (94)	Disagree (71)	Disagree (13)	0.40
9. Our company would like to work with suppliers who have availability of resources and consistency of supply	Agree (95)	Strongly agree (73)	Agree (14)	0.01
10. Our company thinks that logistics and transportation is the number one criterion when selecting suppliers	Disagree (95)	Disagree (73)	Disagree (14)	0.03
11. The delivery of imported wood pallet materials can easily go wrong	Undecided (79)	Undecided (67)	Disagree (14)	0.35
12. Our company does not want to work with countries from overseas, because they tend to have a lot of social and political issues that would affect our production	Undecided (79)	Undecided (66)	Strongly disagree (13)	0.0003

*Measured using a five point interval Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree.

vironmentally certified materials for the manufacturing of wooden pallets. There were no statistical significances found in this item. However, large companies ranked the item as "strongly disagree" and small and medium as "disagree" and "agree."

CONCLUSIONS

The objective of this research was to identify and understand current business practices affecting the U.S. wood pallet industry in five main categories: general information, raw materials, customer service, business management, and external uncertainties. Information was collected through a nationwide survey of 1,500 companies. A total of 202 usable responses were received, yielding an adjusted response rate of 14%, and representing 8% of U.S. wood pallet and container manufacturing according to the U.S Census Bureau [34]. A non-response bias evaluation concluded that medium and large companies (measured by number of employees, gross sales, and pallet output) were more likely to respond to the survey. Data was analyzed using nonparametric procedures and presented by industry size.

It was found that small companies reported for 2009 an average production of 135,276 units, while medium size reported 982,707 units, and large companies 4,134,888 units. Previous research by Bush and Araman [10] had reported 512,533 production units in 2006 as an aggregate. It is difficult to conclude a trend for 2009 production given that the scales are different for each study.

Not many industries reported to purchase raw pallet materials (cants, lumber or pallet parts) from international suppliers. In those cases, the raw materials came mostly from Canada (Spruce, pine, fir, Douglas fir) and from South America (eucalyptus and radiata pine). However, surveyed industries were asked about their main known barriers to import pallet raw materials. Most of the answers from small and medium enterprises show that they are "undecided" and could not tell what factors might be critical or not leading to conclude that mostly large size firms are purchasing raw pallet materials from international suppliers. Large companies indicated that price and tariffs are critical for imports while paperwork, quality, and language are not considered a barrier. This information could be very useful for small and medium size firms that wish to start purchasing raw pallet materials to overseas suppliers.

When industries were asked about their perception regarding local suppliers, in general the surveyed firms had an acceptable opinion of local suppliers. Most important factors impacting purchasing decisions are business related: cost, quality, reliable supplier, delivery on time, and availability of materials (no statistical significance among groups). Technical aspects such as machinability, durability, density, strength, and stiffness came in second place. When firms were asked to compare local suppliers to international suppliers, the general agreement in three groups is that they do not perceive a better performance or advantage from international suppliers over local suppliers. Interesting was also the indication that neither group considers much of environmental certified raw materials, (only 14% reported they believe their customers will pay more for this type of product). Same results have been obtained in similar studies in other wood products industries [44].

Business management trends in the wood pallet industry are very similar as in other forest products industries. Results confirm that wood pallet manufacturers are demanding short lead times in their orders to suppliers (mean averages 7.26 days, 7.44 days, and 7.57 days small, medium, and large size firms). This leads to the conclusion that large orders of the same material or product are no longer the standard practice; but rather a mix of small quantities of different materials. Thus, wood pallet industry suppliers have to accommodate to this trend in order to be competitive. When the industries were asked about supply chain management practices such as number of suppliers, supplier trust and communication, and involvement of suppliers in strategic planning, there was an indication that large firms tend to understand and practice these activities more than small and medium size companies. Given that the wood pallet industry has been relatively insulated from the fierce competition from low-cost imports (such as the furniture industry), this sector should take advantage of strong relations with suppliers and closeness to customers in order to improve their competitiveness. Sanders and Premus [45] concluded that information sharing with supply chain partners is one of the tenets of supply chain management, and has shown to reduce costs by reducing transaction costs and uncertainty. If wood pallet firms could get into a higher level of engagement with their suppliers, more benefits might be withdrawn.

Opportunities for improvement at the manufacturing level can be identified in the low ratings given to manufacturing cost, use of pull production system, little access to consultants for continuous improvement, and investments in process and products. Innovation can be achieved not only in physical products, but in the manufacturing process and the service, by providing more and better services to customers, like flexibility in volume and time. For instance, information technology has been shown to benefit other sectors in the wood products industry [46]

Outputs of this study can be used by manufacturers to make strategic decisions about their business processes and practices (strategic planning is very important especially for small and medium enterprises). Also, organizations that support the industry can benefit by designing more effective assistance programs to improve the industry's competitiveness. Nevertheless, the wood pallet industries perceived that policy and government regulations are not communicated in the most appropriated manner. This is critical for the long stability of the sector considered that all surveyed firms perceived the industry as very competitive.

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Retention and Diffusivity of Tocopherol in Packaging Films

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ABSTRACT: LDPE, LDPE/PP blend, and PP films impregnated with 300 ppm tocopherol were produced using cast film extrusion. Retention of tocopherol in the films after production and release of tocopherol from the films to 95% ethanol (a fatty food simulant) at 30, 40 and 50ºC were measured using UV/Vis spectrophotometry. A Fickian diffusion model with appropriate initial and boundary conditions was fitted to the release data. Results show that tocopherol retention is more than 90% of the initial loading. Diffusion of tocopherol in the films follows Fickian diffusion, with diffusivity in LDPE being the highest followed by LDPE/PP and PP. Temperature has a greater effect on tocopherol diffusion in PP than in LDPE.

INTRODUCTION

MIGRATION involves the movement of chemical compounds from package to food, and this mass transfer phenomenon is especially important when the package is in direct contact with the food [1]. Migration is undesirable if the migrating chemical compounds are some plasticizers or additives that are potentially harmful to human health [2–5]. However, migration is desirable for controlled release packaging (CRP) applications in which migrating compounds, such as antioxidants or antimicrobials, are used to inhibit lipid oxidation or microbial growth for quality and safety enhancement [6]. For example, an antioxidant can be impregnated into a packaging film and then be slowly released onto the food surface to prevent onset of lipid oxidation. Com-

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pared to the traditional method of adding antioxidant directly into the food, this slow but sustained release of antioxidant is more effective because it replenishes the antioxidant consumed in oxidation reaction so that the effective antioxidant concentration can be maintained for a longer period of time [7].

Tocopherol is a well-known antioxidant added to foods [8]. It has also been used as a stabilizer during extrusion of polyolefins to reduce off-odor and off-taste formation [9–12]. In recent years, there has been a great interest in using tocopherol to develop CRP technology [6], but good results are not always observed. For example, Wessling *et al.* [13] showed that a low density polyethylene (LDPE) film impregnated with 3400 ppm α-tocopherol inhibited the oxidation of a linoleic acid/water emulsion at 6°C in dark and under open-air exposure, whereas no significant retardation was observed at 20 and 40°C. Lee *et al.* [14] reported that a laminated pouch consisting of a HDPE layer and a heat seal layer impregnated with 73 ppm α-tocopherol failed to retard the oxidation of a freeze-dried model food product containing linoleic acid at 45°C and 50% RH.

To develop effective controlled release films impregnated with tocopherol, the release kinetics of tocopherol must be well understood. Controlling the release of tocopherol is important because too slow release of tocopherol may not be sufficient to prevent lipid oxidation, while too fast release may cause pro-oxidation or degradation of tocopherol [16]. The release of tocopherol from a packaging film involves three steps: diffusion in the film, dissolution at the film/food interface, and diffusion in the food matrix [15]. Among these steps, diffusion of tocopherol in the film is often rate determining. Diffusivity is a useful parameter describing how fast tocopherol diffuses in polymer films.

A practical approach to control diffusion is to manipulate the composition and structure of packaging film. Wessling *et al.* [17] reported that α-tocopherol could not release from polypropylene (PP) film but could release from LDPE film. Obinata [18] also showed that release of tocopherol from PP into 95% aqueous ethanol was much slower than that from HDPE and LDPE. These studies suggest that release of tocopherol can be controlled by judicious selection of packaging polymer.

The objectives of this research are: (1) to determine retention of tocopherol in several common packaging polymers after cast-film extrusion, and (2) to estimate diffusivities of tocopherol in these polymers at various temperatures and compare them with literature values.

MATERIALS AND METHODS

Materials

A natural tocopherol product (mixture of 10% α-tocopherol, 5% β-tocopherol, 65% γ-tocopherol and 20% δ-tocopherol) extracted from soy bean was donated by Cargill Inc. (Minneapolis, MN, USA). Barefoot LDPE and PP resins (those without added antioxidants) were provided by Berry Plastics (Chippewa Falls, WI, USA). HPLC grade solvents were purchased from Fisher Scientific Inc. (Suwanee, GA, USA).

Film Production

LDPE, PP and LDPE/PP blend films impregnated with 3000 mg/kg tocopherol films were produced using a Collin cast-film line at Berry Plastics (Chippewa Falls, WI, USA). The LDPE/PP blend film was consisted of 50% LDPE and 50% PP. Film thicknesses were obtained using a Digitrix II Micrometers (NSK/Fowler, Tokyo, Japan) measured at twenty randomly selected locations from each film (Table 1).

Total Extraction of Tocopherol from Films

Total tocopherol extraction from the films was conducted to determine the tocopherol retention in the films after cast-film extrusion. Extractable tocopherol percentage was estimated from the amount of extracted tocopherol divided by the amount of tocopherol originally loaded into the films. 1.00 ± 0.03 g film was cut into small pieces (1 cm × 1 cm) to maximize the surface area and placed into a 125 ml Pyrex flask. 40 ml methylene chloride, a solvent able to dissolve a wide range of organic compounds, was used to loosen up the film structure and extract tocopherol from the film [18]. The flask was agitated at 100 rpm in dark at 30ºC in an environmental chamber (Lab-Line Instruments, Inc., Melrose Park, IL, USA). The methylene chloride extracted solution was withdrawn after 48 hours, filtered with 0.2 μm PTFE filter

Table 1. Film Thickness and Tocopherol Retention.

	LDPE	LDPE/PP	PP
Thickness ($\times 10^{-5}$m)	10.88 ± 0.10	9.37 ± 0.07	10.02 ± 0.04
Retention (%)	91.08 ± 0.03	95.48 ± 0.36	97.83 ± 0.30

(Millipore Corporation, Billerica, MA, USA) and measured by UV/Vis spectrophotometer (UV1700, Shimadzu, Kyoto, Japan) at 295 nm. The concentration of tocopherol was determined using a standard curve of tocopherol in methylene chloride.

Release Study of Tocopherol from Films

Release study was conducted using 95% ethanol as fatty food simulant [19] to determine release kinetics of tocopherol from the films. Percentage of tocopherol released at a given time was estimated from amount of dissolved tocopherol in 95% ethanol divided by amount of total extractable tocopherol from films. 1.00 ± 0.03 g film was cut into small pieces (1 cm × 1 cm), put into a 125 ml Pyrex flask piece by piece to prevent sticking, and immersed in 40 ml 95% ethanol. The flask was agitated at 100 rpm inside a dark environmental chamber at 30, 40 and 50ºC. The liquid samples were withdrawn periodically, filtered with 0.2 μm PTFE filter, and measured using UV/Vis spectrophotometer at 295 nm. Concentration of tocopherol was determined using a standard curve of tocopherol in 95% ethanol.

Estimation of Tocopherol Diffusivity

Diffusivities of tocopherol was estimated using the following equation [20]:

$$\frac{M_{F,t}}{M_{F,\infty}} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left[\frac{-D(2n+1)^2 \pi^2 t}{L_p^2}\right] \tag{1}$$

where $M_{F,t}$ is mass of tocopherol in ethanol at a particular time t (s), $M_{F,\infty}$ is the mass of tocopherol in ethanol at infinite time (in equilibrium), L_P (m) is film thickness, D (m^2/s) is diffusivity of tocopherol in film, and t (s) is time. This equation assumes that (1) mass transfer resistance of tocopherol from film surface to ethanol was negligible, (2) initial concentration of tocopherol in ethanol was zero, (3) there was no concentration gradient of tocopherol in ethanol, (4) diffusivity and partition coefficient were constant at a given temperature, and (5) interactions between ethanol and the film were not considered. Nonlinear regression was used to fit this equation to experimental data. Diffusivity was estimated using a program written in MatlabTM R2009a based on minimizing the sum of the squared of errors between the experimental and estimated values.

RESULTS AND DISCUSSION

Tocopherol Retention in Films

Table 1 shows that more than 90% of the originally loaded tocopherol was extracted from the films. Hence it is concluded that retention of tocopherol after cast-film extrusion was more than 90%. In comparison with other studies, α-tocopherol retention in LDPE films was reported to be less than 40% by Wessling *et al.* [13] and in range of 75–80% by Siró *et al.* [21]. The differences may be due to the different film processing conditions.

Release Kinetics of Tocopherol from Films

Figure 1 shows that tocopherol release is much faster from LDPE film than from LDPE/PP and PP films. At 30ºC, 90% tocopherol was released from LDPE after 9 hours, but the same amount of tocopherol released from LDPE/PP and PP films took 1090 hours (~45 days) and 2500 hours (~104 days), respectively. The differences between tocopherol release from PP and LDPE may be explained by the molecular structures of these two polymers. Due to the larger crystalline regions, PP polymer chains are more compact and thus they impose more restriction to the movement of tocopherol. Similar observations were also reported by Obinata [18] and Zhu [22].

Estimation of Tocopherol Diffusivity

Figure 2 shows that the predicted diffusivities closely match the experimental diffusivities at 40ºC. Although not shown, the same is also observed for 30 and 50ºC. The good match suggests that the assumptions in Equation (1) are reasonable; for example, the diffusion of tocopherol in the films follows Fickian diffusion and there is negligible interaction between the 95% ethanol and packaging polymers.

Table 2 shows that the diffusivity of the LDPE/PP film is much lower than the average diffusivity of the LDPE and PP film. This confirms the results by Zhu *et al.* [22] that diffusivity does not vary linearly with LDPE/PP ratio.

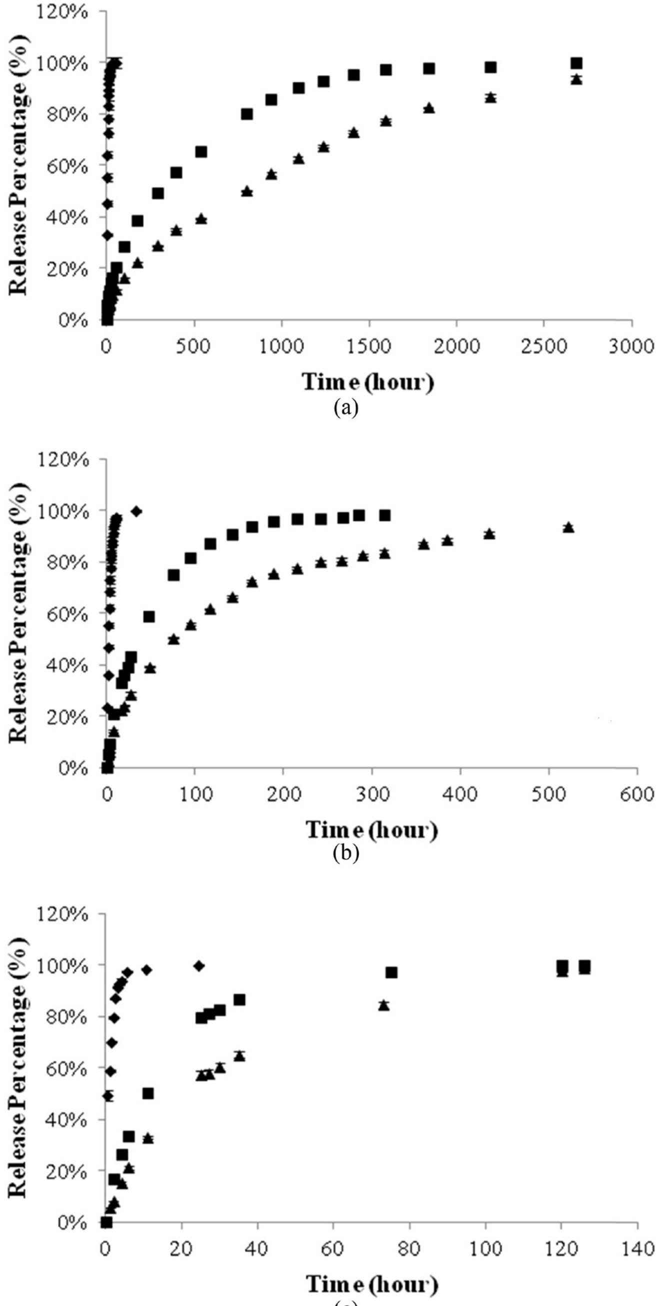

Figure 1. *Release of tocopherol from films into 95% ethanol at 30ºC (a), 40ºC (b) and 50ºC (c): ◆: LDPE, ■: LDPE/PP, ▲: PP.*

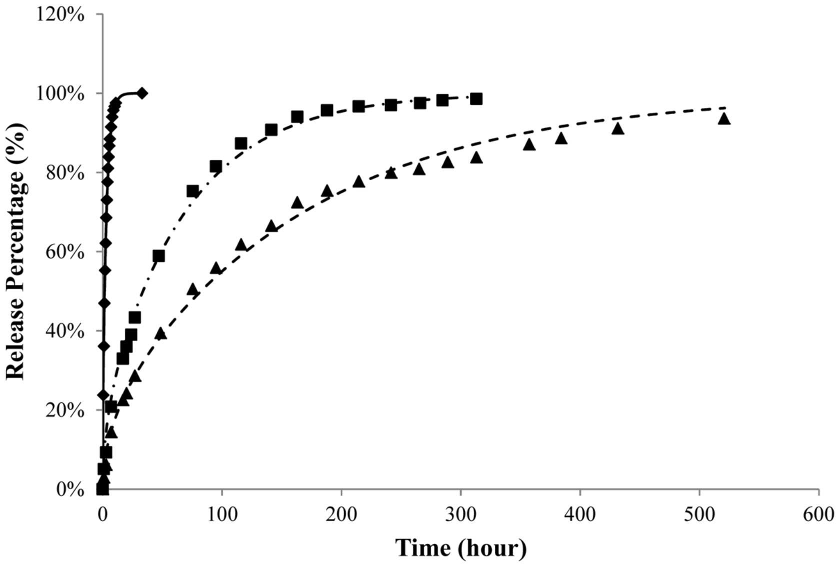

Figure 2. *Experimental versus predicted release of tocopherol from various packaging films at 40 °C. Experimental: ◆: LDPE, ■: LDPE/PP, ▲: PP. Predicted: —— LDPE, -·-·-: LDPE/PP, ----- PP.*

Table 3 summarizes the tocopherol diffusivities in LDPE at 30ºC from the literature. The diffusivities obtained in this study using cast-film extrusion are in the same order of magnitude as the literature values obtained by blown-film extrusion.

Temperature Dependence of Diffusivity

The Arrhenius equation was used to describe the temperature effect on diffusivity:

$$D = D_0 \exp\left(-\frac{E_a}{RT}\right) \tag{2}$$

where D is diffusivity, D_0 is constant, E_a is activation energy for diffusion (J/mol), R is Universal Gas Constant (8.314 J/mol K), and T is absolute temperature (K). The Arrhenius plots in Figure 3, derived from the logarithmic transformation of Equation (2), show that temperature has a significant effect on diffusivity. E_a is related to the energy required for a migrant to move through the polymer matrix [23], which were estimated as 48.5, 135.7 and 141.2 kJ/mol for the LDPE, LDPE/PP, and PP films, respectively. The results indicate that less energy is

Table 2. Diffusivity of Tocopherol in Different Films at Various Temperatures.

	Diffusivity Estimation (m^2/s)		
Temperature (ºC)	**LDPE**	**LDPE/PP**	**PP**
30ºC	7.20×10^{-14}	4.31×10^{-16}	2.04×10^{-16}
40ºC	1.03×10^{-13}	3.56×10^{-15}	1.67×10^{-15}
50ºC	2.39×10^{-13}	1.19×10^{-14}	6.50×10^{-15}

required for tocopherol to move in LDPE than that in LDPE/PP and PP. Graciano-Verdugo *et al.* [24] reported that E_a were 126.5 and 105.9 kJ/mol respectively for 19.07 and 30.18 mg/g α-tocopherol impregnated LDPE films.

CONCLUSION

More than 90% of tocopherol was retained in LDPE, PP, and LDPE/PP films after cast-film extrusion. The percentage of retention is higher than those reported in the literature, perhaps due to the processing conditions. The diffusion of tocopherol follows Fickian diffusion with

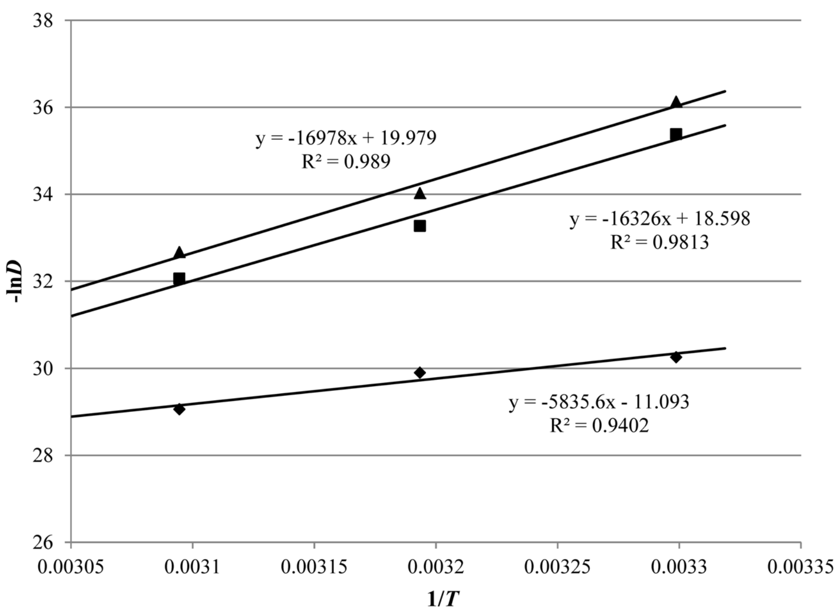

Figure 3. *Temperature dependence of tocopherol diffusivity for various packaging films: ◆: LDPE, ■: LDPE/PP, ▲: PP.*

Table 3. Comparison of Tocopherol Diffusivities at 30°C.

Polymer	Processing Method	*D* (m^2/s)	Reference
HDPE + TiO_2/EVOH/LDPE (tocopherol 40 mg/g)	Blown-film extrusion	3.06×10^{-15}	[25]
LDPE (tocopherol 20 mg/g)	Blown-film extrusion	3.03×10^{-14}	[24]
LDPE (tocopherol 40 mg/g)	Blown-film extrusion	5.11×10^{-14}	[24]
LDPE (tocopherol 3 mg/g)	Cast-film extrusion	7.20×10^{-14}	This study

the diffusivity in LDPE being highest, followed by LDPE/PP and PP. Temperature has a greater effect on tocopherol diffusion in PP than in LDPE.

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Measurement and Analysis of Vibration and Temperature Levels in Global Refrigerated Intermodal Container Shipments from South to North America along Atlantic Ocean

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ABSTRACT: This paper is one of two papers that will review various previous research and present results from a study conducted on measurement of physical and climatic conditions that occur inside refrigerated ISO inter-modal containers. This first paper covers shipments of packaged and palletized fruit from refrigerated packing houses in South America in refrigerated ISO intermodal containers from Brazil to United States across the Atlantic Ocean. The study measured vibration and temperature levels in a containerized shipment where recorders measured the acceleration levels and temperature data while the instrumented and loaded containers traveled on truck and ship. Measured data shows that extreme vibration levels occur while containers travel on trucks on poor road conditions followed by rail and ship travel. It also shows that good temperature control is possible with loading packages so that good air flow is permissible in the perimeter of the load. Lowest vibration levels and temperature variation occurs when they are loaded on a ship and are traveling on sea.

1.0 INTRODUCTION

1.1 Inter-modal Shipments

INTER-MODAL SHIPMENTS or inter-modal transport involves the shipping and handling of cargo or freight in an intermodal container

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over multiple modes including truck, rail and ship without the individual handling of any freight when changing the shipping modes. It therefore reduces cargo handling, and so improves security. Also due to reduced handling, it reduces damages and losses, and shipment time. Shipments from ports in China to ports in Europe can cross through sealed intermodal containers across North America on truck and rail providing reduces shipping times and costs, and preventing additional handling and therefore reducing risk of loss and damage.

A recent paper published by the authors covered the development and history of the first containers used to move packaged goods [1]. The advent of the container was to reduce time in loading ships at ports in shorter times, thereby improving global trade. The first account in the world for moving freight in metal containers on a ship was witnessed on April 26th, 1956, in the United States of America. Levinson [2] has described how this marked the beginning of an enterprising business venture in the shipping industry, reducing loading and unloading times. In the following decades this industry developed to an extent where consumers now have access to products manufactured or produced several thousand miles across both land and sea. In a recent study [1] shipments of dry goods using intermodal containers travelling on trucks, rail and ships from remote regions in India to major ports and distribution centers on both the east and west coasts of the United States have been discussed. The data collected in this previous study on dry ISO intermodal containers, where no temperature control inside the container is maintained is discussed in this paper and compared to refrigerated containers. Intermodal transportation goes back to the 18th century and predates the railways. In the United Kingdom, containers were first standardized by the railroads in the 1920's, allowing both railway and privately owned vehicles to be carried on standard container flats that were small, being 1.5 or 3.0 meters long (5 or 10 ft), and mostly made of wood. Wood pallets made their first major appearance during World War II when the United States military assembled freight on pallets, allowing fast transfer between factories and warehouses, to trucks, trains, and ships. Because of no freight handling at each change in shipping mode, fewer personnel were required and loading times were decreased. The U.S. Department of Defense introduced the first introduced standardized metal intermodal containers in 1968, which were then adopted by the International Organization for Standardization (ISO).

According to the European Commission Transportation Department, it has been estimated that up to 25% of accidents involving trucks can be attributable to inadequate cargo securing [15]. Freight or cargo that is improperly secured can cause severe accidents and lead to the loss of cargo, the loss of lives, the loss of vehicles, ships and airplane; not to mention the environmental hazards it can cause from hazardous material spills and fires. There are many different ways and materials available to stabilize and secure cargo in containers used in the various modes of transportation. Conventional methods and materials such as steel banding and wood blocking and bracing have been around for the past century, and are still widely used. In the last few years the use of several, relatively new, and in some cases safer methods of load securement have become available through innovation and technological advancement including polyester-strapping and -lashing, synthetic webbings and air bags. Polyester and nylon plastic bands have replaced metal bands for glass shipments [2].

Standardization of intermodal container sizes has enabled vast improvements in port handling procedures. In addition opening of the Suez Canal and Panama Canals in the 20th century helped move products between Asia and Europe, and likewise between Atlantic and Pacific shipping routes. Table 1 [1] shows the standard container sizes based on ISO 1496-1, Series 1, Part 1, standard for general cargo. Nearly 90% of non-bulk cargo worldwide today is transported in metal containers on ships. With the current expansion of the Panama canal and the engagement of building larger container ships by ship-builders, it is clear that trends of moving products globally on container ships will continue to grow in the 21st century.

Figure 1 shows a typical container ship. Some of the ships can carry over 14,500 TEU's. It has been estimated that 18 million total contain-

Table 2. Standardized ISO Container Sizes [3].

Rank	Length	Width	Height	Volume	TEU
1	20 ft (6.1 m)	8 ft (2.4 m)	8.5 ft (2.6 m)	1,360 cu ft (39 m^3)	1
2	40 ft (12 m)	8 ft (2.4 m)	8.5 ft (2.6 m)	2,720 cu ft (77 m^3)	2
3	45 ft (14 m)	8 ft (2.4 m)	8.5 ft (2.6 m)	3,060 cu ft (87 m^3)	2 or 2.25
4	48 ft (15 m)	8 ft (2.4 m)	8.5 ft (2.6 m)	3,264 cu ft (92.4 m^3)	2.4
5	53 ft (16 m)	8 ft (2.4 m)	8.5 ft (2.6 m)	3,604 cu ft (102.1 m^3)	2.65
High Cube					
6	20 ft (6.1 m)	8 ft (2.4 m)	9.5 ft (2.9 m)	1,520 cu ft (43 m^3)	1
Half Height					
7	20 ft (6.1 m)	8 ft (2.4 m)	4.25 ft (1.30 m)	680 cu ft (19 m^3)	20 ft (6.1 m)

Figure 1. Container Ship.

ers make over 200 million trips per year. In the past six decades, metal containers have contributed towards the expansion of globalized trade.

Table 2 describes the busiest container cargo ports in different regions in Asia, Europe and North America, and the container volume they handle for the period 2004–2010. Contaimner volume is measured in Twenty-foot Equivalent Unit (TEU) i.e. a 20-foot (6.1 m) long ship-

Table 2. ISO Container Traffic from Top 50 International Ports (in thousands TEU).

Rank	Port	Country	2010	2009	2008	2007	2006	2005	2004
1	Shanghai	PR China	29,069	25,002	27,980	26,150	21,710	18,084	14,557
2	Singapore	Singapore	28,431	25,866	29,918	27,932	24,792	23,192	21,329
3	Hong Kong	PR China	23,699	20,983	24,248	23,881	23,539	22,427	21,984
4	Shenzhen	PR China	22,510	18,250	21,414	21,099	18,469	16,197	13,615
5	Busan	South Korea	14,194	11,954	13,425	13,270	12,039	11,843	11,430
6	Ningbo	PR China	13,144	10,502	11,226	9,349	7,068	5,208	4,006
7	Guangzhou	PR China	12,550	11,190	11,001	9,200	6,600	4,685	3,308
8	Qingdao	PR China	12,012	10,260	10,320	9,462	7,702	6,307	5,140
9	Dubai	UAE	11,600	11,124	11,827	10,653	8,923	7,619	6,429
10	Rotterdam	Netherlands	11,140	9,743	10,784	10,791	9,655	9,287	8,281
11	Tianjin	PR China	10,080	8,700	8,500	7,103	5,950	4,801	3,814
12	Kaohsiung	Taiwan	9,180	8,581	9,677	10,257	9,775	9,471	9,714
13	Port Klang	Malaysia	8,870	7,309	7,970	7,120	6,326	5,544	5,244
14	Antwerp	Belgium	8,470	7,309	8,663	8,176	7,019	6,482	6,064
15	Hamburg	Germany	7,910	7,007	9,737	9,890	8,862	8,088	7,003

(continued)

Table 2 (continued). ISO Container Traffic from Top 50 International Ports (in thousands TEU).

Rank	Port	Country	2010	2009	2008	2007	2006	2005	2004
16	Tanjung Pelepas	Malaysia	6,540	6,000	5,600	5,500	4,770	4,177	4,020
17	Los Angeles	USA	6,500	6,748	7,850	8,355	8,470	7,485	7,321
18	Long Beach	USA	6,260	5,067	6,350	7,316	7,289	6,710	5,780
19	Xiamen	PR China	5,820	4,680	5,035	4,627	4,019	3,342	2,872
20	New York/ New Jersey	USA	5,290	4,561	5,265	5,299	5,093	4,785	4,478
21	Dalian	PR China	5,260	4,552	4,503	4,574	3,212	2,665	2,211
22	Laem Chabang	Thailand	5,190	4,538	5,134	4,642	4,123	3,834	3,529
23	Bremen/ Bremerhaven	Germany	4,890	4,578	5,529	4,912	4,450	3,736	3,469
24	Jakarta	Indonesia	4,720	3,800	3,984	3,900	3,280	3,282	3,170
25	Tokyo	Japan	4,280	3,810	4,271	3,818	3,969	3,593	3,358
26	JNPT (India)	India	4,280	4,061	3,953	4,060	3,298	2,667	2,361
27	Valencia	Spain	4,210	3,653	3,593	3,043	2,612	2,410	2,145
28	Ho Chi Minh City (Saigon)	Vietnam	4,110	3,563	3,100	2,532	2,532	2,122	1,868
29	Colombo	Sri Lanka	4,080	3,464	3,687	3,380	3,079	2,455	2,221
30	Lianyungang	PR China	3,870	3,021	3,001	2,001	1,302	1,005	—
31	Jeddah	Saudi Arabia	3,830	3,091	3,326	3,068	2,964	2,836	2,426
32	Salalah	Oman	3,490	3,490	3,068	2,600	2,390	2,492	2,229
33	Port Said	Egypt	3,480	3,300	3,202	2,127	2,127	1,522	869
34	Yingkou	PR China	3,340	2,537	2,030	1,371	838	634	—
35	Felixstowe	UK	3,300	3,100	3,200	3,300	3,000	2,700	2,717
36	Yokohama	Japan	3,260	2,555	3,490	3,400	3,200	2,873	2,718
37	Manila	Philippines	3,250	2,815	2,977	2,800	2,638	2,625	2,698
38	Surabaya	Indonesia	3,040	1,140	—	—	—	—	—
39	Khor Fakkan	UAE	3,020	2,750	2,112	1,850	1,730	1,929	1,819
40	Gioia Tauro	Italy	2,850	2,857	3,468	3,445	2,900	3,161	3,261
41	Savannah	USA	2,830	2,356	2,616	2,604	2,160	1,902	1,662
42	Algeciras	Spain	2,810	3,042	3,324	3,152	3,257	3,180	2,937
43	Balboa	Panama	2,760	2,012	2,011	2,167	988	663	—
44	Santos	Brazil	2,720	2,252	2,675	2,533	2,208	2,240	1,883
45	Bandar-Abbas	Iran	2,590	2,206	2,000	1,723	1,408	1,293	—
46	Durban	South Africa	2,550	2,110	2,560	2,511	2,334	1,955	1,717
47	Nagoya	Japan	2,550	2,113	2,817	2,890	2,740	2,470	2,304
48	Ambarli (Istanbul)	Turkey	2,540	1,835	2,262	1,940	1,446	1,186	—
49	Kobe	Japan	2,540	2,247	2,432	2,432	2,413	2,250	2,177
50	Vancouver	Canada	2,510	2,152	2,492	2,307	2,208	1,767	1,665

Table 3. TopTwenty Container Shipping Companies in Order of TEU Capacity in 2011.

Company	TEU Capacity	Number of Ships
A.P. Moller-Maersk Group	2,150,888	545
Mediterranean Shipping Company	1,638,962	414
CMA CGM	1,100,007	384
American President Lines	589,879	147
Evergreen Marine Corporation	554,725	152
Hapag-Lloyd	541,811	124
COSCO	498,437	134
CSAV	469,428	128
Hanjin Shipping	448,051	98
China Shipping Container Lines	440,236	122
NYK Line	365,034	95
Mitsui O.S.K. Lines	363,188	94
Orient Overseas Container Line	353,338	77
Hamburg Süd	338,778	109
Zim Integrated Shipping Services	322,685	96
K Line	318,193	82
Yang Ming Marine Transport Corporation	313,379	77
Hyundai Merchant Marine	271,604	52
Pacific International Lines	227,649	126
UASC	199,082	50

ping container. Thus a 40-foot (12.2 m) container is 2 TEU. Shanghai is now the busiest port in terms of total TEU volume handled. Table 2 describes the actual TEU (in thousands) transported through the various seaports. The busiest ports used to be Rotterdam (based on container volume) and Singapore (number of ships processed), but since 2005 it has been Shanghai both in tonnage and total number of ships handled.

It has been often conceptualized by packaging engineers that temperature and humidity extremes occur during shipment at sea in long voyages that may cross the equator to tropics. Also there are few previous studies that have monitored both the physical and climatic effects that occur to the cargo and inside space of containers that undergo various inter-modal forms of transportation. The physical handling of containers during transfer from ship to train or truck has also been overlooked. Singh et-al [9] monitored ships carrying cargo in break-bulk holds, palletized and unitized form, and full containers from various ports in Central America (Panama and Honduras) to North America and Europe. These refrigerated shipments contained boxed cargo containing harvested bananas. Results showed that containerization significantly reduces both physical and climatic abuse to highly sensitive fresh produce such as bananas, as compared to break-bulk and palletized boxes loaded into a vessel.

2.0 MATERIALS AND METHODS

2.1 Instrumentation and Set-Up Parameters

Two different types of data recorders were used for measuring climatic changes related to temperature and physical movement due to vibration in terms of acceleration levels. For measuring temperature, the equipment used was ESCORT Mini manufactured by Escort data logging systems (Auckland, New Zealand). One temperature recorder was mounted near the ceiling of the cargo hold on the front end of the ISO container (Figures 3 and 4). The highest change in air temperature inside a container occurs in the upper region of the container headspace where radiation effects and convection effects are most prominent during container stationary or travel conditions.

The shipment that was monitored consisted of fresh mangos that

Figure 2. *Refrigerated Container Monitored on Flat Bed Trailer in Brazil.*

Figure 3. *Mounting Temperature Recorder Inside Container.*

Figure 4. *TempTale® 4 Temperature Data Recorder.*

were harvested and packed in corrugated trays in Petrolina, Brazil. The fresh mangos are graded and sorted based on size and quality of fruit, and then they go through a grading process that allows for them to be uniformly packaged in similar groups onto wooden pallets. Figures 4–10 show the grading, sorting, packaging, palletizing and pre-cooling processes. The packaged trays are then palletized onto wood pallets, and unitized using corner posts and plastic straps that are tensioned horizontally to prevent side-side shifting and load stability. The pre-cooled palletized fruit was then transferred into the instrumented ISO refrigerated container shown in Figure 2.

The recording parameters for measuring temperature were as follows:

- Trip Duration: 30 days
- Interval between each reading: 2 minutes
- Measurement Range: –30°C to 70°C

For measuring vibration and transient shock levels describing the physical environment, the equipment used was a SAVER 3X90 manufactured by Lansmont Corporation (Monterey, CA, USA). This recorder has a tri-axial accelerometer to measure the vibration levels for vertical,

Figure 5. *Cleaned Mangos are Graded and Sent Down Different Packing Lines.*

***Figure 6.** Erected Trays and Packing of Mangos.*

***Figure 7.** Packing of Sorted and Graded Mangos in Trays.*

Figure 8. *A tray of freshly packaged mangos in 9 count configuration.*

Figure 9. *A wood pallet with corner posts being loaded with filled trays.*

Figure 10. *Cooled and palletized mangos in refrigerated storage.*

lateral and longitudinal movements. These were mounted at the center of the floor in the front position of the containers as shown in Figure 11 to prevent minimum obstruction to loading and unloading of palletized fruit in and out of the container.

The recording parameters were as follows:

- Timer-triggered event interval: 6 minutes
- Timer Event size: 1.024 sec
- Signal-triggered event threshold level: 0.5G
- Signal event size: 1.024
- Pre-trigger data: 50%
- Post trigger: 50%

After the vibration recorder was mounted on the floor and the temperature recorder was mounted on the top of the container, it was loaded with palletized loads of fresh mangos. These loaded trailers are then closed and the shipment moves by truck to the major port. In the case of this study, the ISO refrigerated container left the Agrobras packing house facility, in Petrolina, Brazil on October 10th October, 2011, to the port of Pecem in Brazil by truck, an approximate distance of 676

Figure 11. *Vibration Recorder (SAVER®).*

Figure 12. *Palletized Loads in Cooling Rooms Prior to Loading.*

Figure 13. *Refrigerated Container Being Instrumented Prior to Shipment.*

kilometers. Shown in Figure 11 are the palletized loads of fresh mangos in corrugated trays that are in forced air cooling tunnels. Figure 12 shows the inside of the Hamburg Sud refrigerated container that has been cooled, and is in the process of being instrumented with recorders for temperature and vibration.

2.2 Travel Routes and Handling Transport Equipment

The shipments were instrumented and monitored for shock, vibration, and temperature changes. These shipments originated from Petrolina, Brazil from a large packing house for fresh mangos for export to the United States on 10th October, 2011. The container was loaded on flat-bed trailers as shown in Figure 2. The trucks with the instrumented container, and other filled containers then travelled on road to the city of Pecem, Fortaleza, Brazil, a major export port in Brazil. All these were then transferred to the ship and then sailed from Brazil to United States along the Atlantic Ocean on 15th October, 2011. The ship arrived in US waters on October 27th, 2011 at the port of Philadelphia. Subsequent to FDA inspection the ISO container was then transferred to another flat bed trailer in Philadelphia, United States and shipped to the Bifulcos distribution center in Pittsgrove, New Jersey. The fruit was received on November 1st, 2011, and then the recorders with the saved data were retrieved for data analysis.

3.0 DATA AND RESULTS

The first set of data discussed is temperature changes inside the containers in various locations when the containers were both stationary and transporting on truck and ship. Figure 14 shows the temperature distribution and variation inside the refrigerated container through the whole journey before the container was loaded at origin and after all the pallets were removed. The maximum variation is approximately 5°C inside the top portion of the container.

Data representing the various physical events measured by the accelerometers as changes in acceleration were also analyzed. Figures 15 shows acceleration levels (Grms) of all dynamic events recorded in the nose end of the same container for shipments from Brazil to United States. The inter-modal shipment consisted of surface travel using truck in Brazil till the container arrived at the port in Brazil. The container was handled with automatic cranes and transferred onto a ship bound for United States that arrived in Philadelphia, PA. They

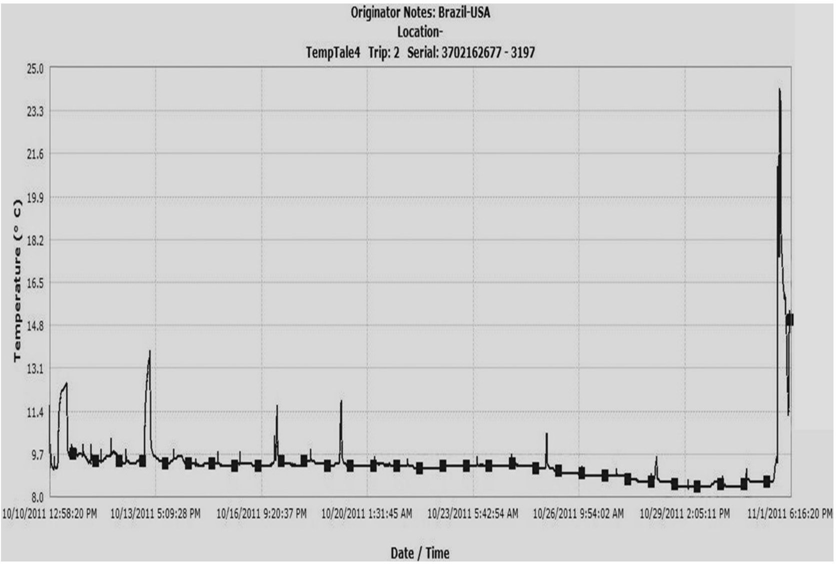

Figure 14. *Temperature data from ISO container originating in Petrolina, Brazil to destination Philadelphia, USA.*

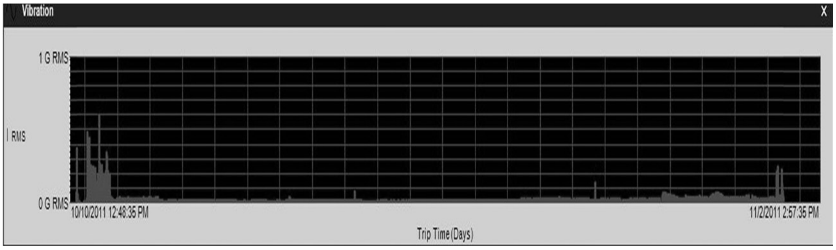

Figure 15. *Vibration Data Profile Inside Refrigerated Container from Brazil to United States (October 10, 2011 to November 2, 2011).*

were then transferred to truck flat-bed to be brought to an international import distribution center in New Jersey. The results show that the highest dynamic (physical) events occur when the containers are moved on land using truck. Travel over sea on a ship produces the lowest dynamic events.

The data was further analyzed in the form of Power Density Spectrums for all three orientations (vertical, lateral and longitudinal). The data is presented in the form of vibration spectrums developed for the whole trip based as a composite 'average'. The data in Figure 16 shows

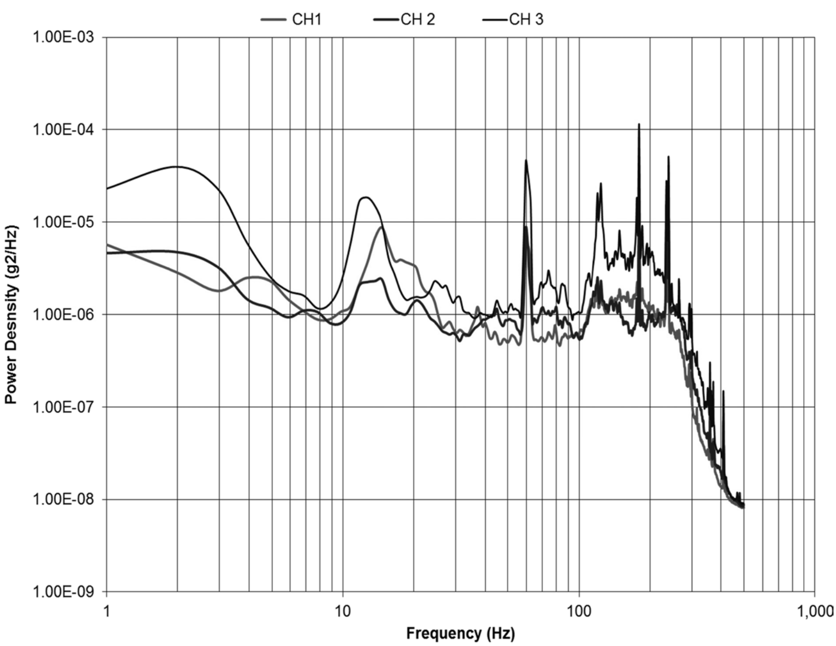

Figure 16. *Composite power spectral density* from channel 1 (longitudinal), 2 (lateral) and 3 (vertical).*

the composite average spectrums for the entire trip in vertical, lateral and longitudinal direction of travel of the ship and truck.

In comparison the average spectrums in vertical transport are lower than those measured in surface transport in North America and India. This is probably because of averaging of the data with low levels of vibration input during the prolonged sea travel.

CONCLUSIONS

1. The highest variation of temperature levels recorded in this study inside *refrigerated* containers in the month of October 2011, and with excess of 5000 km travel on truck and ship from South to North America was 5°C.
2. The highest temperatures inside closed containers occur when they are stationary and on land, not at sea.
3. The highest vertical dynamic levels in an intermodal shipment consisting of ship, rail and truck occur due to truck at the start and the end of the journey.
4. There can be a large variation in temperature inside the container based on the angle of the sun, and location inside. The top of the container and side facing the sun usually have the highest temperature levels during the day. However the quality of insulation used in the manufacture of the ISO container, the type and capability of the refrigeration unit, and air flow will provide a more uniform temperature control inside the container for temperature sensitive products.

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Concise Review: Irradiation of Food Packaging Materials

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ABSTRACT: Irradiation is widely known to be an effective means of sanitizing products. It has been approved as a non-toxic and efficient non-thermal method after years study since World War II. The United States Food and Drug Administration (FDA) regulates food irradiation applications and food materials such as packaging. Foods are usually prepackaging before irradiation to prevent recontamination. A list of approved packaging materials is provided in in 21 CFR 179.45. As the number of packaging materials and structure options grow, research needs to keep pace in order to obtain approvals to permit use of these new materials and structures. Additionally, packaging polymers contain a variety of additives that are typically a proprietary aspect of their production. These additives protect polymers from oxidation, ultra-violet light, reduce surface friction and other functions. Different additives alone and in combination must also be evaluated to determine their safety with regard to food irradiation. Relatively little work has been done on the evaluation of packaging film additives for irradiation applications. This review is meant to summarize the most relevant work to date.

1. FOOD PACKAGING—FOOD CONTACT MATERIALS

FOOD packaging materials constitute a significant portion of materials regarded a food contact material. Food contact materials require regulatory approval in order to protect consumers from compounds inadvertently released from food contact materials into foods. The United States Food and Drug Administration has developed a lexicon for describing the issue. Section 409 of the FD&C Act defines a Food Contact Substance as any substance that is intended for use as a component of materials used in manufacturing, packing, packaging, transporting or holding food if the substance is not intended to deliver a technical benefit or effect to the food.

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A FCS may be added to a Food Contact Material (FCM) and a FCM may be used to fabricate a Food Contact Article (FCA). The FCS, which may be reviewed for approval through submission of Food Contact Notification submission to FDA, is typically a single compound. For plastic food packaging, the substance in question may be a monomer or an additive to the polymer such as an antioxidant compound that is required to protect the polymer during processing and fabrication into an FCA. A FCM may contain multiple FCS's. The FCA is the finished item or package, which might be a film or bottle.

Recent trends suggest that use of plastic packaging materials has been increasing dramatically and this trend should be expected to continue into the future [1]. Some of the most commonly used food packaging plastics include the polyolefins, which includes the polyethylenes (low density, linear low density, high density, metallocene, etc.), and polypropylene, polyethylene terephthalate (PET), polystyrene (PS) and several types of nylon.

With additives, properties of polymers may be modified for protection and enhancement. Different additives help to control or enhance specific performance characteristics of polymers. In most food packaging applications, polymer additives play an indispensable role, and the incorporation of those additives such as antioxidants, stabilizers and plasticizers is necessary. For example, antioxidants suppress polymer degradation from oxidation reactions. The polyolefins typically require anti-oxidant additives to protect the polymer from oxidation during production processes. PET is more thermally stable and therefore requires little or no antioxidants [2]. UV stabilizers are added to inhibit or absorb harmful UV radiation that degrades polymers. Anti-blocking agents minimize adhesion between films such as PE and PP, which are very likely stick together without the additives. Plasticizers improve flexibility to obtain flexible films, containers and snap-on lids. Slip additives reduce friction between film surfaces to improve handling, particularly through automated machines. Antistatic additives prevent problems caused by static electricity.

Zweifel (2009) described a period of robust polymer additive chemistry development between 1975 and 1985, which opened doors to new applications, lower cost and better performance [2]. According to Zweifel, combinations of hindered phenolics (primary antioxidants) and posphites (secondary antioxidants) as antioxidants are widely used in polyolefins. For polyolefins, the most commonly used primary antioxidants are AO-1 (Irganox E 201), AO-2, AO-3 (Irganox 1076), AO-18 (Irganox 1010). The most commonly used secondary antioxidants is PS-2 (Irgafos 168). The most important UV stabilizer are 2-hydroxybenzophenones, 2-hydroxyphenyl-benzotriazoles, organic nickel compounds, and hindered Amine Light Stabilizer (HALS). HALS-2, HALS-3 and HAL3-14 have been approved by FDA for use in food contact materials [2].

2. IRRADIATION

2.1 Background

Irradiation of Food

Ionizing radiation is well known to be extraordinarily effective in damaging molecules required for biological processes. It is this quality of ionizing radiation that makes it attractive for use in sanitizing foods. Unlike heat, which induces so much chemistry that heat treated foods have significantly changed quality attributes such as color and texture, irradiation is capable of destroying microorganisms and spores with minimal chemistry induced collateral damage to the food. In a similar fashion, irradiation is capable of selectively inactivating faster growing cells in produce that are responsible for their maturation and demise, thus extending the shelf life of items such as fresh mangoes and inhibiting sprout formation in potatoes [3].

Food irradiation is possibly the most extensively studied food preservation process in history. Some of the first documented studies on irradiation for food preservation date to World War II [4]. The first regulation for the use of gamma radiation for food processing was published by FDA on February 1963 [5]. Additional regulations broadened irradiation sources to include 10MeV electron beam and 5 MeV x-ray were published [4]. In 1979, FDA established an irradiation foods committee known as the Bureau of Foods Irradiated Food Committee. This committee supported irradiation as a safe and effective food process [6]. Food irradiation has gained support from governments of 42 countries [3] as well as many international medical, scientific and public health institutions [7]. It is mostly used for sanitization of spices and seasonings. Foods currently permitted to be irradiated in the USA are listed in Table 1 [8]. FDA approvals are a first step. Adoption by the food industry is required to significantly reduce preventable food borne illness and death. It was recently reported that there were 1,270 foodboren disease

Table 1. Foods Permitted to be Irradiated Under FDA Regulations [8].

Dose Level	Purpose	Applied Products
Low dose (up to 1 kGy)	Kill Trichinella spiralis	Pork
	Slow ripening	Fresh foods
	Kill Arthropod	Foods
Medium dose (1–10 kGy)	Microbial disinfection	Dry enzyme preparations (10 kGy)
	Pathogen control	Fresh, or refrigerated, or frozen uncooked meat; Seeds for sprouting; Fresh or frozen molluscan shellfish
	Control of salmonella	Eggs
	Control of foodborne pathogens and extension of shelf-life	Fresh iceberg lettuce and spinach
High dose (10 kGy–50 kGy)	Microbial disinfection	Spices and seasonings
	Sterilization	Frozen packaged meat (solely NASA)

outbreaks in United States in 2006, resulting in 27,634 cases and 11 deaths [8].

Irradiation of Food Packaging

Mechanisms of interactions of ionizing radiation with food and packaging materials are known. Radiation sources used for food irradiation are known to be incapable of inducing radioactivity in the food or packaging material. The primary action of the ionizing radiation is to chemically ionize molecules by imparting sufficient energy to outer shell electrons such that they are ejected from the associated atom. Scattered electrons further scatter other electrons until the energy is finally absorbed. Scattered electrons leave behind broken chemical bonds that are chemically active and can either reform bonds or react with other molecules. Ionizing radiation is not unique in its ability to break chemical bonds resulting in chemical changes. Other forms of energy, and most commonly heat energy, causes similar changes, but in much greater proportion as indicated by obvious damaging changes to materials subjected to severe thermal energy treatments. For the purpose of microbial sanitization, ionizing radiation is particularly effective in causing damage to large molecules such as DNA, which are critical to the biological process. Therefore, ionizing radiation is capable of sanitizing materials with relatively much less collateral damage to the base material that it can sometimes be difficult to observe significant changes in physical properties.

Foods are typically irradiated after packaging in order to reduce the possibility of recontamination. Therefore, food contact materials must be compatible with irradiation. At high doses, ionizing radiation is known to darken glass and to make paper packaging materials brittle [6]. Irradiation of halogenated plastics can be problematic due to the variety of additives and plasticizers typically used [10].

In plastics, ionizing radiation is known to often simultaneously induce cross-linking and scission of polymer chains. Cross-linking is often desirable since it may result in improved strength and barrier to migration and permeation [11]. Chain-scission results in shorter chains resulting in reduced physical properties [12]. Short polymer chains and small chemicals either released or created as a result of irradiation may be able to migrate into foods and therefore are considered to be indirect food additives. Therefore, it is important to understanding of the fundamental chemical processes associated with irradiation of packaging materials in order to be able to predict, experimentally measure and to estimate potential toxicity based on worst-case possible concentrations in the daily diet.

Additives

Packaging materials and in particular plastic packaging typically contain chemical additives and proprietary additive blends to impart a variety of properties to the material. Often such additives are necessary to protect the material through the processes required to create, fill and seal the food package. While effects of irradiation on commonly used base polymers have been studied extensively, effects of irradiation on additives alone and within polymers have not been studied as extensively.

FDA published a list of base packaging materials evaluated as safe materials for irradiation [Table 2, 21 CFR 179.45]. In the past, approvals to irradiate packaging materials in contact with food could only be obtained by submission of a food additive petition. In 1999, the food contact notification (CFN) process was established and became another acceptable mechanism to obtain FDA approval. Currently, there are no effective food contact notifications for the irradiation of packaging materials, though a number of recent authorizations have been approved via the Threshold of Regulation (TOR) exemption process described in 21 CFR 170.39. The recent TOR exemptions all involve packaging constructions and proposed use conditions under which the prepackaged food is irradiated in an inert atmosphere and/or frozen and under vacuum conditions where the levels of radiolytic products would be expected to be extremely low [13].

Paquette (2004) reviewed the history of the timeline of approvals of food packaging materials for irradiation. Most of the base polymers occurred in the 1960s, which was prior to commercial development of our modern inventory of packaging film additives. It was also concluded that more data of radiolytic products formed in irradiated packaging materials should be collected with modern analysis methods and dietary exposure calculation methods [14].

Food packaging additives are also susceptible to chemical changes and degradation [12]. Resulting radiolytic products can migrate into food and could affect food quantity and safety. Although antioxidants and/or stabilizers for polymers used as food contact materials are regulated by FDA via 21CFR178.2010, there is a question as to whether additional approvals are required to use polymers approved for irradiation that contain additives that are approved for use in food contact materials, but without specific approval for their use with irradiation.

Table 2. § 179.45 Packaging Materials for Use During the Irradiation of Prepackaged Foods.

21 CFR Citation	Packaging Materials	Max Dose [kGy]
Section 179.45(b)	Nitrocellulose-coated cellophane	10
	Glassine paper	10
	Wax-coated paperboard	10
	Polyolefin film	10
	Kraft paper	0.5
	Polyethylene terephthalate film (basic polymer)	10
	Polystyrene film	10
	Rubber hydrochloride film	10
	Vinylidene chloride-vinyl chloride copolymer film	10
	Nylon 11 [polyamide-11]	10
Section 179.45(c)	Ethylene-vinyl acetate copolymer	30
Section 179.45(d)	Vegetable parchment	60
	Polyethylene film (basic polymer)	60
	Polyethylene terephthalate film	60
	Nylon 6 [polyamide-6]	60
	Vinyl chloride-vinyl acetate copolymer film	60
		60

Allen *et al.* (1988) studied degradation of additives in polymer when irradiated. One study showed that the degradation products of Irgafos 168 have more potential to migrate into food simulating liquids (FSL) than Irgafos 168 itself when irradiated up to 10 kGy [15]. Therefore, besides the base polymer and additive, irradiation-induced decomposition of polymer additives is creating questions about migration of decomposition products into foods.

2.2 Knowledge Gaps

Effect of Irradiation on Polymers and Additives

Bourges *et al.* (1993) reported that 2,4-di-tert.-butyl-phenol (2,4DTBP), {2,6-di-tert.butyl-4-(propen-loic)-2,5-cyclohexadien-l-one)acid (QM, quinone methide), and 3,5-di-tertbutyl-4-hydroxybenzaldehyde (3,5DTBHB) migrated into food stimulating liquid as degradation product of antioxidant (Irganox 1010, Irgafos 168) in PP [16]. Other studies suggested that 2,4DTBP and 1,3-di-tert-butylbenzene (1,3 DTB) are degradation products of antioxidants like Irgafos 168. [17][18][19][20] However, Kawamura (2010) pointed out that 2,4DTBP was also found in non-irradiated samples, suggesting that breakdown of additives is not unique to irradiation. Other compounds might lead to production of 2,4DTBP other than formed by irradiation. Therefore, we need to determine whether other food processes, such as thermal treatments also lead to these breakdown products and if so, whether further study should focus solely on the effects of ionizing radiation [21].

Kawamura (2004) also studied irradiated PS and found it to be more protective of additives than the polyolefins. Even at absorbed doses up to 50 kGy, antioxidants in PS decreased much more slowly than in PE and PP as indicated by the amount of degradation products released [21]. Similar conclusions were offered by Stoffers in the same year. Stoffers found that Irganox 1076 in PS shows little change up to 54 kGy irradiation [20]. While these results are not surprising given the highly conjugated, energy absorbing benzene ring structure that is part of PS, these studies suggest that we should expect different results from different additive packages in different polymers, making it impractical to study every combination of additive and polymer. Reactions between polymers and additives, polymer breakdown products and additives, polymer breakdown products and additive breakdown products, additives and additives, additives with additive breakdown products, additive breakdown products and other additive breakdown products and all of those components and the atmosphere and foods is too complicated to study individually. Therefore, a sensible and comprehensive approach to studying migration from food packaging additives needs to be developed.

Less research has been done on irradiation of UV stabilizers as for antioxidants. Kawamura (2004) studied effects of gamma irradiation on various UV stabilizers (both in bulk form and blended into PE sheets), all stabilizers studied, including Cyasorb UV-24, Seesorb 101, Tinuvin P, Seesorb 202, Cyasorb UV-531, Tinuvin 326, Tinuvin 120, Uvitex OB, Tinuvin 32, Tinuvin 328 were found to migrate into n-heptane from PE sheets [21]. The author mainly focused on additive stability in PE, PS and PP. Information about radiolyic products from UV stabilizers was not provided.

Goulas *et al.* (1996) detected irradiated PVC plasticizer migration. They reported that dioctyladipate (DOA) plasticizer migrated into skin covered chicken than skinless chicken with both irradiated and unirradiated samples. DOA migration was found to be time dependent rather than dose dependent [22]. Subsequent work indicated that plasticized PVC film should not be used for irradiation with high-fat foods [23]. Further work evaluated migration from PVC and P(VDC/VC) film containing di-(2-ethylhexyl)adipate (DEHA) and acetyltributyl citrate (ATBC) treated by irradiation up to. No differences in migration levels were observed between irradiated and non-irradiated samples for doses under 4 and 9 kGy. Relatively low concentrations of migrants were found at higher doses and migration increased with dose with no radiation-induced breakdown products detected [24][25]. All of these studies were based on fatty food stimulants such as olive oil, chicken meat and isooctane, representing worst case scenarios.

Komoplprasert (2007) studied irradiation of PET and Nylon. This work demonstrated the stability of PET during thermal and irradiation treatments. This work showed that irradiation does not generate extractable non-volatiles [13]. Breakdown product and migration of additives in PET and Nylon were not discussed.

An important food packaging material that is not approved for irradiation is polyethylene vinyl alcohol co-polymer (EVOH), which offers excellent oxygen barrier properties. However, EVOH with 32% ethylene content is commonly used for flexible and semi-rigid packaging of shelf-stable ready-to-eat (RTE) foods. Komolprasert (2003) tested EVOH stability upon 5–50 kGy e-beam irradiation, and found that EVOH containing α-methyl styrene dimmer is chemically more stable than EVOH without the additives [26]. Young Jae Byun (2007) also demonstrated that irradiation causes cross-linking in EVOH in greater proportion that scission. Cross-linking decreased free volume and improved properties of EVOH. Several volatile compounds were identified as a result of irradiation of EVOH [27]. Current information shows that EVOH is a promising food packaging material for use with long shelf-life irradiated foods.

Analysis Method

Many detection methods were developed to study the degradation and migration of polymers and additives under the effect of irradiation. Morehouse and Komolprasert (2004) summarized those test methods [12]. Among those techniques, High performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC/MS), Fourier Transformation Infrared Spectroscopy (FTIR) are most effective and well developed.

Calculation Method

For radiolytic products based on polymer, 100% migration would be used to estimate dietary concentrations (DC) as the worst-case evaluation. Estimated Dietary Intake (EDI) can be determined to determine dietary exposure to compounds that migrate into foods [28]. These calculations are demonstrated by Robertson (2006) [29].

2.3 Futures and Goal

Food irradiation has been shown to be safe, effective and economical as it is used routinely on medical products, infant formula nipples, disposable medical products, intravenous tools, surgically implantable items, etc. Commercial irradiation facilities have been operating safely in the United States since 1960's and recent advances in non-radioactive, machine generated radiation sources, such as electron beam and x-ray (bremsstrahlung) are generating renewed interest in food irradiation. There is no question as to whether food irradiation will eliminate pathogens and reduce foodborne illness and health, however, there is a question as to availability of modern packaging materials. Therefore, filling the gap in knowledge related to the fate of food packaging materials additives when subjected to radiation promises to reduce a barrier to the application of irradiation.

Lack of a sensible approach for obtaining broad approvals for packaging materials with a variety of additives represents a critical gap in knowledge that is necessary to permit food irradiation technology to progress. Food packaging material additives represents a dynamic market and it is simply not practical for FDA to expect industry to pursue an additive-by-additive evaluation of migration performance after irradiation. An approach that evaluates categories of compounds for the purpose of seeking more broad irradiation approvals for packaging materials is warranted.

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Table 5. Comparison of state-of-the-art matrix resins with VPSP/BMI copolymers.

Resin System	Core Temp. (DSC peak)	Char Yield, %
Epoxy (MY720)	235	30
C379: H795 = 14	285	53

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