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Aim and Scope

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Effect of Sealing Temperature to Required Sealing Time in Heat Sealing Process of a Paperboard Tray

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ABSTRACT: The importance of modified atmosphere packaging (MAP) is significant in fresh food packaging. By using MAP the shelf life of a food product can be significantly lengthened without using preservatives.

MAP requires a strict tightness to the sealing process of the package. The first step to modified atmosphere packaging is to get the package liquid tight.

Unsuccessful sealing causes leaks in the package and even without MAP requirements can cause inconvenience for the consumer. This paper concentrates on the effect of sealing temperature to required sealing time (dwell time) when the used sealing pressure is constant.

Temperature has a clear effect on the required sealing time. However with different material combinations this temperature varies and the optimization of the sealing temperature with every material combination is crucial when maximum production speeds are wanted.

1. INTRODUCTION

MODIFIED ATMOSPHERE PACKAGING (MAP) is the removal and/or replacement of the atmosphere surrounding the packaged product before sealing in vapor-barrier materials. Packing foods in a modified atmosphere can offer longer shelf life and improved product presentation in a convenient container, making the product more attractive to the customer [1].

Modified atmosphere packaging with carbon dioxide as an active gas component has been widely reported to inhibit microbial growth on fresh food products such as fish or shrimp by Goulas & Kontominas [2],

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Hovda *et al.* [3], Rosnes *et al.* [4] and Laursen *et al.* [5] and also meat products as described by McMillin [6].

Paperboard trays in food packaging are used, but lid heat sealing with paperboard trays has not been widely reported except for some patents [10–12]. This suggests that the research is mainly done in corporation's product development projects.

First step to get the package MAP tight is to get it liquid tight. Liquid tightness also affects the usability of the package in small scale production where cooked meals are manually packed to trays that are sealed with plastic lids. This paper discusses the effect of sealing temperature to required sealing time (dwell time) when the goal is a liquid tight package.

1.1. Heat Sealing

Sealing of the lid is a critical step in modified atmosphere (e.g. MAP) packaging, since the production rate and shelf life can be affected by the sealing process and the quality of the seal. In addition to preventing the package from leaking, the seal must also prohibit air from coming in contact with the food [7].

Sealing conditions are a compromise between dwell time and the temperature and pressure of the sealing tools. The requirement is to apply sufficient energy to cause the sealant to fuse together and become one medium [1].

In the most widely used thermal press type of heat sealing, heat conducted from the surface of the thermoplastic films, the bonded surface is heated to the appropriate temperature, and then it is immediately cooled down to complete the bonding [15].

Heat seal technology is used for packaging pre-heated and sterilized foods, baby and family care products, injectable and oral medicines, snacks, toiletries, and components of electronics and precision machines [15].

Because the process is widely used and the product range is very wide, the suitable machine choice depends on the sealed package and the required production capacity.

Heat sealing machines are almost always used with plastic materials. The use of heat sealing in specific paperboard products has not been widely researched. However fibre based packages are a challenger to plastics in primary food packaging.

Several authors [10–13] have researched different methods to obtain

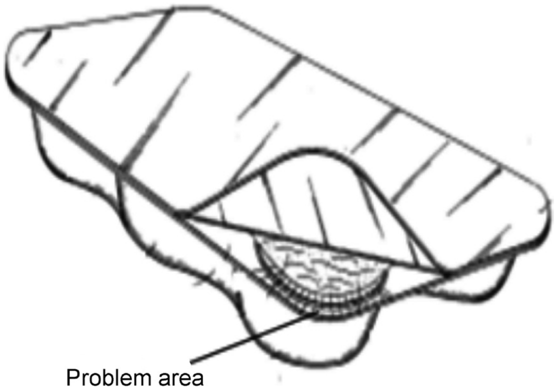

Figure 1. *Problematic area at the tray corner. Modified from [10].*

a tight seal in similar paperboard packages. Some of these solutions are presented next.

1.2. Combined Ultrasonic Bonding and Heat Sealing

Faller [10] presented a possible solution in which arcuately shaped troughs are formed in the face of the flange at each corner of the tray and a plastic cover sheet is filled with food. The cover sheet is first bonded to the tray with ultrasonic bonding. After the ultrasonic bonding heat is applied to the cover sheet to assure complete sealing of the cover sheet to the flange. This solution is presented in Figures 1 and 2.

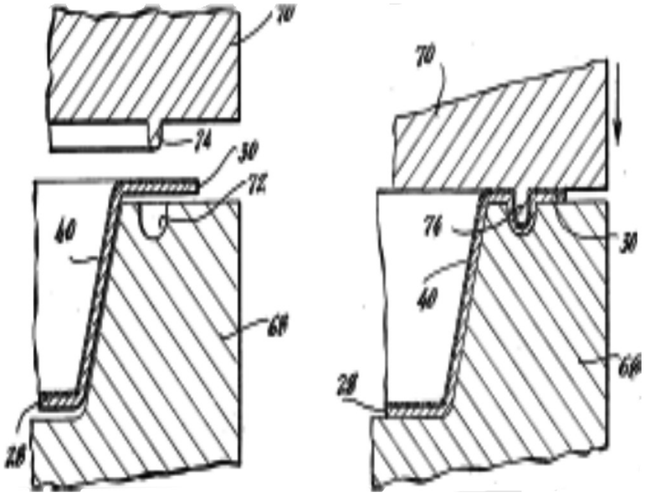

Figure 2. *Close up picture of the sealed area and tool shape [10].*

1.3. Hot Melt or Wax

Seiter *et al.* [11] presented a solution in which a hot melt or wax is applied to the creases in the corners. After this a film cover is adhered to the tray and the hot melt or wax filling should provide a hermetical seal for the interior of the package. This solution is presented in Figure 3.

1.4. Injection Molding

Nylander [12] discusses a technique in which a plastic rim is injection molded to the package. The advantage is that this flat rim should provide a surface in which the lid can be sealed and a gas tight seal should be obtained. Some disadvantages of this technique are the expensiveness of the injection molding tools and machinery, and also the slow speed of the injection molding technology compared to a regular package. A commercial solution of a similar product with injection molded rims is in stores, introduced by Stora Enso [14]. An example of a injection molded rim is presented in Figure 4.

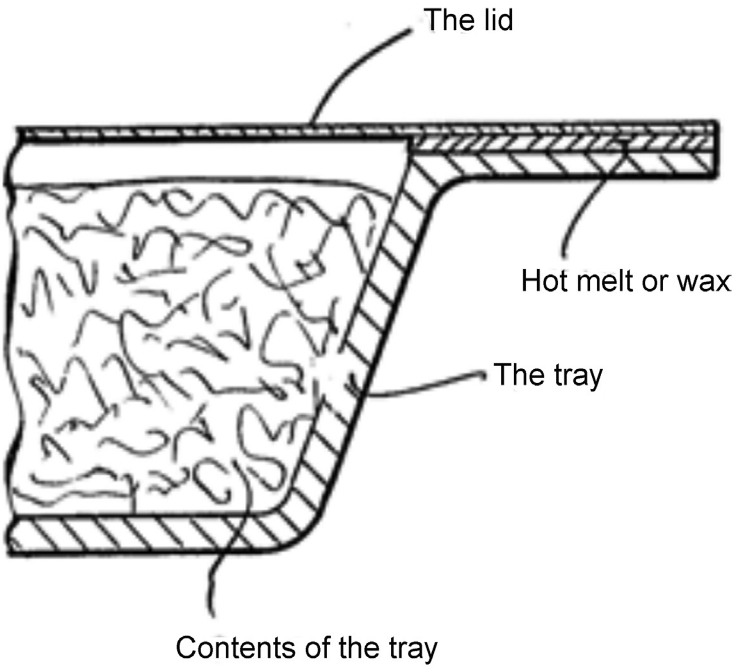

Figure 3. *Hot melt or wax positioning in the corner Modified from [11].*

Figure 4. *An injection molded plastic rim.*

1.5. High Temperature Heating Ridges

Wilkins [13] presents a solution in which the rim area is heated with two heating ridges that come into contact with the underside of the rim. These ridges are heated at a temperature of 500°C. The lid is then lowered to the rim and they are pressed together with a pressure of e.g. 5.5 bar.

According to Wilkins the two adjacent heating ridges provide two adjacent point contacts around the rim of the tray and can conveniently form an air-tight seal with the lid.

The main objective of this study was to research the effect of sealing temperature to required sealing time in the heat sealing process of paperboard tray using constant sealing pressure and to test the liquid tightness of the sealed products. Part of the optimization of the process is to reduce the sealing time as much as possible but still getting a successful sealing. A shorter sealing time is desired because it means faster production in large scale production. In this study the focus was in the sealing temperature and its effect to the sealing time in this process.

Another objective was to examine what kind of methods have been researched to obtain a tight seal in similar kind of paperboard packages. These methods are introduced in Chapter 2.

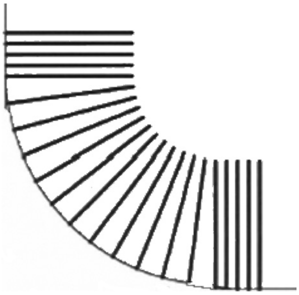

Figure 5. *The shape of the creases in the package corner pictured from above before forming.*

2. MATERIALS AND METHODS

2.1. The Package Format and Materials

The product used in this study was a pressed plastic coated paperboard tray which has creased corners. These creases, which are critical to the package's manufacturing, are clarified in Figures 5, 6 and 7.

It is assumed that the leaks will occur in this area because the creases can form a discontinuity tunnel which causes leaks in the package.

In this work six different tray and lid combinations were tested to research the tightness of the pressed tray. Two base materials were used. Both base materials were paperboard which was coated with plastic. These tested tray and lid combinations and their grammage are presented in Table 1. Trade names of the lids are used in the table.

2.2. Liquid Tightness Tests

Different combinations of tray and lid combinations were tested by

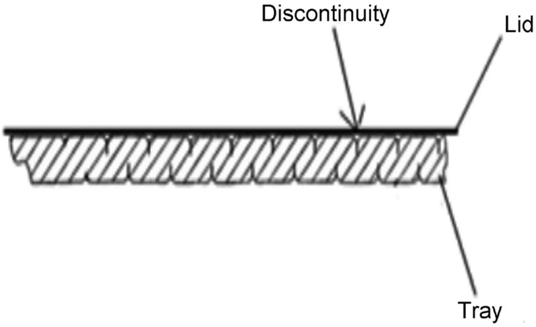

Figure 6. *Shape of the creases (discontinuities) pictured from the side. Modified from [8].*

Table 1. Tray and Lid Combinations.

Tray	Lid	Figure Number
290 g paperboard+40g PET (Package 1)	MSL 65 Bialon (Lid 1)	4
290 g paperboard+40g PET (Package 1)	NFI 208 (Lid 2)	5
290 g paperboard+40g PET (Package 1)	TER EZ-Peel (Lid 3)	6
290 g paperboard+40g PET (Package 1)	TER RC (Lid 4)	7
290 g paperboard+40g PE (Package 2)	NFI 208 PE (Lid 5)	8
290 g paperboard+40g PE (Package 2)	NFI 213 (Lid 6)	9

keeping the sealing pressure at a constant 6 bar which is a standard pneumatic network pressure. The temperature of the upper tool was modified and its effect to the tightness and the required sealing time. A total of six different package and lid combinations were tested. Test tray and lid combinations are presented in Table 1.

At each sealing temperature twenty specimens were sealed and the seals were tested with a colouring solution applying the European standard EN 13676 [9]. The reagents in the colouring solution were dyestuff E131 Blue and Ethanol (C_2H_5OH, 96%). The colour solution consisted of 0.5 g dyestuff in 100 ml ethanol.

The colouring solution was poured into the package and after that the lid was sealed and cooled in room temperature for one minute. After the lid was cooled, the colouring solution was applied to the sealed area for five minutes and the seal was inspected for leaks. An example of a liquid tight seal is presented in Figure 7.

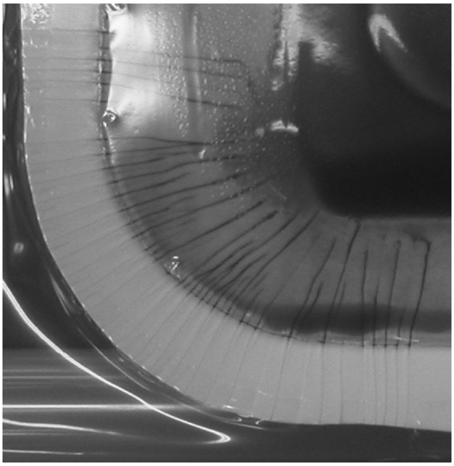

Figure 7. *A liquid tight seal.*

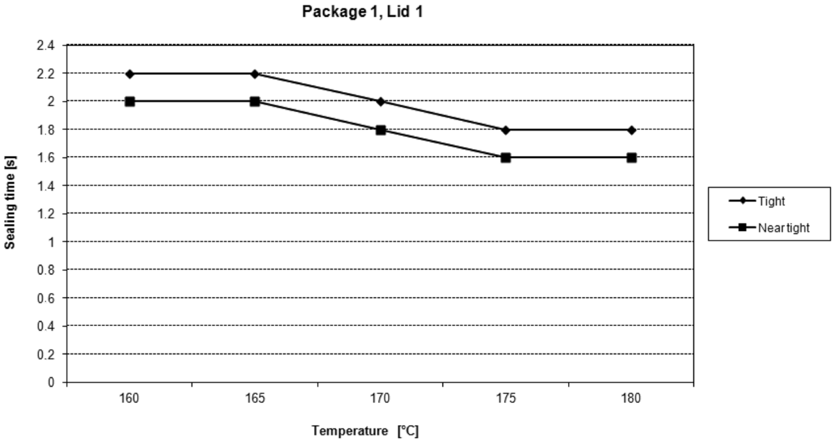

Figure 8. *Effect of temperature to required sealing time for a liquid tight seal with Package 1 and lid 1.*

3. RESULTS AND DISCUSSION

3.1. Liquid Tightness Results

In the liquid tightness tests the value "Tight" was given when all the packages sealed with specific parameters had no leaking seals. The value "Near tight" was given when some of the packages with the parameters were leak proof but some were not. In all package and lid combinations the required sealing time to achieve a liquid tight seal was reduced when the temperature was raised. However with all lid materi-

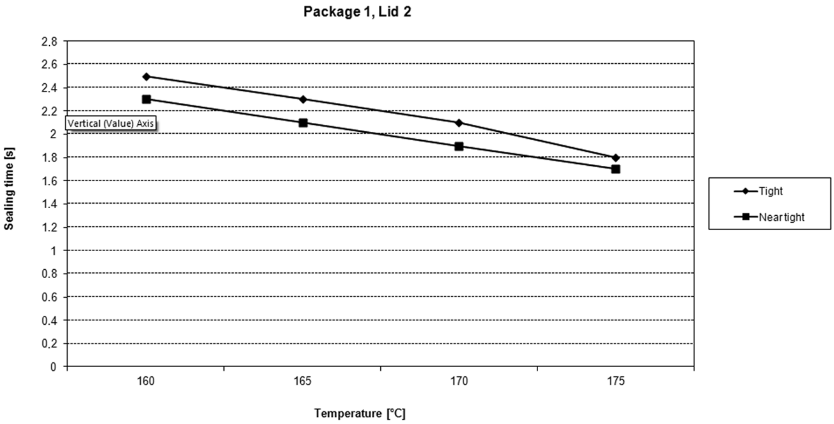

Figure 9. *Effect of temperature to required sealing time for a liquid tight seal with Package 1 and lid 2.*

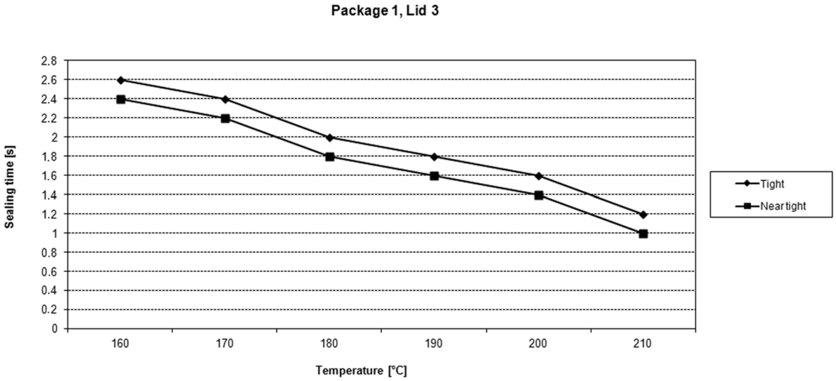

Figure 10. Effect of temperature to required sealing time for a liquid tight seal with Package 1 and lid 3.

als there is a unique temperature point when the lid material fails and is broken by melting. This melting point ranged from 180°C to 215°C depending on the used lid and its material.

Package 1 Liquid Tightness Tests

Package 1 was a tray which's material was PET coated paperboard. It was tested with four different lid combinations which are sealable to PET. Lids 3 and 4 were more heat tolerant than Lids 1 and 2 and the required sealing time was shorter with them. The effect of sealing temperature to reduce the sealing time with Package 1 is visible in Figures 8, 9, 10 and 11.

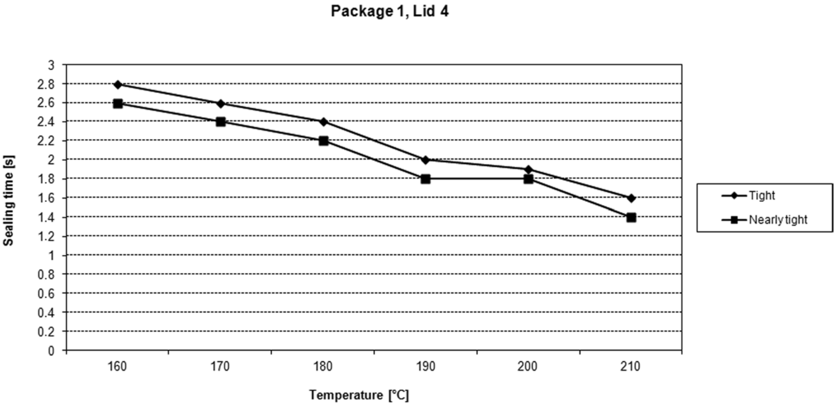

Figure 11. Effect of temperature to required sealing time for a liquid tight seal with Package 1 and lid 4.

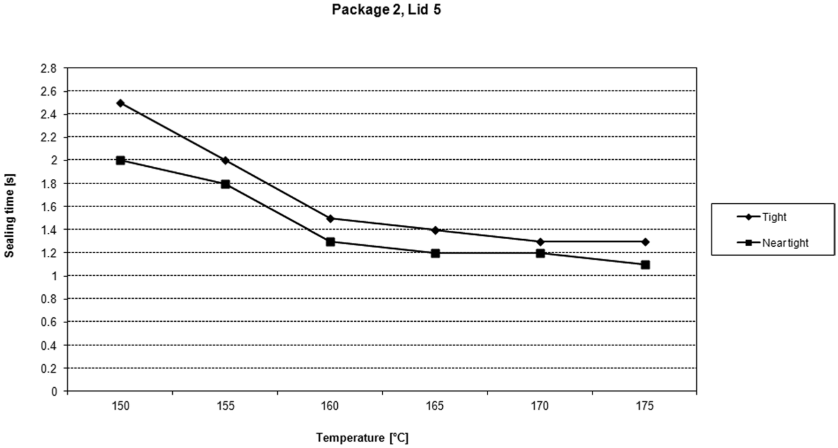

Figure 12. *Effect of temperature to required sealing time for a liquid tight seal with Package 2 and lid 5.*

Package 2 Liquid Tightness Tests

Package 2 was coated which's material was PE coated paperboard. It was tested with two different lid combinations which are sealable to PE. The effect of sealing temperature to reduce the sealing time with Package 2 is visible in Figures 12 and 13.

These creases visible in Figure 14, which are necessary for the pack-

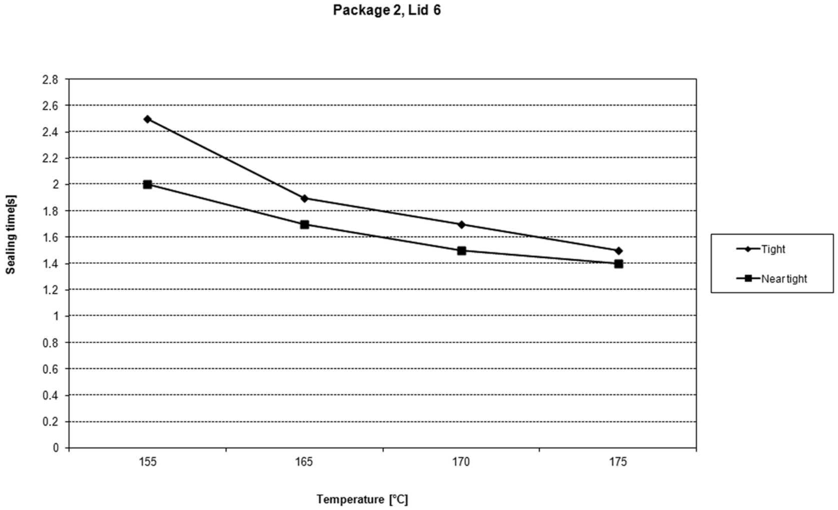

Figure 13. *Effect of temperature to required sealing time for a liquid tight seal with Package 2 and lid 6.*

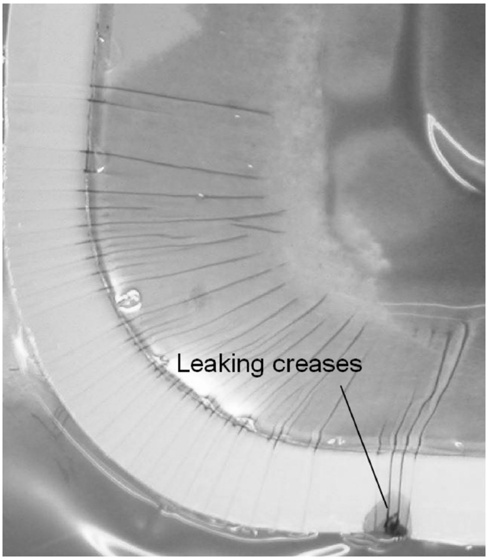

Figure 14. *Problem area of the sealing and two leaking creases highlighted by dye penetrant examination.*

age's manufacturing, cause the seals of the package to leak easily. The critical leaks almost always occur in the last creases of the creased area.

A liquid tight package was achieved with all six lid and package combinations. The best achieved sealing time was 1.2 seconds with the combination Package 1, Lid 3. Sealing temperature has a clear effect on the required sealing time with every material combination.

The most decisive physical factor in the tightness of the package is the creases in the corners. These creases act as a channel which causes the gas to leak from the package.

4. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

It is apparent from all the test combinations that temperature has a clear effect on the required sealing time. However with different material combinations this temperature varies and the optimization of the sealing temperature with every material combination is crucial when maximum production speeds are wanted.

Plastic coated paperboard trays are used in food packaging and liquid tightness of the tray and the sealed lid is acquired. However there are challenges in obtaining a gas tight seal. Several solutions have been presented by different authors but further research is needed to compare and research their performance in production environments.

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Low-cost Move of a Large Superconducting Magnet on a Trailer with Air-ride Suspension

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ABSTRACT: When valuable and delicate scientific equipment is shipped by truck, attention must be paid to vibrations that may cause damage. We present a case study of moving an extremely delicate 6230-kg superconducting magnet, immersed in liquid nitrogen, from Livermore, CA to Seattle, WA, showing the steps of fatigue analysis of the load, a test move, and acceleration monitoring of the final move to ensure a successful, damage-free transport on a budget.

INTRODUCTION

VIBRATION during truck transport may cause damage to delicate goods. Before transporting a unique valuable object, preliminary analysis of the object and vibration tests under the move conditions can provide confidence that the object will not be damaged during shipping. A case study of moving an extremely delicate 6230-kg superconducting magnet along the west coast of the United States follows.

In the summer of 2010, the Axion Dark Matter Experiment (ADMX) was relocated from Lawrence Livermore National Labs (LLNL) in Livermore, California to the Center for Experimental Nuclear Physics

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and Astrophysics (CENPA) at the University of Washington, Seattle. The total driving distance was 1400 km. The experimental apparatus consists of a large cryostat housing a 6230-kg superconducting magnet. The mass of the entire apparatus is approximately 8000 kg. The magnet normally operates at 4.2 K, the boiling point of liquid helium, but was immersed in liquid nitrogen, at 77 K, during the move. The purpose of shipping at this low temperature was to minimize thermal expansion of the interior supporting structure in order to minimize damage to the superconducting magnet coils.

The cryostat is a stainless steel cylinder approximately 4 m tall and 1.6 m in diameter, providing support and insulation for the superconducting magnet [1]. The magnet is suspended inside the cryostat by three narrow steel rods and is restrained from horizontal movement by 4 fiberglass bands attached to the bottom of the magnet [See Figure 1(b)]. A failure of these supports or restraints could result in damage to the main coil, necessitating costly repairs to the magnet.

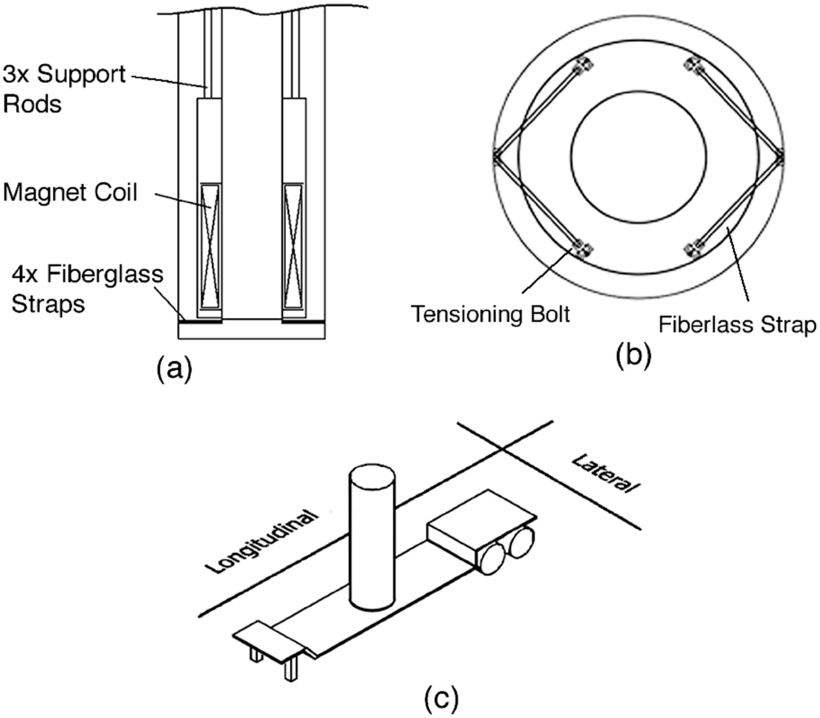

Figure 1. *(a) Diagram of ADMX cryostat. (b) View looking up the cryostat bore, showing the fiberglass straps and tensioning bolts securing the magnet. (c) Diagram showing the orientation of the cryostat and trailer axes.*

To avoid damaging the load, we analyzed primary failure modes [2] and measured the power spectral density (PSD) of the acceleration during a 200 km test run of a flat bed trailer with air ride suspension and a dummy load [Figure 1(c)] [3]. During the actual move we monitored the acceleration PSD of the cryostat to confirm accelerations were within the desired range.

MATERIALS AND METHODS

While as-built drawings for the cryostat were not available, failure modes could be estimated from mechanical reasoning. The primary mechanical resonance of the cryostat is from pendulum motion of the magnet, with the bulk of the restoring force coming from the four fiberglass restraining bands. We model the magnet as a simple harmonic oscillator with mass $m = 6230$ kg and a spring constant $k = 1.7\times107$ N/m provided by the restraining bands. The resonant frequency was calculated to be

$$\nu_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \approx 10 \text{ Hz}$$

Excessive horizontal accelerations at this frequency could have caused catastrophic failure. This mode was insensitive to vertical accelerations [4].

We were most concerned with the failure of the stainless steel bolts that tension the fiberglass straps. This failure could occur for two reasons: a yield failure resulting from a large acceleration that surpassed the tensile strength of the bolts, or a large number of smaller accelerations at the resonant frequency, causing the bolts to work harden and fail from fatigue.

Yield Failure

The tensioning bolts are 1/2″ diameter 316L stainless steel. This alloy has a tensile strength of about 1.2 GPa near the temperature of liquid nitrogen giving a maximum allowable force on the tensioning bolt of 150,000 N [5].

Fatigue Failure

Given the nature of road transport, fatigue failure was our greatest concern. Based on the resonant frequency and an assumption that the trip would require about 40 hours of driving time, we estimated that the magnet would go through approximately 1.5 million cycles. Under these conditions, we estimated the fatigue strength of 316 L stainless steel was approximately 35% of its tensile strength giving a maximum allowable force on the tensioning bolt of $F_{max} = 53{,}000$ N for fatigue failures [6].

The force on the tensioning bolt depends on the resonant frequency of the magnet, ν_0, the Q factor of the cryostat, and the frequency with which the outer cryostat shell is accelerated, ν. The primary damping was due to the air-ride suspension of the trailer with a typical Q factor of 2 [7]. The PSD threshold for the acceleration of the cryostat shell as a function of angular frequency is given by [8]

$$PSD_{Threshold} = \left|F_{max}\right|^2 \left(\frac{(\omega_0^2 - \omega^2)^2 + \left(\frac{\omega_0 \omega}{Q}\right)^2}{k^2 + \left(\frac{m\omega_0\omega}{Q}\right)^2} \right)^2 \tag{1}$$

This threshold represents the maximal magnitude of acceleration that the cryostat can withstand without exceeding the fatigue failure threshold of the tensioning bolts.

Equation (1) shows that the cryostat is most sensitive to accelerations around the resonant frequency of 10 Hz where the fatigue failure threshold drops to 2.6×10^{-3} g^2/Hz, where g is the acceleration due to gravity. The response of the cryostat quickly becomes less sensitive to accelerations at higher frequencies.

The acceleration PSDs of tractor-trailers can vary significantly [7]. To ensure the acceleration threshold would not be exceeded, a test move was designed to measure the accelerations applied directly to the cryostat shell during the transport. A 12-ton forklift (Figure 2) was chosen as a test mass because its center of mass is similar in height to that of the cryostat. The forklift was loaded onto a Double-Drop Air-Ride Low-Boy trailer, and instrumented with an array of accelerometers near its center of mass. The accelerometers measured the vertical, longitudinal and lateral accelerations at a sampling rate of 512 Hz; the data were stored in Omega TSR-101 and OM-CP-SHOCK101 data loggers for later analysis. Accelerations were recorded for a single day of driving under various road conditions.

Figure 2. *A 12-ton forklift used as a substitute mass for the test move.*

While accelerometry packages designed for moving equipment have long since been available [9], the test move indicated that real-time feedback was needed to adjust driving practices, and the system had to conform to the budget allocated for the move. Because of this, A combination of high frequency TSR-101-Transient and lower frequency OM-CP-Ultrashock continuous Omega data loggers were used to acquire and store the acceleration data. A support crew inside the cabin of the trailer monitored a laptop that displayed live acceleration values and kept a running log of notable events. As in the test move, speed and driving style were adjusted dynamically based on information from the lead crew as well as live acceleration readings. The cryostat was moved with the same type of trailer as in the test move, and instrumented in a similar fashion (Figure 3).

RESULTS AND DISCUSSION

Test Move

Figures 4 and 5 show data from a typical section of what was found to be the most promising driving style during the test move. This was achieved by allowing the driver of the pilot car to communicate his assessment of upcoming road conditions with the drivers of the tractor-trailer. Jointly, the drivers dynamically altered their driving speeds based on their experience and expertise. This method yielded the lowest number of dangerous accelerations and minimized the likelihood of damaging the cryostat.

We found that a driving speed of approximately 40 mph was optimal for the move. Speeds much greater than this did not produce a significant increase in the acceleration PSD; however, there was insufficient time for the driver of the trailer to react to warnings of changing road conditions coming from the driver of the lead car. Speeds much less than 40 mph showed no significant reduction in the acceleration PSD.

Figure 5 shows the acceleration PSD for the lateral, longitudinal, and vertical axis, and the threshold failure curve. While a number of high instantaneous acceleration events were recorded, accelerations in the range of the resonant frequency of the cryostat from these transient events were well within the tolerance of the yield failure mode. Fatigue failure, which was a larger concern, was within threshold by a safety factor of ten.

Figure 3. *The cryostat and trailer after arriving at the University of Washington. The smaller diameter cylinder in the foreground housed a non-critical experimental apparatus.*

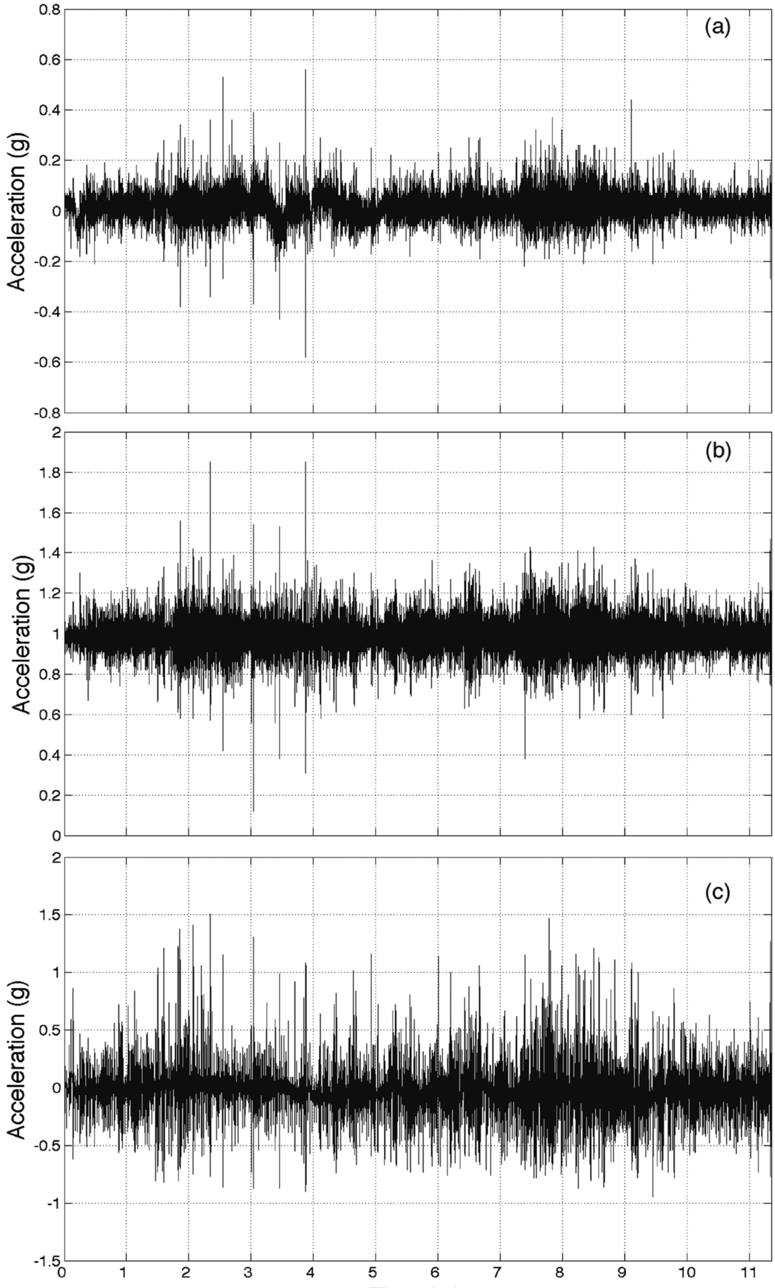

Figure 4. *(Test Move): Time series of (a) lateral (b) vertical and (c) longitudinal axis acceleration for a forklift driven on a tractor-trailer at 40 mph under typical road conditions near Oakland CA.*

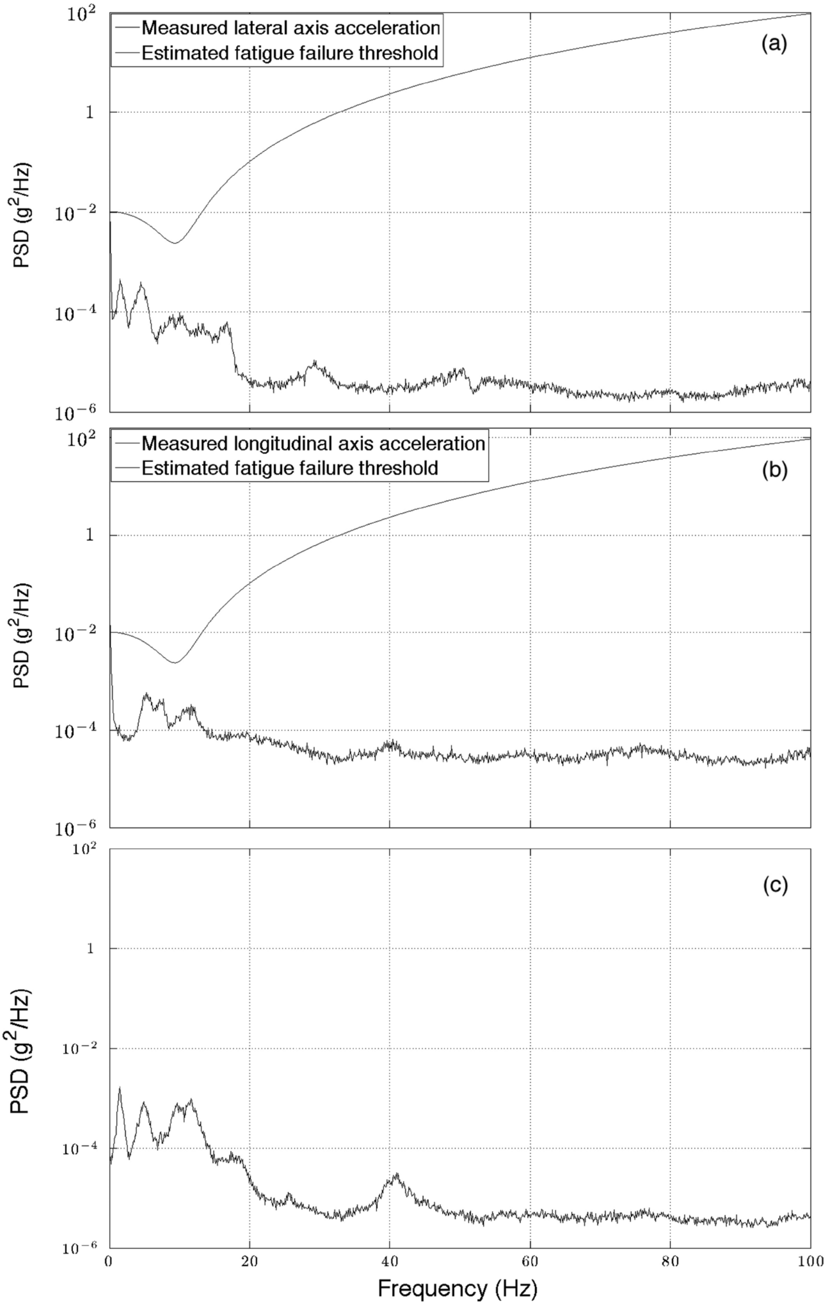

Figure 5. *(Test Move): PSD of (a) lateral, (b) longitudinal and (c) vertical axis acceleration for typical road conditions during test move driven at 40 mph near Oakland CA. Figures (a) and (b) also show the PSD of the acceleration at the fatigue failure threshold.*

Actual Move

Accelerations measured during the move of the cryostat are shown in Figures 6–11. Figure 6 shows annotated time series plots of the lateral and longitudinal axes. Notable events such as potholes, road conditions and times when the trailer was stopped are labeled as observed by the support crew.

Figures 7 and 8 show PSDs of both rough and smooth road conditions from a typical section of data from the move. As in the test move,

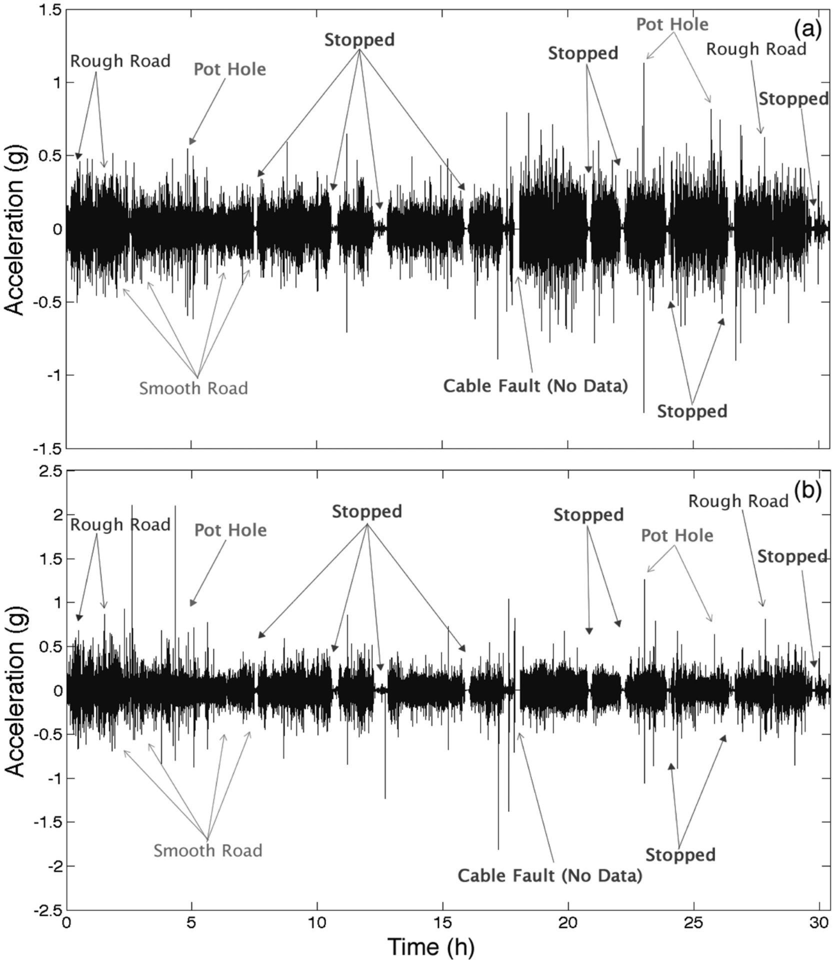

Figure 6. *(Actual Move): Annotated time series plot of (a) lateral and (b) longitudinal acceleration over the move from Livermore CA to Seattle WA.*

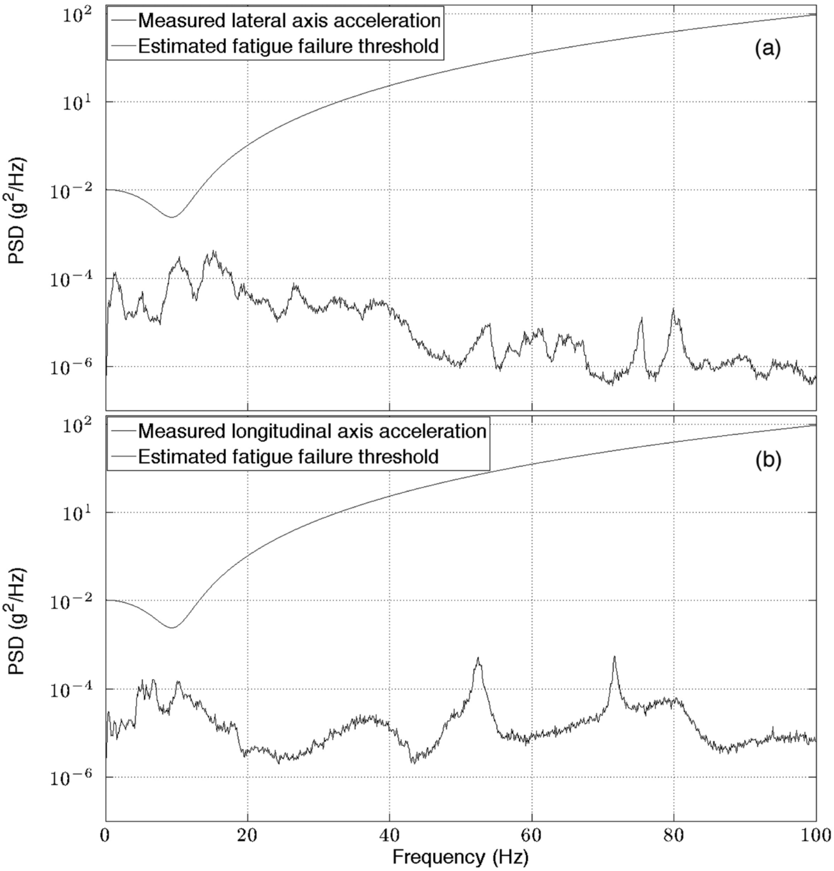

Figure 7. *(Actual Move): PSD of (a) lateral and (b) longitudinal axis acceleration for typical smooth road conditions. Also shown is the PSD of the acceleration at the fatigue failure threshold.*

accelerations in the range of the resonant frequency are well within the tolerances of the yield and fatigue failure modes.

The average power measured at the cryostat during the roughest 10-minute section of road for four coarse-grained frequency ranges (0–1 Hz, 1–10 Hz, 10–100 Hz, and 100–750 Hz) is shown in Figure 9.

To characterize worst-case short-term vibrations from a bump or pothole, 2-second intervals during this 10-minute section were examined. The largest average power in this interval is plotted for each frequency range in Figure 10.

Figures 9 and 10 demonstrate that the large maximum accelerations in the lateral and longitudinal axes shown in Figure 6 are too short-lived or too high frequency to pose a threat to the cryostat.

A comparison of the lateral and longitudinal PSD for smooth and rough road conditions shows a 20% increase in the average amplitude of oscillations on the rough road sections (Figure 11). The oscillation amplitude on a rough road (as perceived by the support crew) is greater than that of the smooth road only at frequencies above about 30 Hz.

CONCLUSION

The cryostat arrived safely at the University of Washington after 30

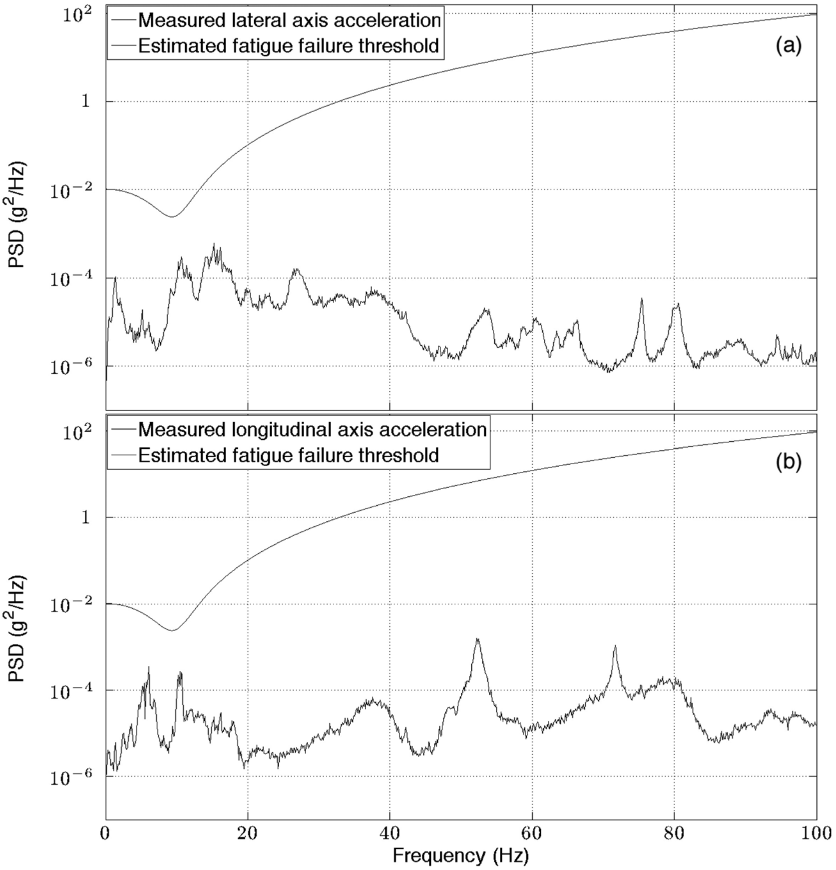

Figure 8. *(Actual Move): PSD of (a) lateral and (b) longitudinal axis acceleration for typical rough road conditions. Also shown is the PSD of the acceleration at the fatigue failure threshold.*

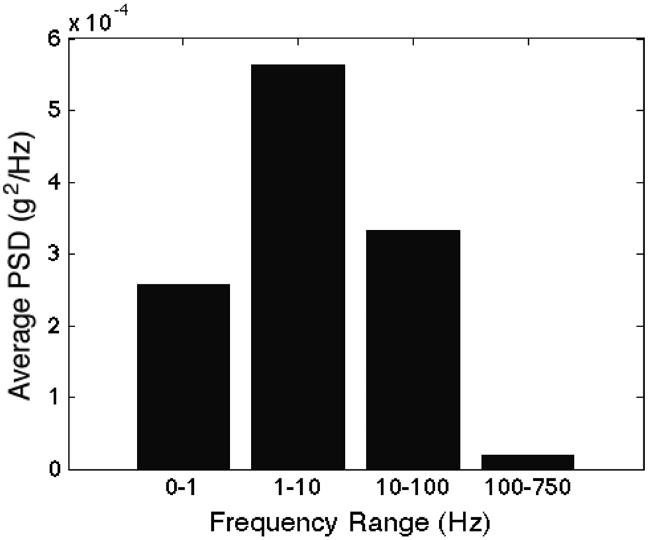

Figure 9. *(Actual Move): Average PSD measured on the cryostat in a given frequency range during the roughest 10 minute section of road.*

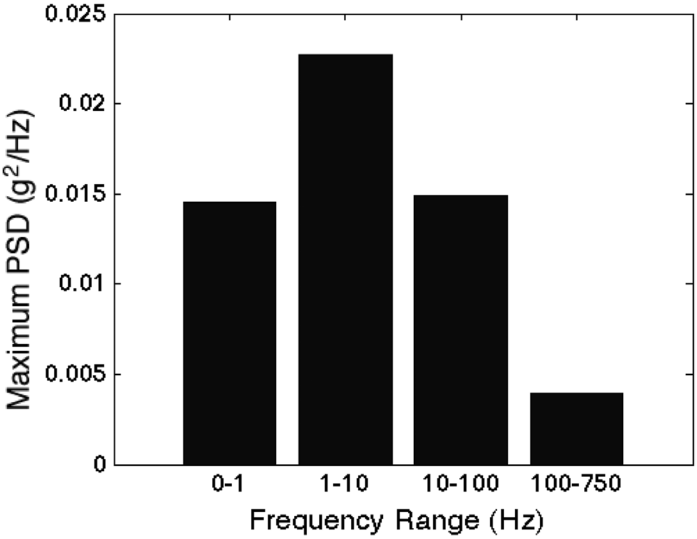

Figure 10. *(Actual Move): Maximum PSD measured over a 2-second interval on the cryostat in a given frequency range during the roughest 10 minute section of road.*

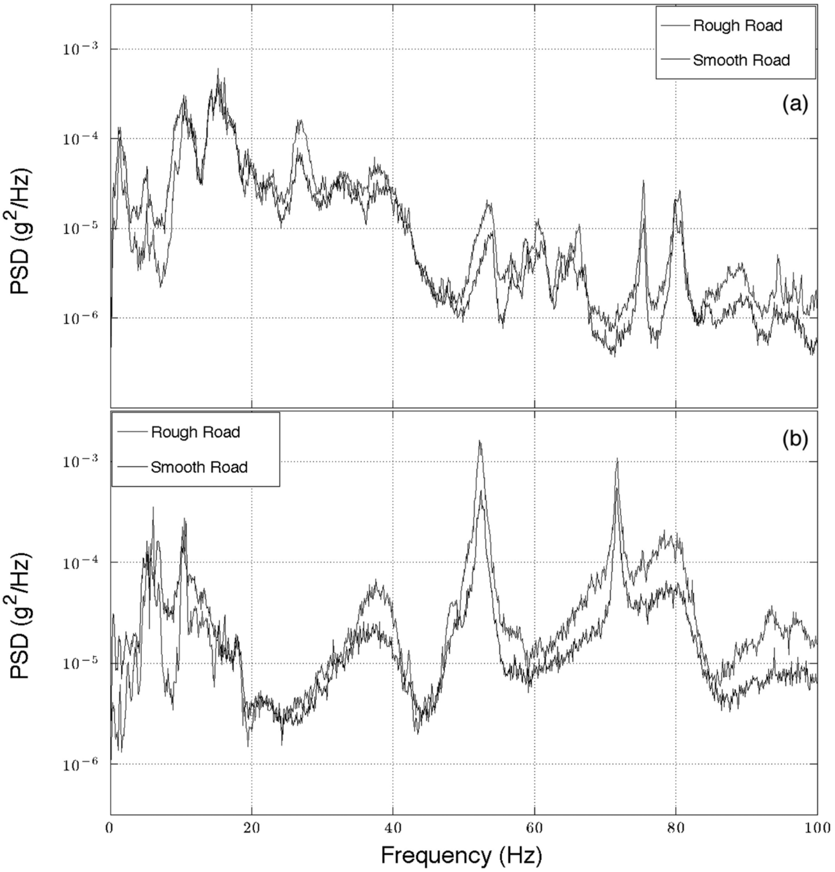

Figure 11. *(Actual Move): Comparison of power spectrum for smooth and rough road conditions on (a) lateral and (b) longitudinal axis.*

hours of driving time over a 3-day period. A heavy-duty forklift was used to transfer the cryostat from the trailer to the experiment hall where a visual inspection revealed no damage. As a final test, the superconducting magnet coil was cooled with liquid helium and ramped to operating current with no faults, verifying the success of the move.

The test move played a large role in the planning and success of the move. It provided accurate estimates of the magnitude and frequency of the accelerations that would be applied to the cryostat and established logistical guidelines to ensure as few surprises as possible during the move.

The real-time shock monitoring system that was designed and assembled for the move was critical to its success and provides a good example of how a very effective system can be constructed inexpensively. The cost of the monitoring system was \$6,000, the test move was \$5,000, and actual move was \$20,000. The total cost of \$31,000 was considerably less expensive than the other shipping options considered: disassembling the magnet or using a crawler system, either of which would have cost well in excess of \$100,000.

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Effects of Radiation Processing on Sensory Quality of Food

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ABSTRACT: This paper is intended to summarize published findings on the effects of ionizing energy on sensory quality (flavor, color and texture) of foods, as well as consumer attitude and market tests on irradiated food materials.

In the area of texture, appropriate doses of irradiation decreased firmness in strawberries, but increased it in onions. Similar doses were also found to help retain moisture, and thus weight loss, in onions and mangos, and reduce surface wrinkling in eggplants, while no detrimental effects were reported on meat products with some irradiated meats reported to be noticeably tender and moist.

With the exception of eggplant, some potatoes and a reversible effect on strawberries, irradiation had little effect on color of most fruits and vegetables. Fresh pork irradiated in the presence of oxygen was more pale (whiter), more yellow and less red than non-irradiated samples, or samples irradiated in the absence of oxygen. However, radiation sterilized meat and poultry products were actually rated superior to canned versions in terms of appearance and texture.

High doses of ionizing energy were detrimental to aroma and taste of certain foods. The most widely reported effect is oxidation in fatty foods caused by emission of free radicals. These oxidation products could render oily fish, meat and meat products (herring, red meat); high sucrose products (raisins, gelatin dessert powder); and dairy products (cheese, ice cream) unpalatable.

All these detrimental effects of high doses were reported to be obviated or greatly minimized when more appropriate lower radiation doses were utilized, and irradiation carried out at low temperatures and/or in the absence of oxygen. Furthermore, preponderance of results of attitude and market tests indicated that consumers either preferred to buy irradiated food products or had no aversion to them.

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INTRODUCTION

CONSUMPTION and enjoyment of food is largely dependent upon the sensory characteristics of food. Therefore, there is a strong link between sensory quality of food and overall human nutrition. Since food preservation and processing techniques can enhance or degrade sensory quality, with nutritional and health implications, it is vital that adequate consideration be given to sensory attributes.

Food irradiation involves the treatment of food with selected types of ionizing energy. The scientific principles, technological requirements, and food engineering applications of the methodology were reviewed by S. NwaneLe ASO [1,2]. Food irradiation process has been researched for many decades; has been approved by many governments and scientific authorities for numerous food products; and has been commercialized in many countries [3–16]. Irradiated food items have also been established to be safe and wholesome not only from the epidemiological, microbiological, nutritional, physical and toxicological points of view; but also in terms of radiation chemistry and radioactivity [11,13,17–30].

Many workers have studied various aspects of the effects of ionizing energy on food packaging materials [31–35]. Recently, Ji and Welt presented a concise review of irradiation of food packaging materials [36]. Komolprasert, Komolprasert and coworkers, and others have studied effects of irradiation on Polyethylene terephthalate (PET) and Nylon. These works included use of radioisotope and machine sources of ionizing energy up to 50 kGy. The authors concluded that gamma and e-beam irradiation did not generate any new (or significantly increase) non volatile radiolytic product in PET and Nylon [37].

Unfortunately, no matter how safe and wholesome a food product is, that food is useless to the body until it is consumed. However, whether food is consumed depends on many factors, including availability, cost, convenience, and sensory qualities of color, flavor and texture [38]. Affordable, safe, high quality and convenient foods are most likely to be consumed in sufficient quantity to satisfy and maintain nutritional balance. Because food palatability is highly dependent upon sensory attributes and can significantly influence food consumption, with possible nutritional and/or public health implications, sensory quality exerts significant sway on consumer acceptance, and as such, on the nutritional impact of irradiated foods to the diet.

Therefore vital consideration must be given to effects of ionizing energy on sensory properties of food. This work attempts to assess available data on such effects.

SENSORY QUALITY AND ITS DEGRADATION

Sensory quality as used here, refer to attributes that are perceived by the senses (i.e. hearing, sight, smell, taste, touch). Attributes may be measured by parameters of sound, appearance, color, aroma, taste, or texture. Parameters can be specified and determined by objective and/or subjective techniques. Sensory quality attributes may be degraded by chemical or physical means. The abrasion of food components by mechanical forces can, for example, destroy geometric and structural integrity of constituent particles, thereby altering texture and other sensory profiles. Chemically, perhaps the most notorious food degradation process is oxidation, especially in fatty foods. The primary products of lipid oxidation are hydroperoxides. However, peroxides rapidly breakdown through secondary reactions to smaller compounds like alkanes, alkenes, aldehydes, ketones, and acids. It is these low molecular weight compounds that ascribe astringent and rancid off-flavors to foods. Oxidative degradation affects color, flavor, texture, safety and nutritive value of foods [39,40].

Degradation of sensory attributes of food can be potentiated by the processing and preservation technologies applied. For example, hot air dehydration can generate foods with aesthetically displeasing texture such as cracks, shrinkage and wrinkles. Aseptic high temperature short time (HTST) processing with scraped surface heat exchanger was reported to compromise the quality of particulate food [41]. Djefal (1993) noted that canning degrades color and other organoleptic attributes of meat and meat products [42]. Berne (1995) highlighted that ultra high temperature (UHT) processes such as steam infusion and injection causes loss of volatile aromas and flavors in milk and fruit juices [43]. Similarly, preservative additives such as sulphur dioxide may destroy vitamins such as thiamine, and taint flavors [44] and [45].

Singh and Heldman [46] noted that freezing at –4°C produced perceptible changes in color and flavor respectively after 3 and 6 days of storage for cauliflower; 4 and 17 days for beans; 5 and 14 days for peas; and 7 and 8 days for spinach. The authors further reported that at –18°C, detectable changes in sensory quality appeared in mackerel, salmon, sea herring and trout after 60 days of storage; and that the changes were significant after 120 days. Also reported were losses in sensory quality of frozen cod, haddock, shrimp, scallop, clam, lobster, oyster, apples, cherries, peaches, strawberries, beef, pork, pork sausage, and lamb. Sensory quality was assessed mainly by color and flavor parameters [46]. In view of potential health and socio-economic consequences of these limitations, sensory quality should be evaluated.

IRRADIATION TREATMENT AND SENSORY QUALITY OF FOOD

Piggott (1992) stated that food flavor is an interaction of product and consumer which cannot be measured directly by instruments [47]. Similarly, CAST (1997) stated that acceptability of foods for consumption is a subjective matter [10]. Available evidence suggests that under currently approved doses of ionizing energy, few foods have elicited negative sensory effects. The exception is possibly the peroxide formation and rancidity observed in certain foods due to oxidative activities. Induction of oxidative reactions by ionizing energy was noted to bear adverse effects on sensory quality of lipid food systems [10,23,24,34,39,48–50]. The most widely recognized effect has been rancidity problem. It is possible that other sensory indicators such as color and texture constituents can also be destroyed by oxidation.

Flavor

Flavor relates to perception of aroma or taste or both which may influence food acceptability during eating [51]. Flavor of irradiated food is thus of grave importance.

Halls (1991) noted that at permitted doses of ionizing radiation, rancid lipid oxidative products like malonylaldehyde can be generated in meat and meat products and that red meat may also develop an off-flavor variously described as “goaty” or “wet dog”. The author however added that these problems are minimized when irradiation is carried out in the absence of oxygen and/or at sub-zero temperatures [34]. Vacuum packaged and irradiated pork did not show further increase in thiobarbituric acid (TBA) value in storage after initial spike at day seven [52–55]. However, TBA values of pork samples packaged in air showed significant increase [48,39,55]. Similarly, pork loins irradiated in air were reported to exhibit strong off-odors immediately after irradiation; but the off-odors subsequently grew weaker during storage due to dissipation effects [52,55].

The Advisory Committee on Irradiated and Novel Foods (ACINF) report stated that 2.2 kGy used to reduce spoilage and pathogenic organisms in oily fish may give rise to peroxide formation and rancidity, depending on the conditions under which irradiation is carried out. The report also noted that at 10 kGy, unsaturated fatty acids can lead to peroxide formation and rancidity which may render the food unpalatable [23].

Treatment of smoked herring with 7.5 kGy was found to markedly reduce acceptability scores due to odor and rancid flavor [50]. The decrease in acceptability paralleled and was attributed to changes in lipid composition. Apparently the 7.5 kGy degraded herring lipid, increasing the quantities of rancidity indices such as free fatty acid (FFA) percentage; thiobarbituric acid (TBA) value; and peroxide value (PV). When the herrings were treated with 2.5 to 5.0 kGy and stored for up to six months, sensory attributes were reported to be good [50].

Anchovy (*Engraulis encrasicalus*) was irradiated at 1 to 3 kGy and stored at 2 ± 0.9°C. There was no marked difference between irradiated and untreated raw and cooked fish samples during the first 3 days of storage. After 10 days of storage, the increase in TBA value of 1 kGy samples was smaller than for 2 and 3 kGy samples. The authors recommended a dose of 1 kGy which would extend the shelf life of anchovy fish by 6 days beyond the shelf life of untreated fish samples [56].

The sterilizing dose of 27.9 or 55.8 kGy was observed to produce adverse changes in the odor of high sucrose products like raisins, gelatin dessert powder, and vanilla dessert powder [24]. Katahdin and Russet Burbank potatoes were irradiated at 0.1 and 1.0 kGy and stored for up to 26 weeks. Mondy and Gosselin (1989) reported that irradiation decreased the levels of crude lipids and phospholipids in the potatoes [57].

Furthermore, ionizing radiation has been noted to elicit negative odors and flavors in dairy products. Irradiation of cheeses, frozen desserts, dried skim milk and ice cream with 40 kGy at –78°C was found to increase off-flavor and aftertaste [49]. Addition of antioxidant prior to irradiation was however noted to be effective in preserving specific sensory quality.

Some studies reported favorable or no adverse influences of ionizing radiation on the aroma and taste properties of food materials. For example, irradiation at pasteurization doses was reported to have little or no effect on flavor [13]. When crabs and fish were irradiated at the low dose of up to 0.25 kGy, the metacercariae of *Clonorchis sinensis*, *opisthorchis viverrini*, and *Paragonimus westermani* were inactivated without affecting flavor and taste [58]. Diop *et al.* (1993) irradiated pulp of tropical fruit Senegal dattock with 10 kGy at –5°C and under inert atmosphere and found no alteration of smell or taste [59]. Similarly walnuts were treated with up to 1 kGy with gamma rays and stored for four months. Irradiation treatment did not affect the indices of lipid oxidation as reported by Jan *et al.* [60]. In addition, CARRAR [61] rated irradiation treatment very good in terms of the preservation of aroma, taste, nutritive value and texture of food products.

Color

When treated with 0.85 kGy, color of the stalk of eggplant fruits was found to change from green to pale yellow, and then to a dark color [62]. Color degradation is attributed to adverse effects of ionizing radiation on chlorophyll. However, when bawku red onions were treated with 0.02 to 0.07 kGy, no discoloration or darkening of the internal buds or meristem regions were reported [62].

Measurement of evolution of color in irradiated strawberries was carried out by Diop *et al.* [59]. The authors found a 22 and 31% reduction in chromatic component a* immediately after irradiation at 1 kGy and 3 kGy respectively. The reduction was attributed to radiation sensitivity of anthocyanic pigment and was observed to be completely reversible after four days of storage. Chromatic component a* is responsible for red color of strawberries. On the other hand, chromatic components b* and L*, which are respectively responsible for the yellow color and luminosity of strawberries were not modified at 1 or 3 kGy [59].

At –5°C and in the absence of oxygen, 10 kGy did not change color in Senegal dattock pulp [59]. Similarly, dried skim milk, cheeses and other milk products irradiated at 40 kGy and –78°C showed little color change [49]. But when Katahdin and Russet Burbank Potatoes were irradiated at 0.1 and 1.0 kGy and stored for up to 26 weeks, increased levels of discoloration and phenols were observed [57].

Beef loins, Pork loins, and Turkey tenders were irradiated at doses up to 10.5 kGy and in vacuum and air packages. In the case of vacuum packaging, the redness of pork and turkey increased due to irradiation but that of beef decreased and yellowness increased with irradiation dose and storage time [63]. With the aerobic packages, the yellowness (b value) of all the samples (beef, pork and turkey) increased with irradiation and display time. The redness (a value) of aerobically packaged irradiated beef and pork decreased as a result of irradiation and display time while that of turkey increased after irradiation but decreased during display time [64]. Furthermore, Lea *et al.*, 1960 observed that appearance of beef irradiated in air was adversely affected [48]. Lebepe *et al.*, 1990 reported that after six weeks storage at 2–4°C, lightness (L value) and redness of 3 kGy irradiated vacuum packaged pork were higher compared to untreated samples [54]. And Lambert *et al.*, 1992 concluded that overall, pork loins packaged in air and irradiated at 1 kGy had lower a values, higher b values and higher L values; indicating a less red, more pale (whiter) and more yellow pork [55]. Yet radiation sterilized meat and poultry products were rated superior to canned versions in terms of appearance and texture [13].

Texture

Ionizing radiation may impact texture of foods depending on dose, and irradiation and storage conditions. Firmness of strawberries with or without calcic fertilization was measured in relation to irradiation dose and storage duration. After one day of storage, 1 kGy reduced firmness by 12 and 17%, respectively in fertilized and unfertilized strawberries. On the other hand, 3 kGy reduced firmness by 15 and 31%. After four days storage, 1 kGy firmness was reduced by 18 and 33% respectively, for fertilized and unfertilized strawberries. Corresponding reductions at 3 kGy were 22 and 75%, respectively [59].

Appiah *et al.* (1993) conducted textural studies on irradiated onions, eggplant fruits, and mangoes. The authors reported that irradiated onions were firmer and less dehydrated than non-irradiated samples. Wrinkling was reduced at 0.50 kGy in eggplant fruits during storage for 28 days, thereby extending product acceptability by additional 13 days. Irradiation to 0.85 kGy reduced weight loss or dehydration in mangoes for more than 1 week [62]. Dehydration in fresh fruits and vegetables typically results in cracks, shrinkages and wrinkles. Anomalous structural and textural features can in addition to promoting nutrient losses also evoke adverse sensory reactions from consumers.

Irradiation doses up to 0.25 kGy were reported not to affect texture of crabs and fish [58]. Some irradiated meats were actually found to be tender and moist, unlike autoclaved versions which were reported to be dry and over cooked [13].

CONSUMER ATTITUDE TESTS

Data on subjective sensory evaluation of irradiated food materials are summarized in Table 1. Roast beef was irradiated with sterilizing doses of 47 to 71 kGy at –30°C, and tasted by 30 and 32 judges at two different sensory tests. On a 9 point hedonic scale, overall acceptance scores of 5.8 and 6.2 were reported for the 30 and 32 judges, respectively [65]. By comparison, hedonic scores for controls were 5.4 and 6.1, respectively. Irradiated Nham (a fermented pork sausage) at 2 kGy was tasted by 138 judges, and 95% of respondents expressed willingness to buy irradiated Nham again (Table 1 item 7) [11,66].

Akingbohungbe [67] in Nigeria, conducted consumer attitude tests with 1 kGy irradiated Ife brown cowpeas, and similarly irradiated yellow maize (DMR-LSR-Y variety) and smoked fish (*clarias sp* and *tilapia nilotica*). In one of the tests, 24 consumers received cowpea samples and were requested to prepare moimoi (a steamed cowpea paste meal) or akara (fried balls of cowpea paste) from each sample. About 42% of the respondents rated the flavor of irradiated cowpea products to be better than that of non-irradiated products, while 58% rated the flavor of both irradiated and non-irradiated cowpea products to be the same. 67% of the respondents expressed willingness to buy irradiated products again. In a separate test, 44% of 36 judges preferred non-irradiated moimoi, 39% preferred irradiated moimoi, while 17% preferred both samples equally. On specific sensory responses for the irradiated cowpea moimoi, 81% of the respondents scored texture, as “smooth”, 78% scored aroma as “sweet”, 75% scored hotness or pepperiness as “alright”, 72% scored appearance as “very appetizing” and 56% scored taste as “good”. The corresponding scores for the non-irradiated moimoi were 81, 72, 75, 56, and 67%, respectively [67].

Twenty two subjects who received Akingbohungbe’s yellow maize were asked to prepare the samples into ogi or akamu (a product of fermented maize flour). After the soaking process, 56% of the respondents rated the texture of irradiated maize to be the same as the texture of non-irradiated maize. About 30% of the respondents rated soaked irradiated maize to be softer than soaked non-irradiated maize, while 15% rated soaked irradiated maize to be harder than soaked non-irradiated maize. At the end of the milling operation, about 56, 48, and 4% of the judges rated the texture of milled irradiated maize to be similar, smoother, and coarser than milled non-irradiated maize, respectively. On taste, 63% of respondents rated irradiated and non-irradiated maize to have the same taste, while 37% rated the irradiated maize product to be more sour [67]. In addition, 93% of the respondents expressed willingness to buy irradiated yellow maize again (Table 1, item 5).

Akingbohungbe administered smoke-dried fish samples to 15 subjects. Subjects were requested to consume the fish with their families in normally cooked and uncooked modes and thereafter to complete a questionnaire designed to allow deductions of consumer acceptance. 80% scored texture of irradiated smoke-dried fish to be drier than that of non-irradiated samples. Taste of irradiated, but uncooked fish was scored better than non-irradiated uncooked fish by 80% of subjects. About 13 and 7% scored taste of uncooked irradiated fish to be similar, and not as good as uncooked non-irradiated fish samples, respectively. After cooking, the flavor of cooked irradiated smoke-dried fish was rated to be better than, and not as good as cooked non irradiated smoke-dried fish samples by 60 and 40% of the subjects, respectively. Also, 88% of the subjects expressed willingness to buy irradiated smoke-dried fish again (Table 1, item 3).

El-Fouly [50] and Appiah *et al.* [62] conducted consumer attitude tests with herring fish. After 21 days of storage, paper packaged smoke-dried herring irradiated at 1 and 3 kGy received a perfect overall assessment hedonic score of 9 on the 9 point hedonic scale (Table 1, item 4 a). Smoked herring irradiated at 2.5 and 5.0 kGy received overall assessment hedonic scores of 4.7, and 4.5 respectively on the 5 point hedonic scale (Table 1, items 4 b & c). After two months of storage, herring was still rated well with regard to color, aroma, flavor, and texture. However, after four months of storage, cold smoked herring irradiated at 2.5 kGy were rejected; while samples irradiated at 5.0 kGy were scored 2.5, 2.6, 2.8, and 2.1, respectively, for color, aroma, flavor, and texture (Table 1, items 4 f & g). Similarly dried *Tilapia nilotica* was irradiated at 2.5 and 5.0 kGy and stored for up to six months [50]. For all hedonic parameters evaluated, which included appearance, aroma, taste, texture and overall assessment, good or better than average scores were reported (Table 1, items 10 a to d).

In a test with strawberries (Table 1, items 9 a to d), fertilized and irradiated strawberries were tasted by 16 judges. Fertilized strawberries irradiated at 1 kGy had an overall acceptance score of 4.3 on the 5 point hedonic scale. Unfertilized strawberries irradiated at 1 or 3 kGy and fertilized strawberries irradiated at 3 kGy had overall assessment scores less than 2.5.

There are other consumer attitude tests not presented in Table 1.

Table 1. Consumer/Sensory Evaluation of Irradiated Food Items.

					Consumer / Sensory Response							
					Hedonic Score (Points)							
Item No	Food System	Applied Dose and Other Conditions	No of Respon-dents/ Tasters	Hedonic Scale (Points)*	Color	Appear-ance	Aroma, Odor or Smell	Flavor or Taste	Texture	Overall Assess-ment	Willingness to buy food item again [% respondents]	Refs.
1	Beef (Roast)	47 to 71 kGy at 243 K (–30°C or –22°F)	30	9	ND**	ND	ND	ND	ND	5.8	ND	65
			32	9	ND	ND	ND	ND	ND	6.2	ND	65
2	Cowpea Product (Moimoi or Akara)	1 kGy	24	ND	ND	ND	ND	ND	ND	ND	67	67
3	*Clarias sp* and *Tilapia nilotica*	1.0 kGy; Smoke dried	15	ND	ND	ND	ND	ND	ND	ND	88	67
4	Herrings	a 1.0 to 3.0 kGy; Smoke dried, paper packet, 21 days storage	ND	9	ND	ND	ND	ND	ND	9	ND	62
		b 2.5 kGy; Smoked	ND	5	ND	4.7	4.8	4.8	4.6	4.7	ND	50
		c 5.0 kGy; Smoked	ND	5	ND	4.5	4.6	4.5	4.7	4.5	ND	50
		d 2.5 kGy; Cold smoked, two months storage	ND	5	3.5	ND	3.5	4.1	3.1	ND	ND	50; In comparison, the control un-irradiated samples were completely rejected by panelists after one month of storage
		e 5.0 kGy; Cold smoked, two months storage	ND	5	4.0	ND	4.0	4.2	3.8	ND	ND	
		f 2.5 kGy; Cold smoked, four months storage	ND	5	Fish rejected	ND	Fish rejected	Fish rejected	Fish rejected	ND	ND	
		g 5.0 kGy; Cold smoked, four months storage	ND	5	2.5	ND	2.6	2.8	2.1	ND	ND	

(continued)

Table 1 (continued). Consumer/Sensory Evaluation of Irradiated Food Items.

					Consumer / Sensory Response							
					Hedonic Score (Points)							
Item No	**Food System**	**Applied Dose and Other Conditions**	**No of Respondents/ Tasters**	**Hedonic Scale (Points)***	**Color**	**Appearance**	**Aroma, Odor or Smell**	**Flavor or Taste**	**Texture**	**Overall Assessment**	**Willingness to buy food item again [% respondents]**	**Refs.**
5	Maize Product (Ogi)	1.0 kGy	22	ND	ND5	ND	ND	ND	ND	ND	93	67
6	Mangoes	a 0.25 kGy; 4 days storage	ND	9	9	ND**	ND	ND	ND	ND	ND	62
		b 0.85 kGy; 4 days storage	ND	9	ND	ND	ND	ND	ND	ND	ND	62
7	Nham (Fermented pork sausage)	2.0 kGy	138	ND	ND	ND	ND	ND	ND	ND	95	11, 62
8	Papayas	0.41 to 0.51 kGy	200	ND	ND	ND	ND	ND	ND	ND	73	66
9	Strawberries	a 1.0 kGy; Plain berry	16	5	ND	ND	ND	ND	ND	2.3	ND	59
		b 1.0 kGy; Berry with calcic fertilization	16	5	ND	ND	ND	ND	3.5	4.3	ND	59
		c 3.0 kGy; Plain berry	16	5	ND	ND	ND	ND	ND	1.4	ND	59
		d 3.0 kGy; Berry with calcic fertilization	16	5	ND	ND	ND	ND	ND	2.1	ND	59
10	*Tilapia nilotica*	a 2.5 kGy; Dried	ND	5	ND	4.5	4.3	4.0	4.1	4.3	ND	50
		b 5.0 kGy; Dried	ND	5	ND	4.5	4.3	4.2	4.7	4.4	ND	50
		c 2.5 kGy; Dried, six months storage	ND	5	ND	3.0	3.2	2.8	3.5	3.1	ND	50
		d 5.0 kGy; Dried, six months storage	ND	5	ND	3.2	3.2	2.8	3.3	3.1	ND	50

*Generally, on a 9 point hedonic scale, a score of 9 represents most acceptable; score of 1, least acceptable or rejected; and a score of 4.5, average. On a 5 point hedonic scale, a score of 5 is considered most acceptable; score of 1 represents rejected; and score of 2.5 is regarded as average.

**ND = Not Determined

Beefsteak, corned beef, ham and turkey irradiated for US space missions were reported to command better degree of doneness and higher acceptability than thermoprocessed versions [68]. Some milk products including cheeses, dried skim milk, frozen desserts, and ice cream were irradiated with 40 kGy at freezing temperatures. Irradiation caused little change in product color and texture, increased off flavor and after taste and decreased overall acceptability. It was further reported that modified atmosphere packaging or addition of antioxidant prior to irradiation treatment were effective in preserving specific sensory attributes and in some cases improved overall acceptability [49].

Shelled walnuts were treated with disinfestation doses and stored at three different temperatures for up to four months. Samples were scored by a panel of judges for color, odor, taste and texture. The authors reported that radiation treatment did not affect any of the sensory parameters tested [60].

Cottee and Kunstadt [69] reported on the 1994 distribution of irradiated food items by Nations Pride Inc. to fairgoers in Tampa, Florida, USA. Consumers were told that chicken was irradiated to reduce *Salmonella,* and that the irradiation process was approved by the American Medical Association (AMA), and the United States Food and Drug Administration (USFDA). By the end of the fair period (17 days), twenty eight thousand samples of irradiated chicken and strawberries were consumed, and over 95% of those offered a sample accepted and ate it. Cottee and Kunstadt also reported on consumer attitude studies performed by three major institutions: The University of Georgia, Gallup organization for American Meat Institute, and Burson-Marsteller for Nordion International Inc. About 45 to 54% of those interviewed were willing to try irradiated products once they understood that irradiation killed *Salmonella* in chicken, *E. coli* in hamburger meat; and was approved by USFDA, and the United states Department of Agriculture (USDA) [69].

In another consumer attitude test performed in the USA, Resurreccion *et al.* [70] found that 45% of respondents will buy irradiated foods, 19% will not, and 36% were undecided. Among those willing to buy irradiated foods, 11% will buy more irradiated fruits and vegetables, 14% more beef and poultry, 18% more pork, and 23% more fish than the present amount of non-irradiated versions they currently buy. Also, about 42 and 10% of these consumers were willing to pay respectively 5 and 10% more for irradiated foods [70].

In Cote d’Ivoire, several local dishes such as rogout, foutou, and foufou were prepared from yam irradiated at 0.1 kGy. The results did not show any differences between irradiated and non-irradiated yam as reported by the Food and Agriculture Organization/International Atomic Energy Agency (FAO/IAEA) [71].

In a test conducted in Argentina, 94% of respondents judged irradiated onions to be very good [66]. Marcotte, [72] catalogued the results of consumer attitude research towards irradiated foods in eleven nations.

MARKET TESTS

Actual market tests of irradiated food products have been performed in many parts of the world. In Abidjan, Cote d'Ivoire, it was reported that consumers rushed to buy 12 tons of yam irradiated with 0.1 kGy, despite the fact that the irradiated yam sold at a slightly higher price than non-irradiated samples. Repeat buyers were said to attribute their preference to the superior color and taste of irradiated yam samples [71].

Loaharanu *et al.* [66] citing the works of Baraldi, Chareon et al, and Moog, noted the following:

1. Italy in 1976—15 tons of irradiated potatoes were sold in one day in three cities.
2. Thailand in 1986—during a three month period in Bangkok, irradiated nham outsold non-irradiated samples at the rate of ten to one. 34% of the respondents bought irradiated nham out of curiosity while 66% bought it in the belief that irradiated nham were free of *Salmonella* and *Trichinella*.
3. France in 1987 and 1988—7 tons of irradiated strawberries were sold to consumers at a slightly higher price than non-irradiated strawberries. It was found that consumers preferred to buy irradiated strawberries because of their better quality [11,66].

In the USA, there have been market tests of irradiated apples, grapefruit, juice oranges, mangoes, papayas, and strawberries. For example, 228 West Central Missouri Shoppers participated in a roadside stand sale of irradiated and non-irradiated apples. Prices for the irradiated apples were varied while the price for non-irradiated apples was held constant. Of the 228 shoppers, 101 (44%) bought only non-irradiated apples; 86 (38%) bought only irradiated apples; and 41 (18%) bought some of both types. Probit regression analyses indicated not only an inverse relationship between the price of irradiated apples and the probability of purchasing irradiated apples; but also a positive relationship between the purchasers' educational level and the probability of purchasing irradiated apples. The authors concluded that the study suggests that consumers may be interested in food irradiation as a possible alternative or supplement to current preservation techniques [73].

In September 1986, a grocery store in North Miami Beach sold 2 tons (100 cases) of mangoes disinfested with 1 kGy. Irradiated mangoes were priced at US\$3.31 kg^{-1} (US\$ 1.49 lb^{-1}) and sold alongside hot-water-dip disinfested samples. The irradiated mangoes were reported to have sold well, with no apparent reluctance from consumers [66,74]. In March, 1987, papayas were test marketed in two supermarkets in Southern California. The papayas were either irradiated at a dose of 0.41 to 0.51 kGy or hot water dipped. Test results showed 68 kg (150 lb) of irradiated papayas versus 6 kg (13 lb) of hot water dipped samples were sold. Consumers attributed their preference to the appearance and taste of irradiated papayas, and about 73% of the 200 respondents stated they would buy irradiated papayas again [11,66,75].

Also in the USA, Carrot Top Inc., Northbrook, Illinois, test marketed irradiated grapefruit, juice oranges, and strawberries in March, 1992. After nine days of test market, about 90% of all strawberry sales were irradiated samples. After twelve days, 90% of all the 53 cases of grapefruit sold were irradiated samples, and 92% of the 61 cases of juice oranges sold were irradiated samples [75,76]. Earlier in January in Laurenzo's market, an Italian grocery store in North Miami Beach, 600 and 450 pints of irradiated and non-irradiated strawberries, respectively, were sold during the first day of market test [74].

A number of other market tests have been carried out in various other Countries, including Bangladesh, Belgium, Chile, China, Cuba, France, Germany, Hungary, Indonesia, Israel, Netherlands, Pakistan, Philippines, Poland and South Africa. Over 15 different food products including apples, bananas, dried fish, chicken, frog legs, potatoes, pulses, sausage, sliced beef, and spices were marketed. Results indicated that consumers either preferred to buy irradiated food items or had no aversion to them [11]. Summary tables of market tests of irradiated foods in 17 countries, and of commercial irradiation of food and agricultural commodities in 24 countries have been presented by Marcotte [72].

CONCLUSION

Presently, the preponderance of available scientific data suggest satisfactory sensory parameters—appearance/color, flavor (aroma, taste), and texture—for irradiated food products. The possible exception is the peroxide formation and rancidity observed in certain foods at high doses. The off flavors that emanate from lipid oxidation when fatty foods are irradiated can be mitigated by irradiating at low temperatures and/or in the absence of oxygen.

Based on the evidence considered in this work, good irradiation practices under currently approved doses of ionizing radiation will not significantly compromise the sensory quality of irradiated foods.

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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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