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COLD SUPPLY CHAIN MANAGEMENT IN PROCESSING OF FOOD AND AGRICULTURAL PRODUCTS

Gholamhassan ASADI[1], Ebrahim HOSSEINI[2]

[1]Department of Food Science and Technology, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran. Phone:+98 21 44865500 Email: asadi@srbiau.ac.ir
[2]Department of Food Science and Technology, Tehran Science and Research Branch, Islamic Azad University, Tehran, Iran. Phone:+98 21 44865464 Email: ebhoseini@srbiau.ac.ir

Corresponding author email: asadi@srbiau.ac.ir

Abstract

The quality and safety of food and most agricultural products during storage time in cold stores and distribution is highly dependent on management and monitoring of time-temperature history concept. Control of temperature should be taken into account throughout the cold chain, from farm or factory to consumers (i.e. farm-to-fork) , to ensure food safety and hygiene and to maintain product quality. Microbiological and biochemical changes take place in food stuffs, and therefore the end quality depends on the temperature and moisture history of products. In order to control the end quality, it is therefore necessary to trace and control the temperature. The Radio frequency identity (RFID) and the Temperature monitoring tags are showing a future in completing the cold chain of perishable products (such as dairy, meat, seafood, fruit and vegetables). Time-Temperature indicators or integrators labels (TTIs) are another traceability tools that could be used as an intelligent shelf life decision system for quality optimization of the food and agricultural products during chill chain. In this paper some important tools for traceability and monitoring of safety and quality of main agricultural products in cold supply chain were reviewed.

Keywords*: Cold chain, Time-Temperature indicators, RFID tags, agricultural products*

INTRODUCTION

Refrigerated foods are one of the fastest growing sectors of the food industries. Continued success relies upon effective management of the 'cold chain', a term used to describe the series of interdependent operations in the production, distribution, storage and retailing of chilled and frozen foods. The control of the cold chain is very important to preserve the safety and quality of cooled and refrigerated foods. A typical cold chain is illustrated in Figure 1.

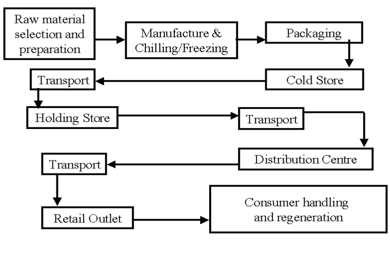

Figure 1. A typical cold chain

Chilling involves reducing food temperatures to below ambient temperatures, but above $-1^{o}C$. This results in effective short-term preservation of food materials by retarding many of the microbial, physical, chemical and biochemical reactions associated with food spoilage and deterioration. However, chilled foods are perishable and they deteriorate progressively throughout their life. The safe and the high quality chilled foods require minimal contamination during manufacture (including cross-contamination), rapid chilling and low temperatures during storage, handling, distribution, retail display and consumer storage (Prusi, 1990). Freezing preserves the storage life of foods by making them more inert and slowing down the detrimental reactions that promote food spoilage and limit quality shelf life. However, it should be recognised that a number of physical and biochemical reactions can still occur and many of these will be accentuated when recommended conditions of handling, production and storage are not maintained. The production of safe frozen foods requires the same attention to good

manufacturing practices (GMP) and HACCP principles as the chilled or fresh foods (Bogh-Sorensen and Olsson, 1990).
A good temperature control is being achieved throughout the cold food chains as a result of improved equipment design, quality control and food safety. Transfer points, e.g. chiller/freezer to cold store, factory to distribution vehicle, retail the cabinets to consumers' refrigerators, are well known problem areas. Monitoring the cold chain requires detailed information on food product temperatures. Temperature monitoring includes both measurement and recording.

Materials and Methods

The quality and safety of food and most agricultural products during storage time in cold stores and distribution is highly dependent on management and monitoring of time-temperature history concept.
In this paper some important tools for traceability and monitoring of safety and quality of main agricultural products in cold supply chain were reviewed.

Results and Discussions

Traditional temperature monitoring

The traditionally temperature management has been applied using thermometers installed in trucks and warehouses and recently some businesses have employed compact temperature loggers for temperature management. When thermometers installed in warehouses and trucks are used for the management, periodical temperature checks are required. In the case of management systems that also use temperature loggers, each logger should be connected physically to a PC and the data collection becomes a manual operation. Conventionally management has been done by sampling individual packages on a per-warehouse basis. However, temperatures at the entrances and deep inside warehouses tend to vary greatly because there is a wide variation in the temperature at the entrance due to the opening and closing of the doors. Therefore, the thermometers installed in the warehouses or trucks are sometimes incapable of recording the correct temperatures of the products. The traceability of the entire chain is important, but the market also needs a simple risk management technique for use in cause analysis as a prior step to fault tracing. For instance, temperature management is applied not only in the food industry but it is also needed in various aspects of various businesses handling products that have a temperature management requirement.
For overcoming these problems, some new techniques should be applied which are real-time and wireless. In the following, some novel methods will be reviewed.

Novel time-temperature monitoring techniques

The wireless temperature sensor allows managers to monitor cold chain and temperature fluctuations over time during shipment and storage of temperature sensitive goods such as seafoods and perishable agricultural products. This system offers information on the entire food chain, from farm to fork, within minutes, compared with hours or days required in current traceability systems. Information is also collected and stored on ingredient and packaging movements, transformation and quality from the source to retailer's shelf around the world.

Radio Frequency Identity (RFID) Tags

RFID recorder is perfect for temperature mapping and cold chain management of seafood and agricultural products. RFID is an area of automatic identification that is gaining momentum and is considered by some to emerge as one of the most pervasive computing technologies in history. In its simplest form, RFID is a similar concept to bar coding. It is seen as a means of enhancing data processes and is complementary to existing technologies. It is a proven technology that has been in use since the 1970. Since 1998 there has been a revolution in new materials and processes that have driven costs for memory chips, batteries and circuitry down dramatically. This has lead to the Radio Frequency Identification (RFID) or so called Smart Label revolution (Das and Harroup, 2000) with predictions that such tags will replace the UPC code in two to three years. There are several companies developing two way RFID temperature sensor tags that record temperature which can be downloading at various receiver ports along the way for abuse analysis. Several others are taking the temperature monitoring one further step i.e. integration as is done in the chemical tag using the microbial kinetic parameters in an on board memory chip. The advantage is that such tags can integrate over all three stages of growth and can have an exact good/no good indicator (light) to eliminate sorting. In addition these tags will store the whole temperature time sequence of exposure thus allowing the processor to determine where abuse occurred. With RFID, by downloading of the data at various points in the chain, product close to being unsafe can be removed before the last stage, thus ensuring a safe food supply.

A more complex description is an electromagnetic proximity identification and data transaction system. Using ‘‘RFID tags’’ on objects or assets, and ‘‘readers’’ to gather the tag information, RFID represents an improvement over bar codes in terms of non-optical proximity communication, information density, and two-way communication ability. Operational RFID systems involve tags and readers interacting with objects and database systems to provide an information and/or operational function.

RFID is used for a wide variety of applications ranging from the familiar building access control proximity cards to supply chain tracking, toll collection, vehicle parking access control, retail stock management, tracking library books, theft prevention, vehicle immobilizer systems and railway rolling stock identification and movement tracking.

A major constraint on the widespread use of RFID technologies is the cost of the tags. The most widely used tags are Electronic Article Surveillance (EAS, class 0) tags, which cost between 1 and 6 US cents each. Over 6 billion of them are used annually. Passive tags (class 1) with some data storage cost between 5 and 10 US cents each in large quantities (several million). High value items, cartons and pallets are being tagged (class 2–4) and here costs may be up to US$100 per tag. At current prices it is not economic to incorporate tags into every retail item. Prices will fall as manufacturing technologies improve. In the last 50 years only one billion RFID passive tags (other than EAS tags) and 500 million active tags have been sold. While the use of RFID technologies is predicted to grow significantly, it may take several years to get to the point where the majority of retail items are tagged.

Time-Temperature Indicators and Integrators (TTIs)

An integrated approach could be used to enable traceability of the cold chain of fresh, chilled meat and fish products by means of tailor-made Time-Temperature Indicators (TTIs). The indicators will be tailored to the shelf life and optimum storage conditions of the products. The use of both chemical and RFID, time temperature integrator tags (TTI) placed on food packages to essentially integrate the time-temperature history and indicate actual shelf life left will be evaluated with respect to cold chain management. Such a tag would be used to make a conservative estimate of time to detect for cold chain management. Thus the time to end of shelf life based on safety criteria would be solved by labelling with the expiration date along with a statement such as "use by the date indicated unless the tag turns red".

An solution to the problem of spoilage and waste is to have a device (TTI) on the pallet, case or individual package that integrates the time temperature exposure in the cold chain with the same temperature response as the spoilage rate of the food or the growth rate of the pathogenic organism. Thus, if properly designed, the TTI would indicate visually to distributors, retailers and consumers depending on the type of tag used, the extent of degradation that has occurred. This TTI tag would need to show a sharp color change just before or at end of shelf life (expiration date) when the spoilage level or pathogen number reaches some critical value that could lead to a consumer or regulatory risk, e.g. the time to be able to detect, TTD, a pathogen in a serving of food. To be on the conservative side, this indicator change should occur at some time (hours, days) before the actual risk is present.

Time-temperature integrators (TTI) are small, physical devices that are placed on the food package to measure the temperature history of a product and indicate a definitive change at the end of shelf-life through “integration” of the time temperature exposure, e.g. "Use food by July 30, 2004 unless dot turns red"(Rice, 1989; Anon, 1989; Sherlock and Labuza, 1992). TTIs are reliable indicators of end of shelf-life for food products if they have similar temperature sensitivities (Ea) as for the food deterioration mechanism (Taoukis et al., 1991). The devices can used on individual consumer packages, so they establish a control system because not all products will receive uniform handling, distribution and time-temperature effects (Labuza et. al., 1992). As a result, TTIs can increase the effectiveness of quality control in distribution, stock rotation practices of perishable foods in grocery stores, and efficiency in measuring freshness by the consumer as we noted earlier. (Sherlock, 1991; Wells and Singh, 1988a, 1988b). Taoukis showed that for the most part, the commercially available TTIs are both reliable and applicable for use in combination with open dating of refrigerated foods including RTE products. Malcata (1990), in addition, showed that although the tags respond more quickly to temperature abuse then the actual food because they are on the surface of the package, thus the response is on the conservative side of safety, i.e. the tag shows an endpoint before the food is spoiled.

Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD), which has been around for many years, is a powerful numerical technique for solving industrial fluid flow problems. CFD calculation involves the use of a computational grid where the governing equations describing fluid flow—the continuity equation and the set of the Navier–Stokes equations, and any additional conservation equations such as energy balance are solved across each grid cell by means of an iterative procedure in order to predict the profiles of velocity, temperature, shear, pressure, and other parameters.

CFD offers a powerful design and analysis tool to the agri-food engineer. In the agri-food industry, many applications involve fluid flow and heat and mass transfer (Sun, 2002).

Most of the early CFD applications in the food industry focused on refrigeration facilities. Research in refrigeration facilities is still continuing. Moureh, Menia and Flick present simulation results of air-flow in a typical refrigerated truck, with experimental verification using laser-Doppler velocimetry. This work aims to improve and optimise the air-distribution systems in refrigerated vehicles for uniform temperature distribution within the loading. Strict temperature control is required throughout the cold-chain (Norton, 2006).

Simulation of large refrigeration facilities using CFD is always a problem due to the limitation in computer capacity. Mirade, Kondjoyan and Daudin adopt a four-step strategy by separating the computation of air velocity field, heat and mass transfer coefficients and product chilling process. This strategy is applied to a large pork chiller containing 290 carcasses. This part is concluded with a paper by Moureh, Laguerre, Flick and Commere on the modelling of the temperature history of a heat-sensitive food product during its shipping and storage in pallets with and without an insulating cover.

CONCLUSIONS

As seen in this review, both chemical and electronic RFID-TTI time-temperature integrators can integrate this abuse and relate it to shelf life expiration. To create these tags there is a need for collection of data on time to detect (TTD) and growth kinetics for each pathogen on each type of food. This data is sorely lacking especially TTD. But once collected, we can set an expiration date based on some level of risk, i.e. the time to detect the pathogen or some higher regulatory action level. This information can then be used to design a time-temperature integrator device, TTI, that chemically or electronically integrates the stage the pathogen or the level its toxin is at and indicate distinctly the end point set as the "expiration date". Thus, the device can be used as a HACCP monitor to evaluate in real time the extent to which temperature abuse during distribution and holding at retail and in the home affects the safety of the product.

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