Food Control 75 (2017) 211–219

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Explorative study of using infrared imaging for temperature measurement of pallet of fresh produce

R. Badia-Melis [a, *], J.P. Emond [c, d], L. Ruiz-García [a], J. Garcia-Hierro [b], J.I. Robla Villalba [b]

[a] Departamento de Ingeniería Agroforestal, ETSIAAB, Universidad Politécnica de Madrid (UPM), Edificio Motores, Avda. Complutense 3, 28040 Madrid, Spain
[b] Sensors Technology Laboratory, Centro Nacional de Investigaciones Metalúrgicas, Consejo Superior de Investigaciones Científicas (CENIM-CSIC), Avenida Gregorio del Amo 8, 28040 Madrid, Spain
[c] Department of Agricultural and Biological Engineering, University of Florida, Gainesville, FL 32611, USA
[d] The Illuminate Group, Tampa, FL 33614, USA

ARTICLE INFO

Article history:
Received 14 October 2016
Received in revised form
3 December 2016
Accepted 5 December 2016
Available online 7 December 2016

Keywords:
Cold chain
Pallet cover
Thermal image
Food temperature
Surface temperature

ABSTRACT

Food industry is currently using thermal imaging to measure temperature of fresh produce, but there is no comparative study between temperatures measured traditionally by temperature probes and the temperatures measured by thermal imaging reported in the literature. This paper is exploring the possibility to use surface temperature measured by infrared (IR) thermal imaging versus temperatures measured by a network of temperature sensors. Two different types of vegetables (chard and cucumber) were covered with three different types of covers (Tyvek® material, Metalized PET and Metalized PET with bubble wrap layer) which are designed to protect shipments of produce against temperature abuses. Each cover/produce combination was exposed to a temperature warm up regime in order to simulate a break in the cold chain during distribution, and it was monitored with the thermal IR camera and temperature sensors for comparisons. Results of temperature measured by thermal imaging showed a differential between 1.9 and 6 °C compared to temperature measured by thermal sensors. These found differences are unacceptable for fresh produce temperature control. The high emissivity of metalized PET produced significant reading errors when using the IR camera. Tyvek® cover had more consistent results due to a higher emissivity value that is closer to the value used by the IR camera. This study is of great value since it is giving instructions of how the thermal camera should be used for temperature measurements for covered pallets.

1. Introduction

The production, storage, distribution and transport of cold sensitive products occur daily around the world. Thus, temperature control is essential for these products.

The biggest challenge is to ensure a continuous cold chain from the producer to the consumer, and to do so, it is necessary to count on adequate monitoring and control systems (Gwanpuaa et al., 2015). Inadequate management of this supply chain can lower the level of quality of fresh fruit and vegetables, causing approximately one-third of these products to be thrown away (Gustavsson, Cederberg, Sonesson, Otterdijk, & Meybeck, 2011). FAO estimates that each year, approximately one-third of all food produced worldwide for human consumption is lost or wasted (FAO, 2013). The economic impact of product losses is about 10% in Europe (6–7% in retailers) and 15% in the USA (Pang, Chen, & Zheng, 2012), while reaching 30% in developing countries (mostly due to lack of temperature control). These product losses occur mostly during transportation over several thousand kilometers (Jedermann, Becker, Gorg, & Lang, 2011). Thus, the major challenge is to ensure a continuous cold chain from producer to consumer in order to guarantee prime condition of goods (Kim, Aung, Chang, & Makatsoris, 2015).

Temperature variations can occur during warehousing, handling and transportation. Inadequate temperature is second in the list of factors causing foodborne illnesses, surpassed only by the initial presence of microflora in foods (Sanchez Lopez & Daeyoung, 2008).

Maintaining appropriate conditions throughout the entire chain

* Corresponding author.
E-mail address: ricardobadia@live.com (R. Badia-Melis).

http://dx.doi.org/10.1016/j.foodcont.2016.12.008
0956-7135/

presents many challenges and negligence or mishandling in the logistics of perishable products is very common, and includes poor or excessive cooling of goods. Jedermann, Nicometo, Uysal, and Lang (2014) reported many examples wherein inadequate temperature control management usually led to losses in the food chain (postharvest, distribution and home).

Several parameters have been reported in the literature that can cause product deterioration apart from temperature, such as relative humidity (RH), free water or condensation, these last two are responsible for microbiological infection and weaken packaging materials (Burg, 2014; Lian, Zhao, Yang, Tang, & Katiyo, 2015). Visual quality and weight loss have been used as performance indicators (Pelletier, Brecht, Nunes, & Emond, 2011). Significant RH variations within an individual cold room (from 55% to 95% RH) have been founded (Ruiz-Garcia, Barreiro, Robla, & Lunadei, 2010). The mentioned unstable RH variations can cause a water loss in fruit and vegetables, as demonstrated by Hübert and Lang (2012).

Storage temperature requirements for fresh produce are critical and can lead to irreversible damages such as chilling injuries for tropical products (Jedermann, Ruiz-Garcia, & Lang, 2009).

It is important to understand heat transfer when studying packaging for temperature protection. There are three types of heat transfer involved with passive thermal protection systems; conduction, convection and radiation (Peck et al., 2015). Each of them play an important role on how the heat is absorbed in the pallet load (pallet covered or not).

Defraeye et al. (2015) presented a review about thermal performance of fresh produce packaging in the cold chain. The study of the influence of pallet covers is not well reported in literature, though Macnish et al. (2012) conducted some experiments studying the benefits of different cover systems over strawberry pallets. The predominant heat transfer mechanisms that affect the loads are radiation and convection. The cover acts as a barrier to these two types of mechanisms and also as barriers to humidity transfer between the external environment and the air trapped between the covers and the product.

This present study is investigating the possibility of using surface temperature readings from a thermal camera as a reference for the pallet temperature. Thermal imaging has already been proven to be a powerful tool when working with real product scenarios. Narayan et al. (2011) discussed nondestructive quality evaluation methods for food, and demonstrate how the cooked level inside a chicken can be assessed using thermal imaging and Artificial Neural Network (ANN). Chen, Zhang, Zhao, and Ouyang (2013) also demonstrated thermal imaging to be a technique for food safety and Castro-Giraldez, Balaguer, Hinarejos, and Fito (2014) implemented thermal imaging as a temperature control for the meat freezing process.

However, when working with Infra-red imaging it is important to take into account the surface emissivity, which depends of the nature of the materials and its emitted radiation. Emitted radiation by the surface is what is measured by thermal imaging apparatus (Bulanon, Burks, & Alchanatis, 2008).

The fresh produce industry is currently using thermal imaging to measure temperature of fresh produce (Dupont, 2016), but there is no comparative study between temperatures measured traditionally by temperature probes and the temperatures measured by thermal imaging reported in the literature.

The main objective of this study is to evaluate the possibility of using surface temperature of a pallet of fresh produce measured by an infrared thermal camera as a valid method to assess temperature distribution. One of the sub-objective is to compare different types of materials for pallet covers as well as different products in different temperature scenarios.

2. Materials and methods

2.1. Materials

An experimental programmable refrigerated cold room was used to simulate conditions encountered during produce distribution. The room is 2 × 1.50 × 1.50 m made of polyurethane sandwich panel of 0.1 m thick. The refrigerated system is an internal evaporation with an external condensation unit of hermetic alternative compressor of 5 kW with R- 134a as a refrigerant. Air speed inside the room is set at 2.5 m s^{-1}. The room temperature sensor is located on the wall of the door at 1.50 m above the floor.

Data loggers were utilized to measure the ambient parameters. U12-013 HOBO measured temperature (range of −20° to 70 °C) and RH (5%–95%). Each logger had two external ports where two temperature probes using thermistors (model TMC6-HD). With an accuracy of ±0.25 °C.

The thermal camera used was Flir brand, E6 model. IR resolution was 160 × 120, with a thermal sensitivity of <0.006 °C, temperature range of −20° to 250 °C, and accuracy of ±2% or 2 °C.

Three different types of pallet covers were used as coverage for the pallets (see Fig. 1). The first was a DuPont™ Tyvek® Air Cargo Cover, breathable, lightweight and made of Tyvek®, 1200 × 1000 × 1700 mm in size. The second cover manufactured by © C&S Packaging Supplier, was made of Metalized PET and raffia, and was not breathable. The third also by © C&S, was a cover composed of three layers, the inside and outside made of Metalized PET with the middle layer made of plastic bubbles. The size of the last two covers was 1200 × 1000 × 1700 mm. The pallet used was 1200 × 1000 mm in size and the plastic grid boxes were 500 × 380 × 280 mm, nine boxes per layer in three layers.

The products used were fresh vegetables, and in all cases the experiments did not start more than 24 h after harvest. Products included 400 kg of chard for the first experiment and 400 kg of cucumbers for the second.

The optimum storage conditions for these products are presented in Table 1. As can be seen, both products can be stored for same period of time since they have similar water content, however cucumber must be stored and transported at higher temperature than chard.

2.2. Methods

A thermal imaging camera records the intensity of radiation in the infrared part of the electromagnetic spectrum and converts it to a visible image, which allows temperature values to be read from the image (FLIR, 2015).

In order to interpret thermal images correctly, it is required to know how different materials and conditions influence the temperature readings from the thermal imaging camera. Emissivity, defined as the ratio of energy emitted from an object to that of a black body at the same temperature, can vary from 0 (perfect white body) to 1 (perfect black body) (Gowen, Tiwari, Cullen, McDonnell, & O'Donnell, 2010).

If the body that emits radiation has emissivity 1 (the radiation of the target is 100% emitted from the target surface), and the camera is set to capture emissivity 1, the apparent temperature will be equal to the actual temperature, however if the body has emissivity lower than 1, and the camera is configured for higher emissivity, the camera is capturing emissivity, transmission and reflection, and taking this last one as the actual temperature. Hence it is needed to reduce the reflectance of the body and thus improve the measurement accuracy, as well as reduce the emissivity set in the camera to make it equal to the body emissivity. The measured temperatures at the surface of the covers used in this study are