Journal of Food Engineering 193 (2017) 76–85

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Industrial viability of the hyperbaric method to store perishable foods at room temperature

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ARTICLE INFO

Article history:
Received 28 April 2016
Received in revised form
24 August 2016
Accepted 28 August 2016
Available online 30 August 2016

Keywords:
Hyperbaric storage
Refrigeration
Strawberry juice
Sensory analysis
Equipment sizing
Production cost
Carbon footprint

ABSTRACT

Preliminary studies at lab-scale have shown that hyperbaric storage at room temperature (HS-RT) allows preserving safety and quality of perishable foods for at least 15 days at moderate pressures (below 250 MPa). However, it is unclear whether this novel storage method would be feasible at larger scale. Thus, the purpose of this research was to assess the industrial viability of HS-RT. The viability factors addressed were (1) consumer perception of the stored products, (2) feasibility of the equipment design, (3) storage cost, and (4) environmental impact. The study is conducted in comparison to refrigeration for the storage of a pasteurized juice during 15 days. Results provide clear evidences of HS-RT viability for factors (1), (2) and (4) while reservations have to be expressed regarding factor (3).

1. Introduction

With or without previous preservation treatment(s), all foods need specific storage conditions until their consumption to avoid or, at least, to retard detrimental quality changes. Common strategies to extend their shelf life during storage are based on the modification of environmental parameters (*e.g.* temperature, humidity, atmospheric gases). Among them, temperature lowering is, without any doubt, the most employed in developed countries. From the initial chilling or freezing of the raw ingredients to product storage in consumer's refrigerator, the cold chain maintains the safety and quality of perishable foods for days, weeks, or months. This is a highly efficient strategy for food storage but it has a major drawback: its low sustainability. Cold facilities are huge consumers of energy, they are expensive and partially responsible for global warming and climatic change. It is estimated that about 50% of total energy in the food industry is consumed by facilities related with refrigeration, which represents about 15% of electricity consumption worldwide (James and James, 2010). Additionally, refrigerants are an important source of global greenhouse gases (GHGs) emissions, and some of them, such as chlorofluorocarbons or hydrochlorofluorocarbons, also split and release ozone destructive chlorine atoms (Wu et al., 2013). Thus, it is believed that, within the food industry, the cold chain is responsible for approximately 2.5% of GHGs emissions (Evans et al., 2014).

Many efforts have been made in the last decades to improve the performance of conventional refrigeration systems, to find new environmental-friendly refrigeration technologies, and to look for new energy saving opportunities in food preservation (Masanet, 2008; Tassou et al., 2010). In this regard, the development of a novel technology that does not need refrigeration facilities, such as hyperbaric storage at room temperature (HS-RT), could represent an important breakthrough in food storage in terms of energy saving, refrigerant elimination, and GHGs emission reduction. HS-RT consists in the storage of foods in a hydrostatic pressure chamber for days or weeks at room temperature. The major advantage of HS-RT over the traditional refrigeration is the elimination of low temperatures that are substituted by *moderate* pressures (below 250 MPa) (Segovia-Bravo et al., 2012). Food is preserved under pressure with no temperature control, and the

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http://dx.doi.org/10.1016/j.jfoodeng.2016.08.014
0260-8774/

only energy consumption occurs during the initial compression step. This novel storage method is often confused with high-pressure processing or high-pressure cryopreservation methods but this is indeed an opposite concept: pressure must be as low as possible (ideally below 200 MPa), time under pressure as long as necessary, and temperature control is needless.

Although recent papers in the literature have revealed that HS-RT could be an interesting method for food preservation (Bermejo-Prada et al., 2014; Fidalgo et al., 2014; Ko and Hsu, 2001; Queirós et al., 2014; Santos et al., 2015; Segovia-Bravo et al., 2012), this storage method has not received much attention. In fact, high-pressure vessels specifically designed for food storage are not commercialized and thus prototype or conventional high-pressure equipment with higher performances is usually used at laboratory or semi-industrial scale (Fidalgo et al., 2015). Until now, published studies have focused on the microbial safety and food quality issues, concluding that HS-RT is an effective method for food preservation. For instance, Segovia-Bravo et al. (2012) reported that the microbiological quality of strawberry juice after 15 days (the longest storage period studied so far) at 20 °C and pressures between 25 MPa and 220 MPa resulted in no growth of aerobic mesophiles, yeasts or molds.

The time has now come to address the viability of this method by adopting an industrial approach. The study of the product quality after HS-RT needs to go farther by evaluating consumer perception. Does HS-RT induce perceptible changes in the product and is it as effective as refrigeration for preserving product organoleptic characteristics? Also, other engineering aspects require consideration: impracticable equipment, a too expensive storage cost, or a very negative environmental impact would jeopardize the viability of this method at industrial scale.

Therefore, the goal of this study is to assess these viability factors (sensory, vessel design, economic and environmental) in the context of HS-RT of perishable foods at large scale. Since HS-RT is proposed as an alternative to refrigeration, this viability study is performed in comparison to refrigeration. Strawberry juice is selected as the stored product for the sake of simplicity in calculations and because of existing positive antecedents (Segovia-Bravo et al., 2012; Bermejo-Prada et al., 2014, 2015; Bermejo-Prada and Otero, 2016; Bermejo-Prada et al., 2016).

2. Material and methods

2.1. Sensory analyses

Instrumental measurements performed until now in strawberry juice stored under pressure have provided encouraging evidences of good quality preservation. However, instrumental measurements and consumer perception are frequently not well correlated. For example, if bad flavors were developed in the product during storage under pressure, HS-RT would be a useless storage method. To evaluate consumer perception, several discriminative sensory analyses were organized as detailed below. Firstly, it was verified whether sensory modifications are induced in the fresh strawberry juice during HS-RT (25 MPa or 50 MPa/20 °C) for 15 days. Then, it was tested if this novel storage method is equivalent to refrigeration in terms of preserving the sensory characteristics of *pasteurized* strawberry juice.

2.1.1. Samples

Fresh strawberries were purchased at commercial maturity from a local supplier before the storage experiment. Strawberry juice was always processed in the same way. The fruits were washed with tap water and processed with a juicer (Royal Blender Turbo 10-Speed, Type 212004, Princess, The Netherlands). The blended strawberry juice was then centrifuged at 3500×g and 4 °C for 10 min (Sorvall Evolution RC Superspeed centrifuge, Thermo Scientific, Spain). The supernatant was subsequently collected, filtered through a 0.1 mm pore diameter sieve, packaged, and stored at −20 °C until used.

2.1.2. Storage experiments

Before each storage experiment, the strawberry juice was thawed by keeping it overnight at 5 °C. Then, it was distributed in thermo-sealed plastic bags of 250 mL, avoiding headspace. Pasteurized samples were prepared by immersion of fresh strawberry juice pouches in a water bath at 90 °C; the core temperature was maintained at 85 °C for 90 s (Roberts et al., 2005; Demirdöven and Baysal, 2014). Once processed, the juice was immediately cooled in an ice-water bath. Finally, fresh and pasteurized samples were placed under the chosen storage conditions (under high pressure or refrigeration) for 15 days.

Storage experiments under pressure were carried out in a pilot-plant high-pressure storage system (model SV1, Institute of High Pressure Physics, Unipress Equipment Division, Poland) as described in a previous work (Segovia-Bravo et al., 2012). Refrigeration took place in a cold chamber at 5 °C.

Firstly, fresh strawberry juices were stored for 15 days at 20 °C and two different pressure levels (50 MPa and 25 MPa) to obtain samples labelled as HP50 and HP25, respectively. Then, pasteurized juice samples were stored for 15 days either at refrigeration (5 °C) or under pressure (25 MPa/20 °C), obtaining samples labelled as TT_R and TT_HP25, respectively (TT = thermal treatment). Control juice at day 0, *i.e.* fresh juice without storage, was encoded as C sample.

2.1.3. Triangle test

To investigate possible sensory differences in the stored juices, the triangle test was used (Meilgaard et al., 2007). Four triangle tests were performed:

(1) TT_R *vs.* C (as a reference of the conventional storage method),
(2) HP50 *vs.* C (to check the effectiveness of HS-RT at 50 MPa),
(3) HP25 *vs.* C (to check the effectiveness of HS-RT at 25 MPa),
(4) TT_R *vs.* TT_HP25 (to test if HS-RT is equivalent to refrigeration in terms of preserving the organoleptic characteristic of thermal-treated strawberry juice).

Panels for each triangle test comprised from 20 to 24 semi-trained judges belonging to the staff of the Institute of Food Science, Technology, and Nutrition (ICTAN-CSIC). Three strawberry juice samples were presented to the judges and each one was encoded by a three-digit random code. The order of presentation was randomly assigned to each judge, ensuring a balanced presentation order of the samples. Juice was served in a transparent plastic glass (30 mL per glass). No information about the aim of the study nor about juice samples was provided to the judges prior to the test. Judges were informed that two samples were identical and one sample was different, and they were forced to identify the odd sample.

2.1.4. Data analysis

The results of the triangle tests were compared with tables of minimal number of correct responses required for significance (UNE-EN ISO 4120:2008).

2.2. High-pressure vessel sizing

The main components of conventional high-hydrostatic-