Journal of Food Engineering 109 (2012) 635–639

Contents lists available at SciVerse ScienceDirect

Journal of Food Engineering

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

Dielectric properties of sea cucumbers (*Stichopus japonicus*) and model foods at 915 MHz

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ARTICLE INFO

Article history:
Received 6 December 2010
Received in revised form 7 June 2011
Accepted 9 June 2011
Available online 12 September 2011

Keywords:
Sea cucumbers
Model food
Gellan
Dielectric constant
Dielectric loss factor

ABSTRACT

Short-time microwave (MW) sterilization is a feasible technology to produce high-quality shelf-stable sea cucumbers (SCs) (*Stichopus japonicus*). Selection of a model food matching the sea cucumbers in dielectric properties (DPs) is one of the most important steps for developing the MW processing. The test results revealed that rehydrated sea cucumber has much lower relative dielectric loss factor (9.73–5.62) than muscle foods, including salmon fillets and sliced beef, which were reported in the literature. The whey protein gel formulations that had been developed in our laboratory as a tool in heating pattern studies for those products are, therefore, not appropriate for sea cucumber. Adding 1.0% gellan powder sharply reduced the amount of whey protein concentrates needed to form firm gels and significantly lowered the dielectric loss factor. The dielectric properties of the sea cucumbers and model food samples with different formulations were measured using a custom-built temperature controlled test cell and an Agilent 4291B impedance analyzer in the temperature range 20–120 °C. Based on comparison of the measured dielectric properties and the calculated microwave power penetration depths among the sea cucumbers and model foods, appropriate formulation with whey protein concentration 5%, whey protein isolation 3%, gellan gum 1%, D-ribose 0.5% and water 90.5% was chosen as the model food for the sea cucumbers for the purpose of MW processing development.

1. Introduction

Sea cucumbers (SCs) are echinoderms from the class Holothuroidea. Some of the commonly found species in markets include *Holothuria scabra*; *Holothuria fuscogilva*; *Actinopyga mauritiana*; *Stichius japonicas*; *Parastichopus californicus*; *Thelenota ananas*; *Acaudina molpadioides* (Ramofafia et al., 2003). They are marine animals with leathery skins and elongated bodies. In Asian countries such as China and Japan, they are regarded as delicacies in cuisines, and also used as traditional medicines (Zhu et al., 2009). In China, many commercial SCs are farmed in artificial ponds. These ponds can be as large as 1000 acres, and satisfy much of the local demand. Coastal communities in these countries trade SCs as a major source of their export earnings. It was reported that world trade of SCs was about US$60 million with a global production at 12,000 ton in the year 1994 (Battaglene et al., 1999).

SCs are well known to have beneficial effects on human health. These echinoderms are used in Asian traditional medicine to maintain fitness during long fishing travels or to prevent, reduce or cure several ailments like constipation, renal deficiency or arthritis (Mamelona et al., 2007). Some varieties of SCs are believed to have excellent functions to heal patients from a clinical surgery, injury, or caesarian operation; and some are also credited to possess similar aphrodisiac powers as attributed to oysters (Fredalina et al., 1999). A study conducted on mice suggested that sea cucumber extract was somewhat effective in reducing internal pain (Ridzwan et al., 2003).

SCs are traditionally harvested by hand and then dried for preservation purposes. Before consumption, they are rehydrated by boiling and soaking in hot water for several days. Conventionally, thermal heating either by steam or hot water is used to process sea cucumbers. But long exposure of SCs in conventional thermal heating severely softens their meat texture, thus limiting their value. Recently, with microwave heating has been explored for salmon sterilization (Kong et al., 2007), the results in suggested that MW heating has a potential to process sea products with superior product qualities.

MW heating is volumetric in nature, where heat is generated within the food product. The amount of heat generation depends on several factors such as dielectric properties (DPs) and thermal

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0260-8774/$ - see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.jfoodeng.2011.06.012

Table 1
Formulation of model food, percentage by weight, including deionized water.

Formulation	#1	#2	#3	#4	#5
WPC, 392	5	7.5	10	7.5	7.5
WPI, 895	3	3	3	2	4
Gellan gum	1	1	1	1	1
D-ribose	0.5	0.5	0.5	0.5	0.5
Water	90.5	88	85.5	89	87
Moisture (after cooking)	89.30	86.58	84.23	88.12	86.15

properties of the product, product size, shape and position, as well as MW-heating cavity configuration (Wang et al., 2004). Knowledge of food product dielectric properties is essential in development of the MW processing. No data, so far, has been reported or published on the dielectric properties of sea cucumbers. *Stichopus japonicus* (*S. japonicus*), is an important cultivated aquatic species enjoyed by consumers in China and Japan, and has a great market value in both countries (Zhu et al., 2009). This research is aimed at determining the dielectric properties of sea cucumbers rehydrated from dry products and to develop an appropriate gel as the model food to emulate the sea cucumbers in MW heating. We are particularly interested in the dielectric properties at 915 MHz because of the potential market opportunities for 915 MHz single-mode sterilization systems developed, after two of the sterilization processes received FDA acceptance in October 2009 and November 2010.

2. Materials and methods

2.1. Preparing the sea cucumbers

Commercial dried SCs (*S. japonicus*) were purchased from an Asian supermarket (Bethlehem, PA, USA). The products were rehydrated with 0–4 °C deionized water for 67 h to get the rehydration ratio of 8.5. The moisture content (88.30 ± 0.67%) was very similar to that of fresh SCs. The rehydrated samples were placed at room temperature for at least 24 h before measurement.

2.2. Preparation of model food gels

Whey protein concentrate (WPC) TM 392 (New Zealand Milk Products, Santa Rosa, CA), whey protein isolate (WPI) 895 (New Zealand Milk Products, Santa Rosa, CA), gellan gum (CPKelco, Chicago, IL), with the addition of D-ribose (Sigma-Aldrich, St. Louis, MO), and DI water were ingredients of gels for dielectric property measurement. The formulations are shown in Table 1. The suspension was mixed in a beaker for 1 h at room temperature using a magnetic stirring device to obtain a homogeneous solution; the solution was transferred into metal tubes (1 in. in diameter and 4 in. in height) and cooked at 80 °C in a water bath for 40 min. The moisture content of the sample was tested and the mean values of three replicates are reported in Table 1. The sample was removed from the molding tube and placed in a custom-built test cell for measurement. The test cell was designed to control sample temperature for dielectric measurement (Wang et al., 2005).

2.3. Dielectric property measuring equipment

The measurement system consisted of an Agilent 4291B impedance analyzer with a calibration kit (Agilent technologies, Palo Alto, CA), a custom-built test cell, a high-temperature coaxial cable, and a Hewlett Packard 85070B dielectric probe kit (Fig. 1). The typical measurement accuracy of the system is ±8% following standard calibration procedures as described in Wang et al. (2003). By this study, dielectric properties of the SCs and model foods were measured between 1 and 1800 MHz.

2.4. Measurement of dielectric properties

During measurement, the sea cucumber or model food sample was placed in the test cell. Measurements were conducted at

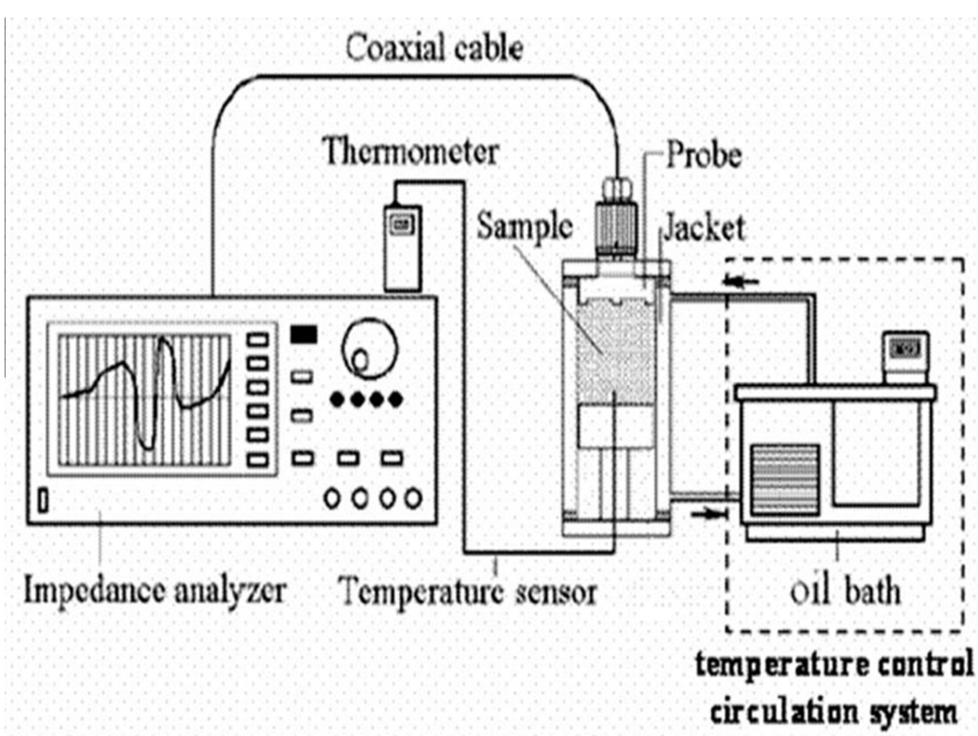

Fig. 1. Schematic diagram of the dielectric properties measurement system (Wang et al., 2005).