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Variability in quality of white and green beans during in-pack sterilization

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Abstract

Non-uniformity in process quality was investigated during in-pack thermal sterilization of food products. This was accomplished through the combined application of the Monte Carlo procedure and a reliable mathematical method for process evaluation. Despite the large coefficients of variation found, the optimum quality process could be designed. The influence of the statistical variability of heating rate index on the retention of green beans' color was studied and an optimum temperature range was found between 125 and 135 °C. The variability in hardness of sterilized white beans, resulting from uncertainties of the combined effect of heating rate index and initial hardness of beans, was also evaluated by simulation. In this case, an optimum global temperature range between 120 and 135 °C was found, independently of the rotation, F_0 value and surface heat transfer coefficient assumed.

Keywords: Sterilization; Pre-packaged foods; Quality retention; Variability; Green beans; White beans

1. Introduction

Adequate evaluation of a process technology's impact on food safety and quality is essential for its viability and market acceptance (Smout, 1999). In the field of food sterilization, the minimum required thermal process should be designed to assure the desired microbial safety, and consequently produce minimal effects on product quality (Banga, Balsa-Canto, Moles, & Alonso, 2003; Lund, 1975). Both heating costs and product quality losses increase as the process time is lengthened (Banga et al., 2003; Clealand & Robertson, 1985).

Variations during thermal processing can arise naturally, even when operating the retort in a standard controlled manner. A sterilization process can be affected by a large number of factors, which are not known accurately (stochastic factors), and are related to: (i) variability in heat transferred to the food product (e.g. retort temperature, rotational speed, surface heat transfer coefficient), (ii) variability in product and container characteristics (e.g. composition of products, product homogeneity, product thermophysical properties, such as thermal diffusivity, initial product temperature, headspace volume, can fill weight), and (iii) variability in parameters of microbial or quality kinetics (k, E_a, D, z, initial spore load, initial quality). Uncertainty in any of these factors will result in an uncertainty in the delivered lethality, with consequent effects on the quality level (Clealand & Robertson, 1985; Hicks, 1961; Nicolai,

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Nomenclature

$(-a/b)$	color retention of green beans
adj.f_h	adjusted f_h value according to APNS method (min)
ANOVA	analysis of variance
c	level number for F_0 value
C/C_0	hardness retention
C_0	initial hardness value (kg/m^2)
C_f	final hardness value (kg/m^2)
CV	coefficient of variation (%)
d	level number for surface heat transfer coefficient
$D_{121.1\,°C}$	decimal reduction time at 121.1 °C (min)
e	level number for temperature
E_a	activation energy (kJ/mol)
F_0	sterilization value (min)
f_h	heating rate index (min)
h	surface heat transfer coefficient (W/(m^2 °C))
h_{fin}	finite surface heat transfer coefficient (W/(m^2 °C))
h_{inf}	infinite surface heat transfer coefficient (W/(m^2 °C))
j_h	heating lag factor (dimensionless)
j_{hB}	heating lag factor corrected according to Ball's 42% rule
$k_{110\,°C}$	degradation rate constant at 110 °C (min^{-1})
LSD	least significant difference
MSE	mean square error
n	sample size
s	standard deviation
T	holding temperature (°C)
t	studentized probability function
$\bar{x}$	average
z	temperature dependence of the decimal reduction time (°C)
α	level of significance

1994; Smout, 1999, Smout, Ávila, Van Loey, Hendrickx, & Silva, 2000a, 2000b; Varga, 1998).

Consequently, commercially sterilized food products are over processed to include additional safety margins that account for inherent variability in sterilization. This inherent variability cannot be avoided, however it is possible to estimate it, in order to develop adequate process assessment (Hicks, 1961; Nicolai, 1994; Varga, 1998). Hicks (1961) was one of the first authors who published work about the nature of uncertainties in canning processes. He discussed the uncertainties in lethality resulting from uncertainties in both heat penetration and bacteriological data. Powers, Pratt, Carmon, Somaatmadja, and Fortson (1962) reported coefficients of variation (CV) for the F_0 values of six products studied ranging from 16.3% to 57.4%, where the variance in heat penetration parameters was considered. Subsequently, many other authors (Hayakawa, De Massaguer, & Trout, 1988; Herndon, 1971; Jones, Pflug, & Blanchett, 1980; Lenz & Lund, 1977; Lund, 1978; Patino & Heil, 1985; Robertson & Miller, 1984; Smout et al., 2000a, 2000b) have studied the influence of variability of various parameters on process lethality.

Variations in quality retention from container to container, in a retort batch, can be so large that it might be difficult, or even impossible, to design an optimal process (Smout, Banadda, Van Loey, & Hendrickx, 2003). On this subject, only Smout et al. (2003) reported the non-uniformity in surface quality (color of green peas) during thermal processing. No other research studies on the effect of uncertainties on quality retention of foods have been reported yet.

Therefore, in this framework, the objective of this study was to investigate non-uniformity in quality retention during in-pack thermal processing of foods. A feasible statistical approach is proposed to assess process optimization design. Two case studies are presented: the influence of the heating rate index (f_h) variability on the retention of green beans' color, and the influence of the combined effect of heat penetration rate (f_h) and initial hardness variability on white beans final hardness retention.

2. Materials and methods

2.1. White beans

Dried white beans were obtained from a canning company and stored dry at 15 °C. Before processing, the white beans were soaked in distilled water at 15 °C for at least 16 h. The heat penetration trials were carried out in a pilot water cascading retort (Barriquand Steriflow retort. Paris, France). The beans were placed in 370 mL glass jars (84 mm height, 75 mm diameter, and 2.6 mm thickness) filled with distilled water and the retort operated in both static and end-over-end rotary modes. The heat penetration parameters, heating rate index (f_h value), lag factor (j_h value), and corrected lag factor according to Ball's 42% rule (j_{hB} value) were calculated using the Ball's (1923) formula method. Adjusted f_h and j_h values were estimated using a semi-empirical approach, the Apparent Position Numerical