A STATISTICAL APPROACH TO PREDICT THE STERILIZATION VALUE FOR CANNED OLIVES

M. GULDAS[1,4], S. GONENC[2] and O. GURBUZ[3]

[1]*Department of Food Technology*
Uludag University
Karacabey Vocational School 16700

[2]*Department of Agricultural Economics*

[3]*Department of Food Engineering*
Faculty of Agriculture
Uludag University
Bursa, Turkey

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ABSTRACT

It is essential that sterilization values be calculated through measurements of temperature from the coldest point of the can during thermal sterilization. However, in practice, the taking of such measurements in an operating food plant can be quite difficult because of time restrictions, and the number of thermocouples and measurements required. For this reason, it is necessary to develop a more convenient way of estimating F *values that uses experimental methods through multiple regression models. The distribution of* F *values and the correlation between the retort temperature and the cold spot temperature of the can were taken into consideration using statistical methods. The estimated results were calculated with very low SD.*

It was found that there was a close relation between temperatures of retort and cold spot with a high correlation ratio, and thus it could be concluded that it is possible to use retort temperature in the estimation of F *values, statistically.*

The experimental and estimated mean averages of F *values were calculated as 13.59 and 13.59 for a 0.5-kg can, 14.15 and 14.16 for a 1-kg can, and 8.22 and 8.22 for a 5-kg can. A high correlation was found between the experimental and estimated* F *values (0.91 for a 0.5-kg can, 0.86 for a 1-kg can and 0.96 for a 5-kg can;* $P < 0.001$*). It was also noted that an inversely proportional relation exists between the size of the can and the* F *value.*

[4] Corresponding author. TEL.: +90-224-662-06-51; FAX: +90-224-676-55-62; EMAIL: mguldas@uludag.edu.tr

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PRACTICAL APPLICATIONS

In addition to measuring F values through experimentation, a more convenient way of estimating F values is sought using other methods. For this purpose, the relationship between the retort temperature and cold spot temperature of a can was investigated making use of statistical data.

It was found that, according to the statistical findings, it is possible to estimate F values by using the retort temperature.

A new statistical approach to estimating F values was developed, investigating previous statistical methods, such as cumulative histograms, Laplace distribution, Kolmogorov–Simirnov test, etc.

INTRODUCTION

Many of the most common processes in the food industry, such as canning, drying, cooking, pasteurization and sterilization, rely on heating (Wang and Sun 2003; Fryer and Robbins 2005).

Thermal processing involves the heating of foods in hermetically sealed containers for a specific time at a specific temperature to eliminate the microbial pathogens that endanger public health, and microorganisms and enzymes that cause deterioration in food during storage. Thermal processing is not designed to destroy all the microorganisms in packaged products, because the long periods of heating required to do this would result in lower product quality. Instead, all pathogenic and most spoilage microorganisms in a hermetically sealed container are destroyed, and an environment is created inside the can that inhibits the growth of the more resistant thermophilic bacteria not fully destroyed by the heat treatment (Maesmans *et al.* 1990; Silva *et al.* 1993; Ramaswamy and Marcotte 2006).

Consumers desire products that have undergone minimum processing, have retained nutrition and flavor, display a long shelf life, are convenient and to which a sufficient expiration margin is added to ensure that every part of the material is safe (Durance 1997). In general, the quality of sterilized canned food depends upon many factors, such as retort temperature, can size and shape, thermal properties and kinetic parameters (Chen and Ramaswamy 2002). The purpose of thermoprocess calculation is to obtain at an appropriate process time under a given set of heating conditions, which will estimate the process lethality of a sterilization process (Ramaswamy and Marcotte 2006).

In previous studies, experimentally assessed thermal variability has been restricted primarily to the measurement of the influencing factors (Patino and Heil 1985; McGinnis 1986; Hayakawa *et al.* 1988; Lebowitz and Bhowmik 1989, 1990; Adams and Hardtenglish 1990; Park *et al.* 1990; Ramaswamy and

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Tung 1990; Tung *et al.* 1990; Marra and Romano 2003; Plazl *et al.* 2005). The literature on the effects of processing factors on lethality and sterility value is also limited (Tung *et al.* 1989; Campbell and Ramaswamy 1992; Akterian *et al.* 1999; Varga *et al.* 2000a; Marra and Romano 2003).

Modeling methods have been developed to help in process design or as a part of a control specification; purely empirical correlations or graphical solutions have been followed by models based around very simple approximations (Marra and Romano 2003; Fryer and Robbins 2005). Numeric modeling is a powerful tool for simulating the heating and cooling process, which results in precise control of the investigation and prediction of the process through the predictive models in the food industry (Wang and Sun 2003; Plazl *et al.* 2005). It is essential to establish a numerical prediction dependent upon the time–temperature relation at the coldest point of a product. A number of simulation procedures in the heat sterilization of food products have been implemented (Silva *et al.* 1993). For this purpose, mathematical or statistical modeling is an appropriate method to verify and to evaluate the relationship among heating parameters, such as time, temperature and product properties, etc. (Chalabi *et al.* 1999).

The F value (sterilization value/lethality) is the total time required to accomplish a stated reduction in a population of vegetative cells or spores (Singh and Heldman 2003). Estimations of the F value were first proposed in 1923 by C.O. Ball, in his research entitled "Thermal Process Time for Canned Food." His results provided reference for canned low-acid foods (Fryer and Robbins 2005). A process was then considered safe if the slowest heating point of a can reached an acceptable F value.

Clostridium botulinum, which affects low-acid foods, is the most common threat to public health, and for this reason, the destruction of the spores of this organism is used as the minimal criterion for heat processing. It has been arbitrarily established that the minimum process should be at least as severe to reduce the population of *C. botulinum* through 12 decimal reductions or 12 logarithmic cycles. It is stated that the decimal reduction time is 0.21 min at 121.1C for *C. botulinum*. Twelve decimal reductions would therefore be equivalent to an F_0 value of $12 \times 0.21 = 2.52$ min. The minimal process lethality (F_0) required is thus 2.52 min (Ramaswamy and Marcotte 2006).

The sterilizing effect (F value) of a thermal process can therefore be computed by integrating the combined lethal effect of exposure at all time/temperature combinations throughout the process.

There are a number of statistical approaches available to evaluate the thermal process variability (Wang *et al.* 1991; Johns 1992; Nicolai *et al.* 1994; Hayakawa *et al.* 1996; Varga *et al.* 2000b).

The distribution function is very important in terms of statistical analysis; thus, it was critical to determine the specific distribution of the F value in the

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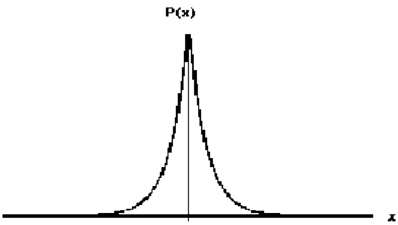
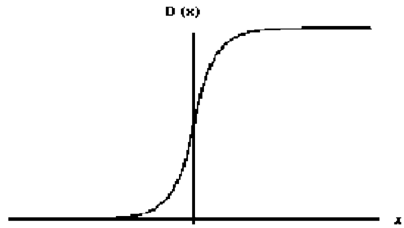
thermal penetration studies. The graphs of density and probability function, from the Laplace distribution (DED), are as follows:





Distribution function

$$F(x) = \frac{1}{2}\exp\left[\frac{|x-\alpha|}{\beta}\right] \quad x \le \alpha \tag{1}$$

or

$$F(x) = 1 - \frac{1}{2}\exp\left[\frac{|x-\alpha|}{\beta}\right] \quad x \ge \alpha \tag{2}$$

$$P(x) = \frac{1}{2b}e^{-|x-\mu|/b} \tag{3}$$

Ryniecki and Jayas (1993) developed a step-response model of automatic determination for the computer control of canned heterogeneous mixed food sterilization, using an *m*th order exponential log transfer function (Laplace transforms lag's response) in their research. Varga *et al.* (2000a) determined that *F* value distribution is not normal, concluding that the *F* value distribution is well described by a gamma function. Varga *et al.* (2000a) connected a link between sample size and distributions by simulation using the software Statgraphics 5.0 (Manugistics, Inc., Rockville, MD) and concluded that normal, lognormal, Weibull, exponential and beta distributions were simulated accurately with more than 100 data, except for gamma distribution.

Statistical distribution analyses are accepted as an alternative approach by selecting a given distribution function as an estimation of a critical temperature of *F* value (Varga *et al.* 2001). However, statistical analyses have been criticized as having limiting factors, such as randomization of data, selection of distribution function and large amounts of data requirements or measurements. However, it is possible to make valid estimations with a sample size (number of measurements) >30 and with alternative distribution functions.

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The basic advantages of using statistical methods over mathematical approaches are convenience in the application, understanding and prediction of various process parameters. In the study, the statistical methods were used with three different aims:

(1) determining F value distribution;
(2) determining differences of F value depending upon can size;
(3) prediction of F value by using time-retort temperature data.

MATERIAL AND METHODS

Physical Properties and Processing of Olives

Green-yellow olives (Gemlik cv.) were harvested in the first week of October from an orchard in Mudanya, Turkey (southeast coast of the Marmara Sea). On average, the olives measured 20.11-mm high by 16.66-mm wide, determined using a caliper (sensitivity: 0.02 mm, Mitutoyo, Kawasaki, Japan). The average weight of 1,000 olives was 330 g, and the net weights for 0.5-, 1.0- and 5.0-kg sizes of cans were 350, 800 and 4,150 g, respectively. The container sizes were 0.5 kg (73 × 110 mm), 1 kg (99 × 119 mm) and 5 kg (154 × 242 mm).

The olives were stored in a brine solution (8% NaCl) for 2 months before canning, and were then transferred to a tank for two-stage alkaline treatment, washing and aeration. In the alkaline treatments, 1.5 and 1.2% NaOH solutions were used in order. After each alkaline treatment, the olives were washed and air bubbled in the tank for 24 and 18 h, respectively.

Ripe olives were canned with brine containing 2% salt and 0.2% ferro-gluconate. Before sealing, the cans were filled with hot brine (90C) and passed through the exhaust tunnel. The cans were then seamed with a COMACO, AIM 4R (Italy) can seamer.

Determination of Thermocouple Locations and Cold Spot

The thermocouples used were copper-constant (type A/S) from Ellab (Copenhagen, Denmark), calibrated against a quartz thermometer in an oil bath at 90C. Rounded needle-type thermocouple probes (GKM 13009 CO52, Ellab, Roedovre, Denmark) were used to measure the temperatures at the cold spot of the cans.

Measurements of the cold spot in the cans were carried out with programmed retort cycles and were recorded at 1-min intervals during thermal sterilization. In the preparation of the cans, thermocouples were placed in predetermined points in order to monitor the cold spot temperature during the process. In this study, we considered the convection heating approach in order to measure cold spot temperature and to locate the thermocouple probes.

In the retort processing of canned liquid–solid mixtures during sterilization, determination of the cold spot location is an important issue, for which we used the findings of the studies of Ramaswamy and Marcotte (2006) for canned olives with brine. Liquid foods containing loosely packed particulates, like canned olives in brine, demonstrate semilogarithmic curves after a relatively short lag and exhibit a much steeper slope, and are referred to as convection heating foods. This kind of product exhibits a broken heating behavior or curve between the heating and cooling stages of the sterilization cycle. Our canned samples comprised 30, 20 and 17% (w/w) liquid (brine) for the 0.5-, 1.0- and 5.0-kg cans, respectively. As seen from Fig. 1, we recorded very similar curves regarding cold spot temperatures (can temperature [CT]) during the sterilization of canned olives, and consequently decided to use the convection heating method. Before the actual determinations, a series of measurements along the vertical axis from the bottom of the cans was carried out to determine the true cold spot in the case of each can. For convection-heated foods, the thermocouple is generally placed at a point 1/10 along the vertical axis from the bottom of the can. From this point, measurements were taken at around 0.2-mm intervals along the axis from 1.10, 1.19 and 2.42 cm from the bottom of the respective cans until the coldest temperature was obtained. Consequently, the cold spots were determined as 1.90 ± 0.2, 2.63 ± 0.2 and 3.81 ± 0.2 cm from the bottom along vertical axis for the 0.5-, 1.0- and 5.0-kg cans, respectively, assuming the cans were standing upright. The thermocouple probes were mounted at these predetermined cold spot locations along the vertical axis.

The needles of the thermocouples were placed into the empty cans first, and then the olives and brine were poured gently into the cans; in this way, temperature measurements were obtained from the liquid phase (brine).

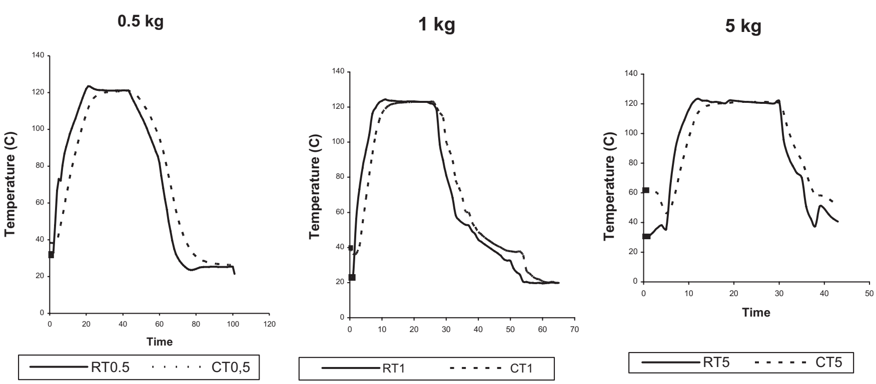

FIG. 1. RETORT TEMPERATURE (RT) AND CAN TEMPERATURE (CT) RELATIONS

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In the thermal sterilization process, the cans were placed into a basket measuring 70 × 70 × 81 cm. Because only nine thermocouples were available during our testing, measurements were carried out over five runs. The retort was designed to accommodate four baskets in each cycle/run. For the measurement three baskets, in which the cans were carefully spaced to ensure good circulation of air, each contained three cans installed with thermocouples. The baskets were placed into the retort at the top, middle and bottom to ensure an accurate measurement, and the position of the baskets in every run was also changed.

An Ellab CTF 9008 digital recorder with a track sense data logging system (TS version 4.01, Ellab) was used to register the temperature data in the retort and can samples. This system was calibrated prior to the experimental setup to kill the most harmful microorganisms in canned olives. After the system attained the set retort temperature, it automatically began to cool.

Retort Cycle

During thermal sterilization, the set temperature of the retort was 122C and the inner pressure was 2.0–2.1 bar, adjusted for each batch. The cycle period was approximately 40–50 min. The whole retort was reloaded for each batch or run, ensuring all the batches were true replicates.

A four-basket industrial scale, water cascading horizontal automatically controlled retort (Lubeca LW 3003 ROS, Ratingen, Germany) with a 1,000-kg capacity and an automatic heating and cooling control system was used. The retort was used in static mode. The experiments were performed disrupting the normal operation at the factory.

F Value Determination

The general method used in this study to determine the integrated sterility value (lethality) at the coldest spot of the canned food products is (Silva *et al.* 1993; Ramaswamy and Marcotte 2006):

$$F_0 = \left[\int_0^t 10^{\frac{T(t)-T_r}{z}} dt \right] \tag{4}$$

F_0 = lethality/sterilization value;
T_r = reference temperature (121.1C);
z = 10°C (temperature sensitivity indicator, which represents the temperature range between which the D value (decimal reduction time) curve passes through one logarithmic cycle);
T = current temperature.

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The pH value and acidity of our samples were 5.46 and 0.19%, respectively. According to the pH values obtained from the canned olives, the target microorganism was *C. botulinum*, and therefore the sterilization temperature was designated as 121.1C.

Statistical Analysis

Statistical analyses have been made in Statistical Package for the Social Sciences for Windows Release 10.0.1 standard version (SPSS Inc., Chicago, IL).

Cumulative histograms scatter graphics, Kolmogorov–Simirnov test, Wilcoxon signed rank test, Pearson correlation, multiple regression, descriptive statistics and curve estimations were used for the analysis. The Kolmogorov–Simirnov test was used to verify *F* value distribution (Hsu *et al.* 2002). A nonparametric test, the Wilcoxon signed rank test, was used to determine the differences between two groups that have dissimilar sample sizes, like Laplace or DEDs (Snedecor and Cochran 1987).

Three-dimensional isometric views of the observed and estimated data were drawn up using CATIA Drawing Software, version 5.12 (IBM, Armonk, NY).

RESULTS

Evaluation of *F* Value Distribution

The descriptive statistics of the experimental data (retort temperature, CT and *F* value) is shown in Table 1. *F* value distribution was predicted in various ways. First of all, cumulative histograms and *F* value/time scatter graphs for each size of can were drawn in order to obtain the distribution tendency of *F* values (Fig. 2). Cumulative histograms and scatter diagrams show that the distribution of *F* values fits a DED, also known as Laplace distribution.

TABLE 1.
DESCRIPTIVE STATISTICS OF EXPERIMENTAL DATA

	Retort temperature (*Tr*)			Can temperature (*Tc*)			*F* value		
Can type	0.5 kg	1.0 kg	5.0 kg	0.5 kg	1.0 kg	5.0 kg	0.5 kg	1.0 kg	5.0 kg
N	102	66	44	102	66	44	102	66	44
Minimum	21.44	19.00	30.60	26.17	17.70	45.80	0.00	0.00	0.00
Maximum	123.42	124.30	123.50	120.85	122.90	121.40	21.53	19.64	16.73
Mean	74.56	68.93	88.12	75.97	65.82	92.04	13.59	14.15	8.22
Median	87.32	54.90	104.90	83.50	54.40	99.75	20.70	19.66	7.53
SD	41.08	42.09	36.51	37.85	38.09	28.93	9.42	8.06	7.34

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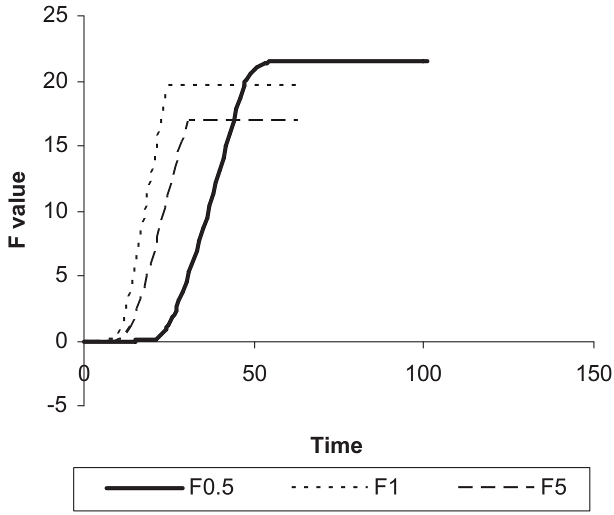

FIG. 2. *F* VALUE DISTRIBUTION ACCORDING TO CAN SIZES

This distribution type was verified by the Kolmogorov–Simirnov test, which showed that distribution of *F* values, depending upon can size, was well fitted into DED (Eq. 1). In addition, it was also observed that there was a tendency toward normal and uniform distributions in larger sample sizes (number of measurement).

Although it is possible to create large sample sizes through the Monte Carlo simulation technique (Hayakawa *et al.* 1988; Law and Kelton 1991; Wang *et al.* 1991; Xie and Sheard 1995; Hayakawa *et al.* 1994; Varga *et al.* 2000b) and to obtain a normal distribution curve, in practice, sterilization is limited by time, and so it is very difficult to obtain large sample sizes. Data generation methods were not available for the analyses, and using the Monte Carlo simulation might cause misleading results because of the central limit theorem. According to the central limit theorem, even if distribution in the original population is far from normal, the distribution of samples means $\bar{X}$ tends to become normal as the number of samples increases (Snedecor and Cochran 1987). The Gaussian (normal) distribution is a continuous symmetric distribution that follows the familiar bell-shaped curve. The distribution is uniquely determined by its mean and variance. It has been noted that, empirically, many measurement variables have distributions that are at least approximately normal. Even when a distribution is nonnormal, the distribution of the mean of many independent observations from the same distribution becomes arbitrarily close to a normal distribution, as the number of observations increases. Many frequently used statistical tests make the assumption that data

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TABLE 2.
DIFFERENCES OF *F* VALUE IN DIFFERENT CAN SIZES

		Mean rank	Sum of ranks	Z
$F_1 - F_{0.5}$	Negative ranks	17.53	315.50	
	Positive ranks	35.48	1,454.50	
$F_5 - F_{0.5}$	Negative ranks	0	0	
	Positive ranks	17.50	595.00	
$F_5 - F_1$	Negative ranks	19.00	703.00	
	Positive ranks	0	0	
$F_1 - F_{0.5}$				–4.29*
$F_5 - F_{0.5}$				–5.09*
$F_5 - F_1$				–5.32*

* Statistically significant at 1% level.

come from a normal distribution. Thus, it is very important to determine the distribution of a valid sample size and to evaluate the criterion through the specific methods or tests of a given distribution.

The F value data show a similarity with order statistics in which data values in a sample are sorted into increasing order, where the ith order statistic is the ith largest data value. For a sample size N, common order statistics are the extremes, the minimum (first order statistic) and maximum (Nth order statistic) (Snedecor and Cochran 1987; Averous *et al.* 2005; Hu and Zhuang 2005). The F value distribution is light-tailed (Varga *et al.* 2000a) and has a straight line (linear) between the upper and lower tails (Afaghi *et al.* 2001).

The differences of F values at the coldest point of the cans were confirmed using the Wilcoxon signed rank test (Table 2). In this test, the negative signs should be ignored because they show only the direction of differences as absolute values (Snedecor and Cochran 1987).

Estimation of *F* Value

Simple time/retort temperature and time/F value distributions can be estimated individually using various methods. In our study, both the time/retort temperature (T_r) and time/F value curves have been determined by curve estimation (Fig. 3). Curves of different can sizes were estimated from recorded data using linear, exponential, quadratic and cubic functions. It has been observed that the individual time/T_r and time/F value curves of each can size were well defined by cubic and quadratic functions. The reliability of the model/estimation was evaluated by multiple regression coefficients (R^2)

$$R^2 = 1 - \frac{(1 - r^2)(n - 1)}{(n - N - 1)} \tag{5}$$

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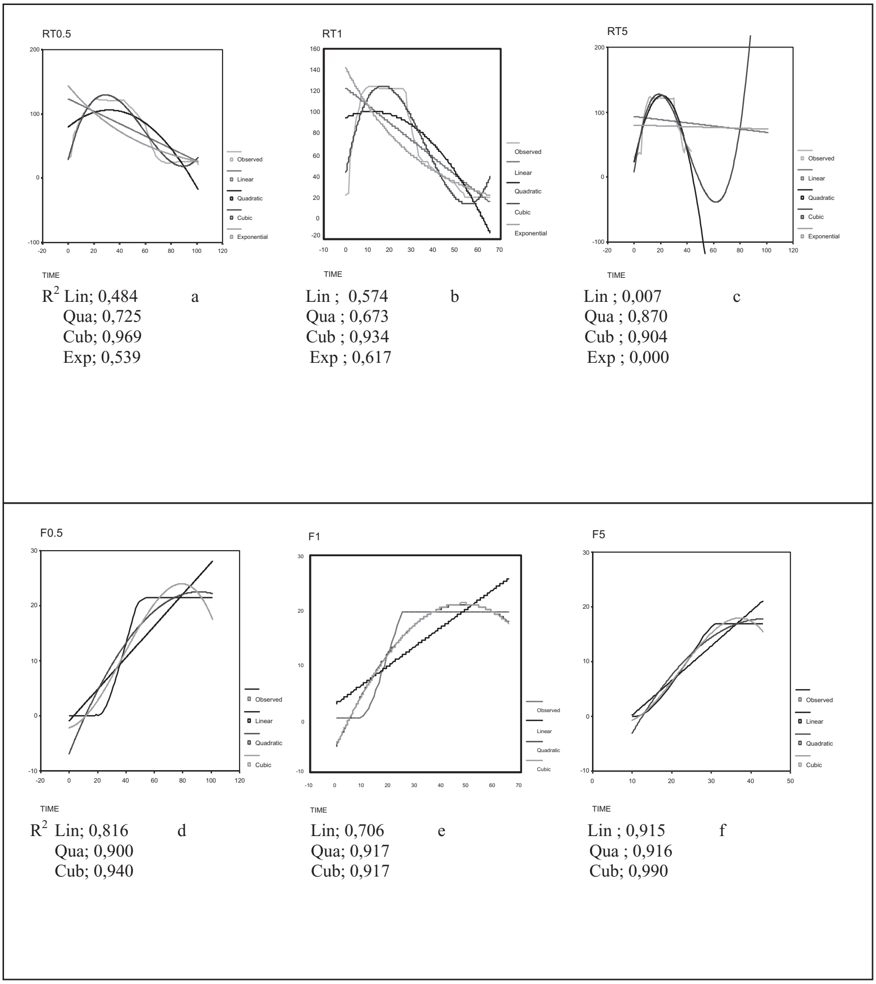

FIG. 3. CURVE ESTIMATIONS FOR RETORT TEMPERATURE AND *F* VALUE
(a)–(c), Curve estimations of retort temperatures (*Tr*); (d)–(f), curve estimations of *F* value. lin, linear; qua, quadratic, cub, cubic; exp, exponential; RT, retort temperature.

The *F* value is the function of retort temperature, CT, time, product-related properties, initial temperature, can type, size and head space. CT is also a function of retort temperature and time. There is a high correlation between retort temperature and CT during the sterilization process, as shown by the broken heating curves (Fig. 1) (Pearson correlation coefficients are 0.948, 0.953 and 0.927 for 0.5-, 1.0- and 5.0-kg cans, respectively; $P < 0.001$). These

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high correlation coefficients may cause an imperfect multicollinearity problem in estimations (Gujarati 1992); for this reason, one of them should be used in numerical modeling of canned foods during heat sterilization. Additionally, Ramaswamy and Marcotte (2006) imply that most formula methods make use of heat penetration parameters (heating rate and heating rate lag factor) obtained from a logarithm of the temperature difference between the retort and the product heating time. In addition, Adams and Hardtenglish (1990) reported that retort temperature distribution is a major factor to be analyzed, as required by good manufacturing practices and related food legislation. For this reason, in this study, we have mainly considered retort temperature for the statistical estimation of the *F* value, because it is more practical to measure retort temperature than cold spot temperature.

Although the individual distribution of *F* values is neither normal nor linear, *F* value/retort temperature and time relations can be estimated by multiple regression (Giannoni-Succar and Hayakawa 1982; Tejadillos *et al.* 2003; Zanoni *et al.* 2003). Linear regression attempts to model the relationship between two or more variables by applying a linear equation to observed data. The general purpose of multiple regressions is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable. In the multivariate case, when there is more than one independent variable, the regression line cannot be visualized in two-dimensional space, but can be computed easily. In general then, multiple regression procedures will estimate a linear equation of the form

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \varepsilon \qquad (6)$$

Estimated coefficients of *F* value are given in Table 3.

TABLE 3.
ESTIMATED PARAMETERS OF THE REGRESSION MODEL OF *F* VALUE

	$F_{0.5}$	F_1	F_5
n	102	66	44
α (constant)	−4.61*	−3.45*	−2.08*
β_{Tr}	0.03*	0.05*	−0.01*
β_T	0.31**	0.44**	0.54**
R^2	0.82	0.73	0.92
SD	3.98	4.21	2.12
F	232.55	87.34	237.14

* Significant at 10% level; ** significant at 1% level.

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$$F_{0.5} = -4.615 + \underset{(0.013)}{0.029}\, Tr_{0.5} + \underset{(0.019)}{0.316}\, t$$
$$(1.834)$$

$$F_{1} = -3.454 + 0.050\, Tr_{1} + 0.436\, t$$
$$(2.554)\ (0.019)\quad (0.042)$$

$$F_{5} = -2.085 - 0.015\, Tr_{5} + 0.543\, t$$
$$(1.041)\ (0.009)\quad (0.025)$$

The experimental and estimated F value means were calculated as 13.59 and 13.59 for the 0.5-kg can, 14.15 and 14.16 for the 1-kg can, and 8.22 and 8.22 for the 5-kg can, respectively (Table 4), whereas the maximum F values for the 0.5-, 1.0- and 5.0-kg cans were calculated as 21.53, 19.64 and 16.73 min, respectively (Table 1). In the estimated F values of each can size, negative F values were displayed, especially in the initial phase (Tables 2 and 3), however these extreme values do not affect the validity of the current estimation.

A comparison of the experimental data and estimated values (F value/ retort temperature and time) is given in the three-dimensional drawings in Fig. 4.

There is a high correlation between experimental and estimated F values for each can size. The Pearson correlation coefficients are 0.91 for the 0.5-kg can ($n = 102$), 0.86 for the 1-kg can ($n = 66$) and 0.96 ($n = 44$) for the 5-kg can ($P < 0.001$). These correlation coefficients between the observed and estimated data show that the statistical estimation model is suitable for use in the thermal processing of canned olives, and could also provide a sufficient approximation in the numerical modeling software used for the heat sterilization of canned foods.

TABLE 4.
EXPERIMENTAL AND ESTIMATED F VALUE

	$F_{0.5}$		F_1		F_5	
	Experimental	Estimated	Experimental	Estimated	Experimental	Estimated
n	102	102	66	66	44	44
Minimum	0	−3.67	0	−2.33	0	−2.56
Maximum	21.53	27.98	19.64	25.88	16.73	20.62
Mean	13.59	13.59	14.15	14.16	8.22	8.22
SD	9.42	8.55	8.06	6.91	7.34	7.04

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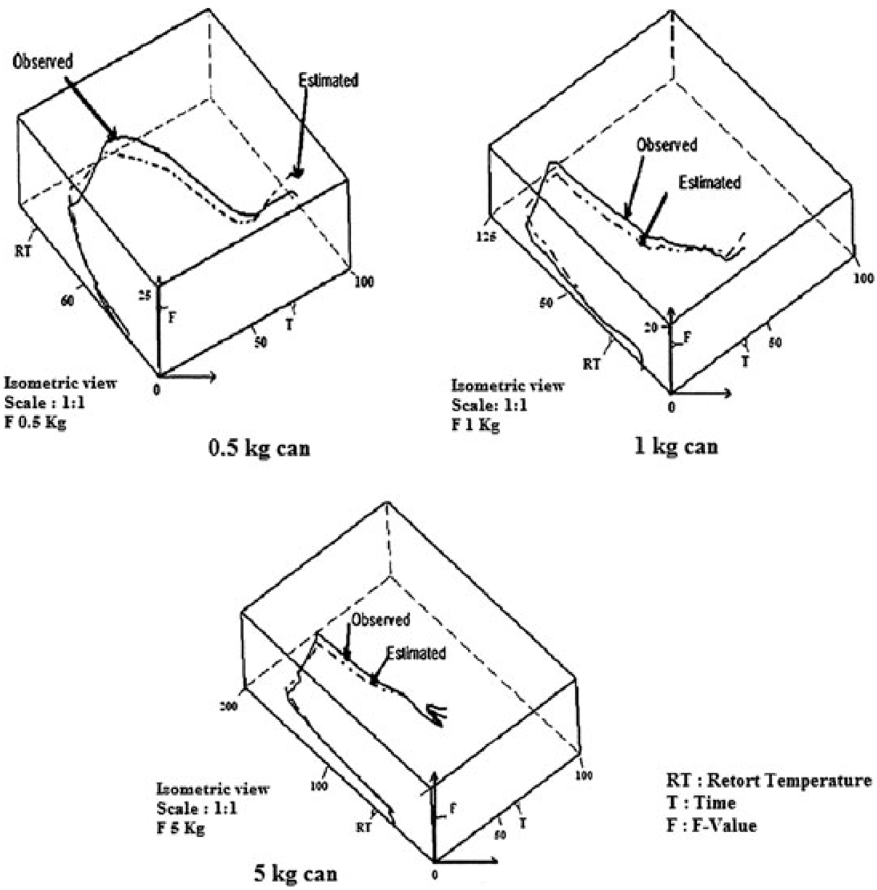

FIG. 4. ISOMETRIC VIEWS OF OBSERVED AND ESTIMATED *F* VALUE CURVES

DISCUSSION

In previous studies, sterilization values were determined based on the cold spot temperature of the can. In this study, a new approach to determining *F* values was developed and tested using integrated statistical methods.

The steam used for heating during commercial sterilization first heats the environment of the retort and then the canned products in the retort. In other words, the cold spot temperature of a can depends on changes in the retort temperature. For this reason, the main variable used to predict the sterilization value in our research was chosen as the retort temperature, which was more

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practical. Therefore, interaction among the variables of thermal sterilization (retort temperature, sterilization value and time) was investigated, after which the F values belonging to two process variables (retort temperature and cold spot temperature) were compared. The results were verified successfully with a low SD.

NOMENCLATURE

DED	double exponential distribution
e	natural logarithm (Euler's e)
F_0	lethality/sterilization value
F_n	F value of n kg can
n	number of observations
N	number of terms
P	Pearson correlation coefficients
$P(x)$	probability function
R^2	multiple regression coefficient
T	current temperature
t	time
Tc_n	can temperature of n kg can (C)
T_r	reference temperature (121.1C)
Tr_n	retort temperatures for n kg can (C)
X	variable
Y	dependent variable
Z	critical value of Wilcoxon signed rank test
z	10C (Temperature sensitivity indicator which represents the temperature range between which the D value (decimal reduction time) curve passes through one logarithmic cycle)
β	scale parameter
μ	mean

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