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Determination of Thermal Process Requirements for Baked Soybeans Canned in Brine and Tomato Sauce – A Comparative Study of the Methods of Process Calculation

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Thermal process schedules were evolved for baked soybean canned in 2.5% brine (pH 5.66) and in tomato sauce (pH 4.98). The cold point of plain A 2½ cans filled with brine and tomato sauce were found to be on central axis 2.0 cm and 4.0 cm above the base of the cans. The corrected process time (Pt) to achieve sterilization value (F_0) corresponding to 6.0 min for A 2½ can size at 121.1°C in still vertical retorts calculated by improved general and lethal rate paper methods were found to be 35.6 min and 36.8 min, respectively for baked beans canned in brine and 40.8 min, and 40.4 min, respectively for baked beans canned in tomato sauce. Process times were also calculated by six different formula methods. The process times to achieve F_0 value of 6.0 for baked soybean in brine were found to be 34.6 min by Ball's method; 33.7 min by Stumbo's method; 35.7 min by Steele et al method; 38.05 min by Steele and Board's method; 37.7 min and 38.4 min by Pham's methods. The corresponding process time for baked soybean packed with tomato sauce were 37.8 min; 37.8 min; 38.9 min; 37.3 min; 39.9 min and 40.4 min, respectively. Pham's method gave highest process times for both types of canned products. Process time obtained by the method of Steele et al was found similar to the value obtained by the improved general method for baked soybean in brine medium.

Keywords: Thermal processing, Soybean, Canning, Graphical method, Formula method, Brine, Tomato sauce, Process time, Heat penetration.

Among wide variety of canned bean products available, baked beans are very popular. The dry beans are soaked in fresh water for 12-16 h at 20-30°C (Lock 1960; Wang et al. 1988) and blanched subsequently for 5-10 min at temperatures ranging from 77-100°C (Jackson and Shinn 1979; Davis et al. 1980). The soaked and blanched beans are often referred to as baked beans because of their appearance. In India, soybean is used as an oilseed and has a very limited use as a vegetable. Sharma et al (1990) studied canning of soybeans in apricot sauce. The evaluation of thermal process requires accurate treatment of the time temperature history of exposure (Nunes and Swartzel 1990).

Several methods for calculation of process time have been developed. General method of Bigelow et al (1920); Lethal rate paper method of Schultz and Olson (1940) and Modified lethal rate paper method of Hayakawa (1973) are used widely. General method of Bigelow et al (1920) is the first scientific method developed for the calculation of process time. It is simple, versatile and can be readily applied to complex heating and cooling curves (Board 1965). A modified lethal rate paper technique was developed by Hayakawa (1973) for estimating sterilizing values.

Several formula methods for calculation of process time have been reported. Formula methods integrate the lethal effects using mathematical procedures (Ghazala et al. 1991). Hayakawa (1979) divided formula methods into two groups : (i) methods based on the accumulated lethality at the slowest heating point, and (ii) methods based on mass average lethality for whole containers. Smith and Tung (1982) and Saikia et al (1994) made a comparative study of different formula methods under Group I. The formula method of Ball (1923) based on the accumulated lethality at the slowest heating point is most widely used. Inaccuracies in the Ball's formula could lead to over-estimation of the lethal value and reduce the margin of safety of process (Merson et al. 1978; Steele et al. 1979). The revised tables for C:g and f_h/U: g overcome the problem to a great extent (Steele et al. 1979). An improved method process time calculation based on sterilizing ratios was described by Steele and Board (1979). This method is independent of the temperature scales used and reduces the number and size of associated tables. Pham (1987) method showed smaller errors as compared to other formula methods in terms of overall errors and standard deviation (SD) associated with process time calculation. Ball (1923); original tables of Ball and Olson (1957); Stumbo's table method (1973); Steele et al (1979) revised tables method; Steele and Board (1979) based on sterilizing ratios and Pham (1987, 1990) methods for $f_h = f_c$ and $f_h \neq f_c$ of formula methods were used and compared to each other for process evaluation in different types of packaging system. In this study methods were used for calculation of process time for baked soybeans canned in brine or tomato sauce in plain cans. The major objective of the present study was to evolve process time for baked soybeans canned in brine or tomato sauce. The process time has been evolved by graphical and different formula methods and compared.

Materials and Methods

Preparation of baked soybeans and tomato sauce:

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Soybeans of variety 'PK-472' procured from Crop Research Centre, G.B. Pant University of Agriculture and Technology Pantnagar, (India) were cleaned, graded and soaked overnight in water (beans to water ratio 1:5) at room temperature (27 ± 2°C), washed well with tap water and blanched for 10 min in boiling water (beans to water ratio 1:5).

Establishment of cold point: Copper constantan non-projecting plug-in-needle-type thermocouples (Model CNS, Ecklund Inc; USA, size 4.2 cm) were inserted at 2.0 cm, 4.0 cm and 6.0 cm height from the bottom position of A2½ (103 mm x 119 mm) cans. Tips of thermocouples were on the central axis of cans. Each can was filled with 470 g of baked soybeans covered with hot 2.5% brine (60°C). In another set of experiments instead of brine, hot tomato sauce (58°C) prepared according to the procedure described by Lal et al (1998) with the exception that 0.2% pectin was added on the weight of the finished product during cooking was used. The viscosity of tomato sauce was (5750 Cp) measured with the help of Brookfield Viscometer (Model LVT) using Spindle No. 1 at 0.6 rpm with high total solids (21.6%) and low pH (3.88), respectively (Tripathi 1997). The filled cans were covered with lids, exhausted to a central temperature of about 60°C and sealed using a double seamer. Thermocouples were connected through a selector switch to a digital temperature indicator (Make Nutronics, India). One thermocouple was placed in still vertical retort. The retort was closed, steam let in and steam pressure was maintained at 1.05 kg/cm². Heating was continued till product temperature reached to a maximum of about 119.4°C (247°F). At this stage, steam supply was shutoff and the cans were transferred to a water tank. Later they were cooled under running tap water. The temperatures of canned products were recorded during heating and cooling phases at a regular interval of 2 min. Temperature of retort and cooling water bath was also recorded simultaneously. The position of thermocouple which gave slowest temperature changes during heating and cooling was selected as the cold point (Desrosier and Desrosier 1987).

Heat penetration studies: The exact positions of thermocouples for the baked soybeans packed in A 2½ plain cans in brine and in tomato sauce were selected as per the method described under cold point section. Thermocouples were placed at 2.0 cm height from the bottom position of can in case of brine medium and at 4.0 cm height from the bottom of can where tomato sauce was used as a covering medium when they were processed in vertical still retorts at 1.05 kg/cm². Thermocouples were placed within cans at these positions and the can temperatures during heating and cooling were recorded at regular intervals of 2 min (Tripathi 1997).

Plotting of heat penetration data: In improved general method, the time-temperature data were plotted on ordinary graph paper for the calculation of process time. A lethal rate paper (special coordinate paper) for process time calculation was also prepared as described in the method of Schultz and Olson (1940). In case of formula method, the heat penetration data were plotted on semi log paper by the procedure described by Stumbo (1973). The straight line portion of the heating curves was ensured that the line passes through points within 1°F of the actual temperature of the can during later phases of heating. Values of f_h, f_c, T_i, T_0, T_h, j_h, and j_c were obtained from the semi log plots of the data.

F-value consideration: All low acid foods should receive a minimum sterilization value (F_0) equivalent to 2.45 min at 250°F (F^{18}_{250} = 2.45) to ensure sterility with respect to *Clostridium botulinum.* The F_0 value of 4.0 to 6.0 min had been reported by Ranganna (1986) for beans in sauce for all can sizes. On the basis of these recommendations, F_0 value of 6.0 min was used in the present study keeping in view for safer side of processing.

Process time calculation: Process time was calculated by improved general method of Ball (1928) and lethal rate paper method of Schultz and Olson (1940) to achieve a sterilization value corresponding to F_0 of 6.0 min recommended by Ranganna (1986). Process time was calculated by the classical formula method of Ball (1923) and the modification suggested by Stumbo (1973); Steele and Board (1979); Steele et al (1979) and Pham (1987, 1990).

Ball's formula method: In the basic formula of Ball (1923)

$$B_B = f_h \, (\log j \, I - \log g) \qquad \text{-------------- (1)}$$

the value of g was obtained from f_h/U: g tables of Ball and Olson (1957).

Stumbo's method: Ball's formula is based on the assumption that j_c = 1.41 which may not be true in all cases. Hence Stumbo (1973) revised tables of f_h/U:g for different values of z and j_c were taken into consideration. Values of g for z value of 10°C (18°F) and j_c of cooling curve ranging from 0.40 to 2.00 were taken from his tables and then Eq. 1 was used to calculate the process time.

Method of Steele et al.: Steele et al (1979) found that the tables of f_h/U:g published by Ball and Olson (1957) were up to 26% of the actual value. Revised table of f_h/U:g developed by them for m+g values of 130°F and 180°F at z value of 10°C (18°F) were used to calculate the process time from Eq. 1.

Steele and Board's method: The method developed by Steele and Board (1979) is based on sterilization ratio for calculation of process time. The following major steps were used for the calculation of process time.

A) An initial value of the cooling phase lethality was assumed as $F_c = 0.1 \times F$

where, F_0 of 6.0 is the considered value in the present study.

B) F_h was the lethality of the heating phase and calculated from Eq. 2.

$$F_h = F - F_c \qquad \text{-------------- (2)}$$

F'_h was calculated from the Eq. 3

$$F'_h = F_h/[F_h \, .\exp \, (\mu.S_b)] \qquad \text{-------------- (3)}$$

where, S_b was obtained from Eq. 4

$S_b = (T_h - T_b) / z$ ---------------- (4)

The process time B was calculated from the Eq. 5

$B = (f_h / \mu). \ln (\mu.j_h . S_0/S_g)$ ---------------- (5)

here, S_0 was the sterilization ratio and calculated by using Eq. 6

$S_0 = (T_h - T_0) / z$ ------------- (6)

In this, S_g was the sterilization ratio at the end of the heating and found corresponding to F'_h value given in Table 1 of Steele and Board (1979).

C) Calculation of F_c was based on the method outlined by Graffin et al. (1971), F_c was calculated from the Eq. 7

$F_c = F_c . F'_c . \exp (\mu . S_{cb})$ ------------- (7)

The S_{co} value was calculated by using Eq. 8

$S_{co} = S_w - S_g$ --------- (8)

and the S_w value was calculated by using Eq. 9

$S_w = (T_h - T_w)/z$ ----------- (9)

F'_c was found corresponding to j_c and S_{co} values were given in Table 2 of Steele and Board (1979)

The value of S_{cb} was calculated from the Eq. 10

$S_{cb} = (T_{co} - T_b) / z = S_b - S_g$ ---------------- (10)

where S_b value was obtained from Eq. 4

All steps from B to C were repeated until F_c calculated agreed to the required accuracy (0.1 min is satisfactory) with respect to assumed F_c.

Pham's method: Pham (1987) developed a method for calculation of sterilizing value U, for the both heating and cooling periods.

$W = -\log_{10} (g/z) + Aj - B/j + C$ -------------- (11)

where, W = U/f, and U = F = 6.0 as F = 6.0 min was taken as considered value in this study. F or U was known as sterilizing value, j was lag factor and f was time constant.

A, B and C were the process specific parameters and calculated by using the following equations:

$A = 0.088 + 0.107 N_2$

$B = 0.102 N_1$

$C = 0.074 N_1 + 0.177 N_2 - 0.653$

In the above equations

$N_1 = z/(T_h-T_1)$

$N_2 = z/(T_h-T_c)$

where, T_h = 121.1°C (heating medium temperature), T_i = initial product temperature (product at start of heating, °C), T_c = 27.2°C (Cooling medium temperature) and z = 10°C (18°F).

Equation 11 holds to ± 3% for W>1 [i.e. for the high sterilizing value range (U/f>1)] and g/z was calculated form the Eq. 12.

$\log_{10} (g/z) = -W + Aj - B/j + C$ ------------ (12)

The value of log g was obtained and computed in Eq. 1 to calculate the process time (B).

Pham (1990) also developed a method for calculation of process lethality U from Eq. 13 when, F_h f_c.

$U = W_h f_h + W_c f_c$ ------------- (13)

where, $U = F^{18}_{250}$ = 6.0 min (considered value in the present study).

Value of W_h and W_c were obtained by Eq. 14 and 15 when high sterilizing value range: for $W_h + W_c > 1$ (Pham 1987).

$W_h = -\log_{10} (g/z) - 0.613 + (0.074 - 0.102/j_h) N_1$---(14)

$W_c = -0.04 + 0.088j_c + (0.177 + 0.107 j_c) N_2$ -----(15)

First, W_c was calculated by using Equation 15, then W_h value was calculated from Equation 13 and the value of log (g/z) was calculated by using Equation 14.

Once log (g/z) value was known, Equation 1 was then used to calculate the process time (B) and corrected process time (Pt).

Results and Discussion

Heat penetration into canned products: The cold point of A2½ cans of baked soybeans filled with brine in which the heating was by convection was found to be 2.0 cm above the base of the cans and with tomato sauce in which the heating was by conduction/slow convection was at 4.0 cm above the base. Similar results were observed by Saikia et al (1994) while estimating thermal process requirements for beans, gourds and curried vegetables. Heat penetration curves and the corresponding lethality curves were plotted on ordinary graph paper for baked soybeans in 2.5% brine and in tomato sauce. The curves showed faster heating in brine than tomato sauce.

Semi log plot of the heating curve for baked soybeans in 2.5% brine was a simple straight line except for the initial curvilinear portion and did not show any break (Fig. 1). The heating was by convection (f_h = 23.5 min) (Table 1). Semi log plot of cooling curve (Fig. 2) was also a straight line (f_c = 19.5 min) (Table 1). Maximum product temperature of the cold point of the can was 119.4°C after processing of cans for 44.0 min with initial temperature of 65.5°C. Semi log plots of heating and cooling curves of baked soybean packed in tomato sauce and processed similarly are shown in Fig. 3 and 4. Both the curves were simple straight lines and did not exhibit any break. The f_h (22.5 min) and f_c (34.0 min) values in the case of tomato sauce are also presented in Table 1. The mode of heating was by convection.

Process time for canned products: The corrected process time (Pt) obtained by improved general method of Ball (1928) to achieve F_0 value of 6.0 min for baked soybean in 2.5% brine and in tomato sauce processed at 121.1°C were 35.6 and 40.8 min, respectively (Table 2). In the case of lethal rate paper method of Schultz and Olson (1940), the plots of can temperatures on special coordinate paper gave lethality curves directly. Corrected process time (Pt) obtained by Schultz and Olson method corresponding to F_0 value of 6.0 min were 36.8 and 40.4 min, respectively for the baked soybeans in

TABLE 1. HEAT PENETRATION DATA FOR BAKED SOYBEANS CANNED IN PLAIN A2½ CANS AND PROCESSED IN STILL STEAM RETORT AT 121.1°C

Variables	Baked soybeans in 2.5% brine	Baked soybeans in Tomato sauce
RT, °C	121.1	121.1
T_c, °C	27.2	27.2
IT, °C	65.5	60.5
Th IT, °C	46.1	4.4
Corrected zero process time, min	8.12	8.12
F_0 used for calculation, min	6	6
m + g, °F	170	170
f_h, min	23.5	22.5
f_c, min	19.5	34
J_h	1.35	1.926
J_c	1.536	1.175

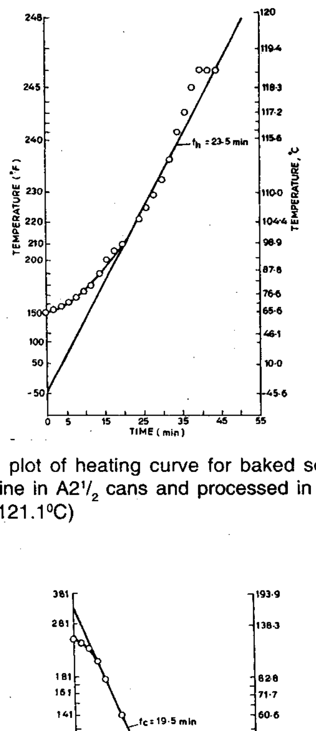

Fig. 1. Semilog plot of heating curve for baked soybeans canned in 2.5% brine in A2$^1/_2$ cans and processed in still steam retort at 250°F (121.1°C)

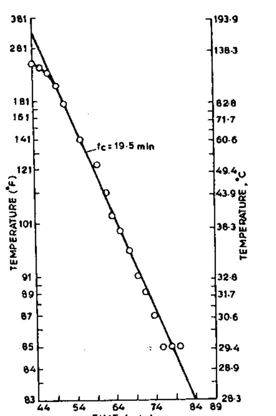

Fig.2 Semilog plot of cooling curve for baked soybeans canned in 2.5% Brine in A2 ½ cans cooled in water at 81 °F (27.2 °C)

Fig. 2. Semilog plot of cooling curve for baked soybeans canned in 2.5% Brine in A2$^1/_2$ cans cooled in water at 81°F (27.2 °C)

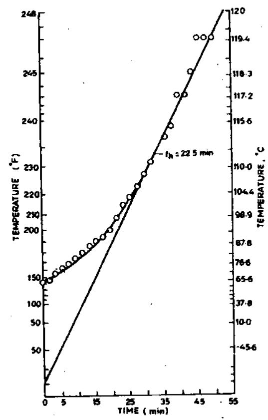

Fig. 3. Semilog plot of heating curve for baked soybeans canned in tomato sauce in A2$^1/_2$ cans and processed at 250°F (121.1 °C) in still steam retort

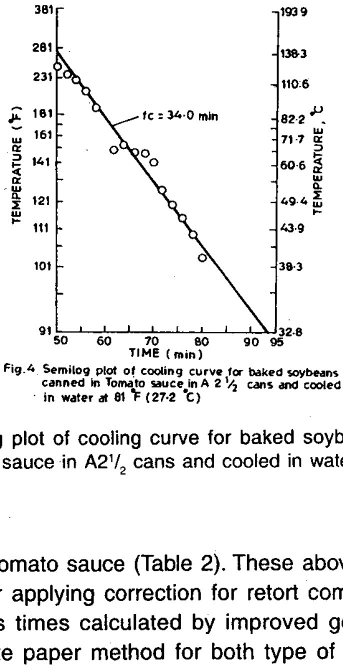

Fig.4 Semilog plot of cooling curve for baked soybeans canned in Tomato sauce in A 2 ½ cans and cooled in water at 81 °F (27.2 °C)

Fig. 4. Semilog plot of cooling curve for baked soybeans canned in Tomato sauce in A2$^1/_2$ cans and cooled in water at 81 °F (27.2 °C)

brine and in tomato sauce (Table 2). These above values were obtained after applying correction for retort come up time (14 min). Process times calculated by improved general method and lethal rate paper method for both type of products were almost same because both the above methods differ only in approach adopted for plotting lethality curve and their basic principle was also same (Nath 1996).

Process time calculated by different formula methods for baked soybeans canned in brine or in tomato sauce are given in Table 2. It was found to be 34.6 min for baked soybean in brine by Ball's formula method when original tables of Ball and Olson (1957) for f_h/U: g and m + g values were used. The calculated value of 33.7 min obtained by using revised tables of Stumbo (1973) for change in J_c was very close to the process time obtained by Ball's method. In case of baked soybeans in tomato sauce the calculated process times were found to be same (37.8 min) by both the methods. The process times for baked soybean in 2.5% brine obtained

TABLE 2. PROCESS TIMES* CALCULATED BY GRAPHICAL AND FORMULA METHODS FOR BAKED SOYBEANS CANNED IN A2½ CANS AND PROCESSED IN STEAM REPORT AT 121.1°C

Methods	Process time (min) for baked soybeans in	
	2.5% brine	Tomato sauce
Improved general method of Ball (1928)	35.6	40.8
Lethal rate paper method of Schultz and Olson (1940)	36.8	40.4
Ball (1923): Original tables of Ball and Olson (1957) for f_h / U:g, m+g values	34.6	37.8
Stumbo (1973): Table for g_c values at different j_c values	33.7	37.8
Steele et al. (1979): Revised tables for f_h/U:g, m+g values	35.7	38.9
Steele and Board (1979): Based on sterilizing ratios	38.05	37.3
Pham (1987): $f_h = f_c$	37.7	39.9
Pham (1990): $f_h \neq f_c$	38.4	40.4

* Corrected process time (Pt)

by using other methods were 35.7 min (Steele et al. 1979), 38.05 min (Steele and Board 1979); 37.7 min (Pham 1987) and 38.4 min (Pham 1990). The maximum process time was found by use of Pham (1990) method (Table 2). Process times for baked soybean in tomato sauce were found to vary from 37.8 to 40.4 min (Table 2). The increased processing time in tomato sauce may possibly due to high viscosity, high total solids and low pH. All these factors affect the heating mode and lower down the heating efficiency during thermal processing. The maximum process time for baked soybeans in brine medium was found to be 38.4 min by formula method which was slightly higher than the value of corrected process time (35.6 min) obtained by improved general method. Corresponding process time of 40.4 min obtained by formula method for baked soybeans canned in tomato sauce was found almost similar to the value of corrected process time (40.8 min) by improved general method of process time evaluation.

Conclusion

Corrected process times (Pt) by improved general method of Ball (1928) and lethal rate paper method of Schultz and Olson (1940) were found to be 35.6 and 36.8 min for baked soybeans canned in 2.5% brine, 40.8 and 40.4 min for baked soybeans canned in tomato sauce. The process times were also calculated by use of different formula methods. For canned soybeans in brine, process time obtained from Pham (1990) method was 38.4 min which was slightly higher than the values obtained by improved general method (35.6 min) whereas process time (35.7 min) obtained by Steele et al (1979) was almost similar to the value obtained by improved general method. Process time (40.4 min) for baked soybeans in tomato sauce calculated by Pham (1990) method was found very close to the value obtained by improved general method (40.8 min). Baked soybeans canned in tomato sauce (pH 4.98) required more process time than the baked soybeans canned in 2.5% brine (pH 5.66).

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Nomenclature

B_B	process time uncorrected for retort come-up time
F	process lethality
F_h, F_c	Lethality of heating, cooling phase
F_0	Required process lethality
f	Time constant
f_h, f_c	Slope of straight line portion of semi log of heating, cooling phase
g	Difference in temperature between product centre and retort at the end of the heating period
I	RT - IT
IT	Initial temperature
jI	Designates the point of intersection of the vertical line representing the corrected zero
j	Lag factor
P_t	Actual process time
RT	Retort temperature
S_0, S_g	Sterilizing ratio at the start, end of the heating
Th IT	Theoretical initial temperature
T_c, T_h, T_i	Temperature of: cooling medium, heating medium and product at start at heating process, °C
T_b, T_w	Base or reference temperature, cooling medium temperature, °C

T_0	Initial temperature at the centre of the can
T_{c0}	Temperature at the thermal centre of the can at the beginning of the cooling phase
U	Sterilizing value
W	U/f
W_h, W_c	The dimensionless sterilizing values for the heating and cooling phases
z	Slope of the thermal death time curve, or 18°F (10°C)
μ	The constant ln (10) = 2.3026

Subscripts

c	Cooling
h	Heating
i	Initial
0	Value at the centre

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