final report

Project code: A.MFS.0248

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Date published: January 2011

PUBLISHED BY
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Low temperature cooking of meats

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Contents

1. Background to the project

The introduction to the project brief received from MLA states that "Cooked meats that are ready to eat or are to be consumed with minimal reheating are susceptible to contamination with *Listeria monocytogenes*, which may grow in the product during (its) shelf-life and render the product unsafe for human consumption. Tables have been developed with time-temperature requirements for cooking to deliver to product a 6 *D* (log reduction) in *L. monocytogenes*. These tables are over 20 years old and do not extend to the full range of temperatures that are used in manufacturing and food service operations."

The purpose of the project is to develop a table that shall be applicable for temperatures ranging from 55 to 85 °C. The table that shall be generated shall specify the exposure times at the SHP (slowest heating point) of cooked meats required to achieve, at least, a 6 log reduction in *L. monocytogenes*. The table will be based on data obtained from a literature review of the heat resistance of *L. monocytogenes* in a variety of meat and other products.

2. Project objectives

The objectives of the project are as follows:

1. Review the scientific basis for time-temperature requirements in current food regulation. This shall include review of the codes issued by AQIS and USFDA and, where applicable, Good Manufacturing Practice recommendations from relevant advisory bodies and research organisations.
2. Review recent data and approaches to determining time-temperature requirements for safety in cooked meat products
3. Prepare time-temperature tables over the temperature range of 55-85°C.

3. Methodology

The papers and other publications that were reviewed are cited in full in Appendix I and in abbreviated form beneath Table 1.

In order to determine the hold time required at a specified temperature to bring about the desired 6 log (6*D*) reduction of the population of *L. monocytogenes* it is necessary to know each of the following,

- The *D* value, or the decimal reduction time, which is the time required at a specified reference temperature to bring about a 90% (i.e. a one log) reduction in a pure culture of the target microorganism (in this case *L. monocytogenes*).
- The *z* value of the target microorganism which is the number of degrees required to bring about a 10 fold change in its *D* value.
- The lethal rate L (at temperatures from 55 to 85 ^{o}C) relative to the lethal rate being unity at the reference temperature.

The equation for calculation of lethal rate is

$$L = Log^{-1} (T - T_r) / z \qquad (1)$$

where T = product temperature at the slowest heating point (i.e. at the core)

T_r = reference temperature

z = number of degrees required to bring about a tenfold change in the decimal reduction time (*D*)

Shown in Table 1 are the reference temperatures, *D* values, *z* values and the test media (where cited) that were quoted in the nine sources that were reviewed. Using these values the lethal rates (L values) for each of the nine data sets were calculated over the 55 to 85 ^{o}C temperature range.

Once L values had been determined using equation 1, the *D* values at the nominated temperatures were then calculated using equation 2.

$$D_t = D_{ref} / L_t \qquad (2)$$

where D_t = the *D* value at the nominated temperature t (between 55 and 85 °C)

D_{ref} = the *D* value at the quoted reference temperature

L_t = the lethal rate at the nominated temperature t (as calculated using equation 1) relative to the lethal rate being unity at the reference temperature

Once D_t values had been determined using equation 2, the hold times required to bring about a six log reduction (i.e. a 6 *D* reduction) in *L. monocytogenes* at each of the core product temperatures between 55 and 85 °C were calculated. The products of these calculations have been presented in the body of Table 1.

When interpreting the data in Table 1 it is important to understand that the time-temperature combinations shown within each of the eight sets of data are equivalent in lethality. This means, for instance, that each of the time-temperature combinations shown in the second column of Table 1 (i.e. Gaze *et al*[1]) will bring about a 6 log reduction in *L. monocytogenes* counts. Similarly, with the other seven sets of data, the time-temperature combinations for each will bring about 6 log reductions in *L. monocytogenes* counts.

It should also be understood that each of the time-temperature combinations in Table 1 express the integrated lethality of a thermal treatment in terms of time at a reference temperature. This means that according to Jemmi and Stephan, and USFDA, 2.0 minutes at 70 °C is the total lethality of the process expressed in minutes at 70 °C even though the heating profile obtained by placing thermocouples at the slowest heating point of the product and recording temperature throughout the entire process (including cooling) may have shown that the core temperature did not reach, or may have exceeded, 70 °C. Had the heating profile been based upon a reference temperature of 64 °C the total integrated process lethality would have been equivalent to exposure at 64 °C for 12.60 min.

Table 1. Hold times (min) at product core temperatures of between 55 and 85 °C required to deliver 6 log reductions in *Listeria monoctyogenes* counts

Reference	Gaze *et al*[1]	Gaze *et al*[1]	ICMSF[2]	AQIS[3], Cox & Bauler[4]	Jemmi & Stephan[5], USFDA[6]	Doyle *et al*[7]	Selby[8]	Vanderlinde & Duffy[9]
Reference temp (°C)	70	64	70	70	64	60	55	64
D value (min)	0.20	2.21	0.27	0.34	2.10	4.47	112.30	2.17
z value (C°)	5.98	5.98	7.50	7.50	7.50	7.90	5.50	8.00
Test medium	Beef steak	Beef steak	Meat slurry	-	-	Beef	Beef bologna	-
Core temperature (°C)								
55	386.85	424.19	162.00	202.20	199.70	115.18	673.80	173.38
56	263.22	288.63	119.17	148.75	146.91	86.06	443.32	130.02
57	179.10	196.39	87.67	109.42	108.07	64.30	291.67	97.50
58	121.86	133.63	64.49	80.50	79.50	48.04	191.90	73.12
59	82.92	90.92	47.44	59.22	58.48	35.90	126.26	54.83
60	56.42	61.86	34.90	43.56	43.02	26.82	83.07	41.12
61	38.39	42.09	25.68	32.05	31.65	20.04	54.65	30.83
62	26.12	28.64	18.89	23.57	23.28	14.97	35.96	23.12
63	17.77	19.49	13.89	17.34	17.13	11.19	23.66	17.34
64	12.09	13.26	10.22	12.76	12.60	8.36	15.57	13.00
65	8.23	9.02	7.52	9.39	9.27	6.25	10.24	9.75
66	5.60	6.14	5.53	6.90	6.82	4.67	6.74	7.31
67	3.81	4.18	4.07	5.08	5.02	3.49	4.43	5.48
68	2.59	2.84	2.99	3.74	3.69	2.60	2.92	4.11
69	1.76	1.93	2.20	2.75	2.71	1.95	1.92	3.08
70	1.20	1.32	1.62	2.02	2.00	1.45	1.26	2.31
71	0.82	0.90	1.19	1.49	1.47	1.09	0.83	1.73
72	0.56	0.61	0.88	1.09	1.08	0.81	0.55	1.30
73	0.38	0.41	0.64	0.80	0.80	0.61	0.36	0.98
74	0.26	0.28	0.47	0.59	0.58	0.45	0.24	0.73
75	0.18	0.19	0.35	0.44	0.43	0.34	0.16	0.55
76	0.12	0.13	0.26	0.32	0.32	0.25	0.10	0.41
77	0.08	0.09	0.19	0.24	0.23	0.19	0.07	0.31
78	0.06	0.06	0.14	0.17	0.17	0.14	0.04	0.23
79	0.04	0.04	0.10	0.13	0.13	0.11	0.03	0.17
80	0.03	0.03	0.08	0.09	0.09	0.08	0.02	0.13
81	0.02	0.02	0.06	0.07	0.07	0.06	0.01	0.10
82	0.01	0.01	0.04	0.05	0.05	0.04	0.01	0.07
83	0.01	0.01	0.03	0.04	0.04	0.03	0.01	0.05
84	0.01	0.01	0.02	0.03	0.03	0.02	0.00	0.04
85	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.03

References cited in Table 1.

1. Gaze *et al*. (1989).
2. ICMSF. (1996).
3. AQIS (1992).
4. Cox and Bauler (2008).
5. Jemmy and Stephan (2006).
6. US Food and Drug Administration (2001).
7. In Doyle *et al*. (2001).
8. Selby *et al*. (2006).
9. Vanderlinde and Duffy (1999).

4. Results and Discussion

Experimentally determined *D* values (and therefore, so-called, 6*D* processes) established under one set of conditions, frequently are compared with those determined by other laboratories under different conditions. However, several authors have commented that there can be limitations when making such direct comparisons and the reasons for this include the following:

- The thermal characteristics (*D* and *z* values) of *L. monocytogenes* are affected by the medium in which the microorganisms are heated (ICMSF, 1996; US Food and Drug Administration, 2001).
- The *D* value of *L. monocytogenes* is affected by 'strain variation, previous growth conditions, exposure to heat shock, acid, and other stresses, and composition of the heating menstruum' (Doyle *et al.*, 2001).
- Gaze *et al* (1989) noted that 'the techniques used by different groups of workers', including the container in which the microorganisms were heated, can affect the heat resistance of *L. monocytogenes.*
- Vanderlinde and Duffy (1999) observed that 'It is possible to extrapolate the time/temperature combinations .... (required by different countries) .... using these (different) z values, although extrapolations can result in errors especially at temperatures well away from the data (the 60 to 76 ^{o}C range) presented.' This means, for example, that the 6 *D* hold time of 673.8 min at 55 ^{o}C (shown in Table 1 and based on the data in the paper by Selby *et al*. [2006].) may not be accurately extrapolated to a 6*D* hold time of 0.01 min (0.6 s) at 83 ^{o}C.
- Different interpretations of data can lead to extrapolation of different conditions required to deliver 6 log reductions in *L. monocytogenes* counts. For example, the time-temperature combinations derived from the paper by Vanderlinde and Duffy (1999) and shown in Table 1 of this report are not only conservative but also they highlight the inconsistencies that can occur when interpreting primary data. In Appendix 1 of their paper Vanderlinde and Duffy include 6 *D* treatments for

L. monocytogenes of 12 min 45 s and 2 min 1 s at 64 and 70 °C, respectively. These values are in agreement with those shown in Table 1, according to AQIS (1992) and Cox and Bauler (2008) who use a z value of 7.5 °C. The 2 min 1 s at 70 °C, as quoted in the Appendix 1 of Vanderlinde and Duffy's (1999) paper, is effectively identical to the conservative 2 min at 70 °C value which is recommended by Gaze *et al* (1989). However, when using a z value of 8 °C (as shown in the body of Vanderlinde and Duffy's paper and in Table 1) the equivalent processes for a 6 log reduction of *L. monocytogenes* become 13.00 min (13 min 0 s) and 2.31 min (2 min 19 s) at 64 and 70 °C, respectively.

It is because of the individual and/or cumulative influence that the factors described above may have on the accuracy of determining minimum heating conditions for *L. monocytogenes* that caution should be exercised when extrapolating 6 *D* values to the second decimal place. For example, whilst the data presented by Gaze *et al* (1989) showed that the exposure times at 70 °C required to deliver 6 *D* processes for *L. monocytogenes* ranged from 0.84 to 1.62 min when heating in homogenates containing steak, chicken or carrot, these authors nevertheless recommended 'that the slowest heating point in a product should be held at 70 °C for 2 min to ensure that it is effectively decontaminated of *L. monocytogenes* if contamination is up to a level of 10^6 per container.' In this instance the recommendation has been conservative and incorporates a 23% increase above the maximum of the experimentally determined heating times in order to accommodate *L. monocytogenes* strains that might exhibit atypical *D* values under some test conditions.

5. Recommendations

In consideration of the inconsistencies that are apparent when comparing data from different studies and the different interpretations of those data, it is recommended that the heat treatments required to deliver 6 log reductions in *L. monocytogenes* should be equivalent to those shown in Table 2.

Table 2. Hold times[1] at product core temperatures of between 55 and 85 °C required to deliver 6 log reductions in *Listeria monoctyogenes* counts

Temperature	Time	
(°C)	(min)	(sec)
55	199	42
56	146	55
57	108	4
58	79	30
59	58	29
60	43	1
61	31	39
62	23	17
63	17	8
64	12	36
65	9	16
66	6	49
67	5	1
68	3	41
69	2	43
70	2	0
71	1	28
72	1	5
73	0	48
74	0	35
75	0	26
76	0	19
77	0	14
78	0	10
79	0	8
80	0	5
81	0	4
82	0	3
83	0	2
84	0	2
85	0	1

1. Based on a D_{64} value of 2.10 min and a z value of 7.5 °C

Points to note in interpretation of the data in Table 2 include the following:

1. The time/temperature combinations in Table 2 are all equivalent processes with respect to the destruction of *L. monocytogenes*. For instance, assuming instantaneous heating and cooling at the slowest heating point of the product, a treatment that maintains the core temperature at 60 °C for exactly 43 min and 1 second is equivalent with respect to the destruction of *L. monocytogenes* to a heat treatment at 70 °C for 2 min.
2. In practice, in commercial rather than laboratory applications, because of heating and cooling lags throughout the product mass, heating and cooling at the slowest heating point will not be instantaneous. For this reason the equivalence of the heat process is determined by integration of the time-temperature profile at the slowest heating point using a known reference temperature and a known z value.
3. The hold times shown in Table 2 are those necessary at constant core (product) temperatures in order to achieve 6 log reductions of *L. monocytogenes*. These hold times should not be confused with the actual process temperatures experienced in the heating vessel (e.g. in the hot water bath, or pasteurisation chamber, or hot air oven, or retort) which may exhibit heating and cooling gradients during a thermal process.

   As a hypothetical example consider the following. Heat penetration trials have shown that to deliver a 6 log reduction in *L. monocytogenes* counts in a 500 g pack of diced beef it is necessary to fully immerse the pack for 58 min in a water bath at 65 °C. In this example analysis of the heat penetration data shows that this process will deliver a pasteurising effect which is equivalent to the recommended 2 min at 70 °C. Calculations also show that equivalent processes could have been achieved by immersion at 55 °C for 250 min, or 74 °C for 3.8 min. This means that each of these three hypothetical processes is equivalent to 2 min at 70 °C at the slowest heating point of the pack.
4. In order to satisfy the recommendations shown in Table 2 and establish a safe thermal process it is necessary to conduct replicate heat penetration trials, under worst-case conditions, using calibrated temperature logging equipment. As a guide it is recommended that at least six heat penetration data sets are gathered.
5. To comply with Good Manufacturing Practice it is recommended that temperature distribution trials throughout the heating vessel are conducted in order to determine whether and where cold spots may be located. Unless identified cold spots can lead to delivery of insufficient thermal processes.

6. Appendix I

References.

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