Crops / Tomatoes / Canning / Acidulation

ACIDULATION OF HOME-CANNED TOMATOES

G. M. SAPERS, J. G. PHILLIPS, F. B. TALLEY, O. PANASIUK and J. CARRE

ABSTRACT

The feasibility of acidifying home canned tomatoes was determined. Citric acid, lemon juice, or vinegar were added at three concentrations to tomatoes which were canned by the raw pack method. The pH of low acid products was lowered effectively by acidulation with lg citric acid monohydrate or 1 tbsp lemon juice per pint. Vinegar was less effective than the other acidulants and also contributed an off-flavor at all levels. Acidulants equilibrated more rapidly when added to filled jars rather than to empty jars before filling. Alternative acidulation recommendations were compared by use of data derived from canning studies and from measurements of the response of high pH raw tomatoes to acidulation.

INTRODUCTION

THE POSSIBILITY that tomatoes having pH values high enough to permit the growth of *Clostridium botulinum* might be used by home canners has prompted canning specialists to consider the need for acidulation. Recently published data indicate that the occurrence of tomatoes having pH values of 4.8 or above is very rare (Sapers et al., 1977, Powers, 1976). Nevertheless recommendations for the addition of acidulants to home canned tomatoes have been issued from a number of sources including state extension specialists (Gould and Gray, 1974), popular magazines (Carper, 1976), home canning cookbooks (Better Homes and Gardens, 1973), and manufacturers of home canning equipment (Anon., 1975a). These recommendations are in some cases inconsistent. For example, the addition of 1/2 tsp lemon juice or 1/4 tsp citric acid per pint container were suggested as alternative (equivalent) means of acidulation although they differed in citric acid content by a factor of 10 (Gould and Gray, 1974). We have found other recommendations which call for the addition of 1 tsp of lemon juice or vinegar per pint (York, 1976) to be of questionable effectiveness, lowering product pH by less than 0.1 pH unit (Sapers et al., 1977). Misleading information of this type has been widely disseminated by the media.

Acidulants may be added to commercially canned tomatoes to reduce the risk of microbiological spoilage in accordance with 21 CFR Part 53.40 (Code of Federal Regulations, 1973). This practice is described in detail by Powers in his recent review (Powers, 1976). The Food and Drug Administration has recently proposed a change in the Good Manufacturing Practice for thermally processed low acid foods (Gardner, 1976) which would classify tomatoes having a pH above 4.6 as a low acid food unless they were acidified to pH 4.6 or below. The current upper limit for tomatoes, pH 4.7, does not provide an adequate safety factor with respect to the ability of *C. botulinum* to grow and produce toxin (Gardner, 1976).

Studies conducted by the USDA at the Eastern Regional Research Center (ERRC) have focused on the occurrence of low acid tomatoes (Sapers et al., 1977, 1978b) and on their response to canning (Sapers et al., 1978a). At this time we report the results of acidulation experiments conducted with low acid tomatoes to evaluate the effectiveness of three acidulants and their compatibility with home canning practices.

Authors Sapers, Talley, Panasiuk and Carré are with the USDA Eastern Regional Research Center, ARS, 600 E. Mermaid Lane, Philadelphia, PA 19118. Author Phillips is with the USDA Biometrical and Statistical Services, Northeast Region and is assigned to the Eastern Regional Research Center.

EXPERIMENTAL

Materials

Samples of 19 cultivars, representing both low and high acid tomatoes, were obtained from Beltsville, MD, Doylestown, PA, Mississippi State, MS, Sodus, MI, and Santa Paula, CA. Tomatoes were transported, ripened, and prepared for analysis and canning as described previously (Sapers et al., 1977; 1978a, b).

Canning and acidulation

Canning experiments were carried out with both ripe and overripe tomato samples which varied widely in acidity. The tomatoes were canned in pint jars by a modification of the USDA raw pack procedure (USDA, 1975) as described previously. Replicate filled jars were acidified after being filled and before being sealed and thermal processed by the addition of acidulants at three concentrations (in duplicate) together with 3g NaCl. Each canning experiment consisted of the six acidified jars, a control (containing 3g NaCl), and a raw composite for analysis. Acidulants included citric acid monohydrate (0.45, 0.72 and 1.00g per 450g product), bottled lemon juice (equivalent to 10, 15 and 20 ml of 5% citric acid solution per 450g product), and distilled white vinegar (equivalent to 10, 20 and 30 ml of 5% acetic acid solution per 450g product). Exact levels of addition of lemon juice and vinegar were calculated from the acidity of each individual bottle, determined by titration with 0.1N NaOH. The quantity of tomatoes in the jars containing lemon juice and vinegar was reduced by a weight equal to the volume of added acidulant so that the net weight and fill of container would be approximately constant. In addition to these acidulants, commercial acidulant tablets developed for home canners (Morton Salt Co., Chicago, IL) also were evaluated. The tablets, which contain 0.454g citric acid (anhydrous) and 2.0g NaCl, were added to the filled jars using one tablet per pint; accompanying controls also contained 2.0g NaCl. All jars were processed in a boiling water bath (100°C) for 35 min.

Canned products were allowed to equilibrate for 1 month at room temperature prior to analysis and sensory evaluation.

Equilibration experiments

Tomatoes were acidified and canned by the standard procedure described above (top addition) and also by adding acidulants and salt to empty jars and then filling with tomato pieces (bottom addition). After being thermally processed, the jars were equilibrated at room temperature for 1, 3 and 6 days. They were opened, and the contents were carefully removed with a small ladle as three 140g portions representing the top, middle, and bottom thirds of the product. Each portion was blended and analyzed separately.

Analyses

Immediately after each set of canning jars was filled, the accompanying raw composite was blended and analyzed for pH, titratable acidity, and response to acidification with 5% citric acid solution, as described previously (Sapers et al., 1977, 1978b). After equilibration, the appearance of canned products was noted, and the samples were blended and analyzed for pH and titratable acidity (Sapers et al., 1978a).

Sensory evaluation

A panel consisting of 16–18 members, screened for ability to recognize different acidulants and levels of acidity, evaluated the canned tomatoes. The tomatoes were blended at high speed for 2 min and served to panelists at room temperature in 2-oz portions. Each panelist was provided with a complete set of coded samples including a control and the acidified products. Panelists were asked to rate the samples using a standard 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely). No high pH canned products (composite pH > 4.5) were given to the panel to avoid any possible risk of botulism. The significance of differences in flavor scores between samples was determined by analysis of variance and Duncan's multiple range test.

RESULTS & DISCUSSION

Effectiveness of acidulants

The response of canned tomatoes to acidulation with citric acid monohydrate was determined with samples representing both high and low pH cultivars (Table 1). The lowest level of addition, 0.45 g/pint, (approx 1/8 tsp/pint) reduced the pH of the canned high pH tomatoes by about 0.2 unit. The highest level, 1g per pint (approx 1/4 tsp/pint), reduced the pH by 0.3–0.4 units. Similar results were reported by Leonard et al. (1960), Lamb et al. (1962), and Pray and Powers (1966). pH reductions at all levels of acidulation were smaller in low pH canned tomatoes than in the higher pH samples.

Table 1—Acidulation of canned tomatoes with citric acid monohydrate

			pH			
			Level of addition (g/pint)			
Cultivar	Source	Ripeness[a]	0	0.45	0.72	1.00
Ace	MI	R	4.59	4.42	4.36	4.27
Ace55VF	PA	OR	4.68	4.44	4.36	4.21
Cal Ace	MI	R	4.60	4.40	4.36	4.28
Garden State	MD	R	4.70	4.52	4.40	4.30
MD122	MD	R	4.64	4.36	4.29	4.18
Nova	MD	OR	4.59	4.34	4.28	4.20
Valiant	PA	OR	4.58	4.38	4.28	4.22
Big Girl	PA	R	4.34	4.18	4.10	4.04
Jet Star	PA	OR	4.26	4.12	4.04	3.96
Jubilee	PA	R	4.16	4.10	4.06	3.96
VF10	CA	R	4.23	4.08	4.00	3.95

[a] R = ripe, OR = overripe

Table 2—pH reduction in tomatoes canned with citric acid monohydrate, lemon juice and vinegar

	pH reduction[a]					
	Citric acid (g/pint)		Lemon juice (ml/pint)		Vinegar (ml/pint)	
Cultivar	0.45	1.00	10	20	10	20
Ace55VF	0.20	0.46	0.20	0.37	0.17	0.30
Big Girl	0.16	0.30	0.17	0.32	0.09	0.17
Fireball	0.16	0.33	0.21	0.38	0.13	0.24
Jet Star	0.18	0.38	0.20	0.37	0.17	0.24
San Marzano	0.16	0.28	0.18	0.35	0.21	0.27
Valiant	0.20	0.36	0.19	0.37	0.16	0.25

[a] Acidulants at approx equal concentrations (g acid/pint)

Table 3—Comparison of acidulants for home canned tomatoes

		Effectiveness[a]	
Acidulant	No. sets	Meq basis	Wt basis
Citric acid monohydrate	52	1.02	1.02
Lemon juice	12	1.01	1.01
Vinegar	26	0.55	0.64
Acidulant tablet[b]	3	1.10	1.10

[a] pH reduction with acidulant/pH reduction in composite titrated with 5% citric acid monohydrate solution

[b] Contains 0.454g citric acid (anhydrous)

We have compared citric acid (powder and tablets), lemon juice, and vinegar, the principal acidulants proposed for home canned tomatoes, at different levels of addition in both high and low acid canned tomatoes to determine their relative effectiveness (Table 2). Vinegar is a weaker acidulant on a molar basis than citric acid or lemon juice, which are similar. Citric acid is the major organic acid in lemon juice (Clements, 1964). We have found bottled lemon juice to be relatively constant in acidity: 5 samples representing 3 manufacturers contained between 5.2 and 5.6% titratable acidity, calculated as citric acid. In previous studies (Sapers et al., 1977), we reported a linear relationship between pH and added acid for acidified raw tomatoes. The same relationship applies to canned tomatoes; initial pH values and slopes for regression equations describing acidification with citric acid were the same (no significant differences at 0.05 level) for cans and corresponding raw composites which were titrated with 5% citric acid solution. We calculated acidification curve slopes for all sets of acidulation data and compared each acidulant to citric acid monohydrate by determining the ratio of slopes for cans and composites (Table 3). This method of comparison avoids the problem of batchwise differences in raw material pH and jar-to-jar variation which complicate the direct comparison of acidulants (Table 2). Citric acid and lemon juice are identical in effectiveness, both having slope ratios close to unity, and vinegar is about 2/3 as effective as citric acid, on an acid weight basis (Table 3). Citric and acetic acids have similar equivalent weights; however, citric acid is the stronger acid, its pk_1 value being 3.14 in contrast to 4.76, the pk for acetic acid (at 20°C). The acidulant tablets appear to be slightly more potent than would be predicted from their specified citric acid content; this discrepancy was subsequently confirmed by analysis of the tablets for titratable acidity.

Equilibration of acidulants

Canned tomatoes acidified with citric acid monohydrate or acidulant tablets, added to the top of the filled jars, equilibrated very quickly, probably as a result of convection during processing (Table 4). The top and bottom portions of the contents of each jar differed in pH by less than 0.1 unit within 1–3 days. However, products which were acidulated by the addition of acid to the bottom of the canning jars before filling, equilibrated much more slowly. Even after 6 days, the top portions of the acidified jars were about 0.3 pH unit higher than the bottom portions. The low pH and appearance of the bottom portions suggest that the acidulants dissolved but did not diffuse from the bottom serum layer through the

Table 4—Equilibration of canned acidified Ace55VF tomatoes

			pH		
Acidulant	Method of addition	Day	Top	Bottom	Difference
Citric acid monohydrate[a]	Top	1	3.95	4.06	–0.11
		3	4.03	4.12	–0.09
		6	4.06	4.08	–0.02
	Bottom	1	4.06	3.84	0.22
		3	4.11	3.80	0.32
		6	4.14	3.82	0.32
Tablet[b]	Top	1	4.18	4.26	–0.08
		3	4.18	4.24	–0.06
		6	4.22	4.14	0.08
	Bottom	1	4.32	4.00	0.32
		3	4.29	3.95	0.34
		6	4.28	3.94	0.34
Control[c]	Top	6	4.38	4.39	–0.01
	Bottom	6	4.40	4.32	0.08

[a] 1g per pint

[b] 1 tablet = 0.454g citric acid per pint

[c] 3g salt per pint

se mass of tomato pieces above. Some acidulation recommendations (Anon., 1975b; Anon., 1976) have specified that acidulants should be added to the jar before the tomatoes in order to achieve an even distribution of acidity. Our results, with the raw pack method of canning, lead us to the opposite conclusion: acidulants should be added after the jars are filled.

Effect of acidulation on acceptability

Sensory evaluation of canned low pH tomatoes to which acidulants had been added indicated that product flavor was not affected adversely by acidulation with citric acid monohydrate or lemon juice, even at the highest levels of addition (Table 5). On the other hand, vinegar was objectionable in some samples at the lowest level and in all samples at higher levels. We obtained similar results with higher pH canned tomatoes prepared from other cultivars including Ace, Ace 55VF, Big Boy, Fireball, Jet Star, Jubilee, San Marzano and Valiant. A number of studies have demonstrated that acidulation with citric acid, at levels comparable to those in our study, did not adversely affect tomato flavor (Powers, 1976). However, off-flavors due to vinegar have been reported by Klippstein (1976) and by Powers (1976). Since vinegar is a weaker acid than citric acid, it would have to be used at higher levels in canned tomatoes to achieve the desired pH reduction. At effective levels, vinegar would probably yield a product with an unacceptable flavor.

Acidulation requirements for high pH tomatoes

Published recommendations for the acidulation of canned tomatoes generally have been based on the results of studies with tomatoes which were not excessively high in pH, i.e., pH 4.3–4.6 (Lopez and Schoenemann, 1971; Pray and Powers, 1966; Leonard et al., 1959; Lamb et al., 1962; Kattan et al., 1956). Only Gould (see Powers, 1976) reported data on the acidulation of higher pH tomatoes (pH 4.5–4.77).

In parallel with the canning studies which yielded data on the acidulation of samples as high in pH as 4.74, we also obtained data on the acidulation of individual raw tomatoes from similar samples having even higher pH values, some as high as 5.1. Linear regression equations describing the titration of 54 such tomatoes with 5% citric acid solution were obtained. Since we previously established that acidulation curves for canned and raw tomatoes were identical, we have used regression coefficients derived from these equations to estimate acidulation requirements if the high pH tomatoes were to be canned. The acidulation requirement, defined as the quantity of acidulant required to lower the tomato pH from its original value to a target pH, can be calculated by dividing the difference between these pH values by the slope of the acidulation curve.

Acidulation requirements for the high pH tomatoes are summarized in Table 6. Three target pH values were used: 4.6, representing the upper pH limit for canned tomatoes proposed by the Food and Drug Administration to minimize the risk of growth and toxin production by *C. botulinum* (Gardner, 1976); 4.3 and 4.4, the latter pH values bracketing the lower limit for the germination of spores of *Bacillus coagulans*, an organism responsible for flat sour spoilage in canned tomato products (Rice and Pederson, 1954).

Acidulation requirements for high pH tomatoes vary widely within and between cultivars. A conservative estimate of the acidulation requirement for all high pH tomatoes should be based, not on the mean, but rather, on a level of acidulation which reduces a given percentage of the high pH tomato population below the target pH. That percentage can be determined from the proposed level of acidulation, the mean acidulation requirement for all cultivars (see Table 6), and the standard deviation for the acidulation requirement, assuming that the acidulation requirement for the high pH tomatoes is normally distributed. We compared a number of recent acidulation recommendations on that basis (Table 7).

Table 5—Sensory evaluation of high acid tomatoes canned with acidulants

Cultivar	Acidulant	Composite pH	Flavor score[a] Control	Low level[b]	High level[c]
Big Girl	Citric acid	4.30	5.50	6.00	5.61
	Lemon juice	4.31	6.58	6.35	6.17
	Vinegar	4.31	6.58	4.82[d]	3.17[e]
Heinz 1350	Citric acid	4.36	6.11	5.94	5.00[e]
	Vinegar	4.28	6.12	4.25[e]	3.43[e]
Manalucie	Citric acid	4.41	6.52	6.41	5.74[d]
	Lemon juice	4.26	5.87	6.12	5.62
	Vinegar	4.30	6.26	5.36	3.31[e]

[a] Nine-point hedonic scale
[b] 0.45g citric acid monohydrate, 10 ml lemon juice or 10 ml vinegar per pint
[c] 1.00g citric acid monohydrate, 20 ml lemon juice or 20 ml vinegar per pint
[d] Significantly different at 0.05 level
[e] Significantly differetn at 0.01 level

Table 6—Acidulation requirements for high pH tomatoes

Cultivar	No. tomatoes pH ≥ 4.75	Mean acidulation requirement[a] pH ≤ 4.6	pH ≤ 4.4	pH ≤ 4.3
Ace	5	0.32	0.67	0.95
Ace55VF	8	0.44	0.87	1.08
Cal Ace	10	0.36	0.61	0.74
Fireball	6	0.44	0.74	0.90
Garden State	20	0.48	0.84	1.02
Others	5	0.45	0.77	0.93
All cultivars	54	0.43	0.77	0.95
	Std Dev	0.12	0.15	0.19

[a] g citric acid monohydrate per pint tomatoes

Table 7—Effectiveness of different levels of acidulation with high pH tomatoes

Acidulant	Level per pint	Percent of high pH[d] tomatoes reduced to ≤ pH 4.6	≤ pH 4.4	≤ pH 4.3
Citric acid monohydrate	1/4 tsp	99.9	95	60
	1/8 tsp	75	5	1
Citric acid tablet[a]	1	60	2	0
Lemon juice[b]	1 tbsp	99	45	15
	2 tsp	75	5	1
	1 tsp	10	0	0
Vinegar[c]	1 tbsp	75	5	1
	2 tsp	20	0	0
	1 tsp	1	0	0

[a] Containing 0.454g anhydrous citric acid
[b] Containing 5% anhydrous citric acid
[c] Containing 5% acetic acid equivalent to citric acid X 0.64
[d] Assuming acidulation requirements for individual high pH tomatoes (Table 6) to be normally distributed.

Only the highest recommended levels of citric acid and lemon juice would reduce essentially all of the high pH tomatoes represented by our data (Table 6) to pH 4.6 or below. Substantial protection against microbiological spoilage would also be achieved, especially with the citric acid recommendation. The lower level of lemon juice and the two lowest levels of vinegar would be virtually worthless in reducing high levels of vinegar would be virtually worthless in reducing high pH tomatoes to or below either target pH (pH 4.6 or pH 4.3–4.4). Other levels of acidulation compared on Table 7 would lower the pH of most high pH tomatoes to 4.6 but not to pH 4.3–4.4. Consequently, if one wished to assure the absence of canned tomatoes exceeding pH 4.6 and also provide protection against spoilage, an acidulation level of 1/4 tsp citric acid monohydrate or one tbsp bottled lemon juice (containing 5% citric acid) per pint would be required. Higher levels of acidulation would reduce the probability of spoilage but would entail the use of inconvenient units of measure, i.e., 4 tsp, and might have an adverse effect on product flavor.

REFERENCES

Anon. 1975a. How to hot pack or cold pack with your home canner. General Housewares Corp., Terre Haute, IN.

Anon. 1975b. Suggest raising acidity when canning tomatoes (Press release). Purdue University, West Lafayette, IN. Sept. 4.

Anon. 1976. Label for Morton New Tomato Canning Tablets. Morton Salt Co., Chicago, IL.

Better Homes and Garden. 1973. "Home Canning Cookbook," p. 44. Bantam Books, Inc., New York.

Carper, J. 1976. Home Canning: The proper way. Readers Digest, August, p. 145.

Clements, R.L. 1964. Organic acids in citrus fruits. 1. Varietal differences. J. Food Sci. 29: 276.

Code of Federal Regulations. 1975. Title 21, Food and Drugs, Section 53.40 Canned Tomatoes; identity; label statement of optional ingredients.

Gardner, S. 1976. Pickled, fermented, acidified and low acid foods. Proposed good manufacturing practices. Federal Register 41(143): 30442.

Gould, W.A. and Gray, E.J. 1974. Canning tomatoes in the home. Cooperative State Extension Service. The Ohio State University. 6/74/10M.

Kattan, A.A., Ogle, W.L. and Kramer, A. 1956. Effect of process variables on quality of canned tomato juice. Proc. Am Soc. Hort. Sci. 68: 470.

Klippstein, R. 1976. Cornell University. Personal communications.

Lamb, F.C., Lewis, L.D. and Kimball, J.R. 1962. Factors affecting the pH of tomatoes. Research Report 61-C-44. National Canners Assoc., Berkeley, CA.

Leonard, S.J., Pangborn, R.M. and Luh, B.S. 1959. The pH problem in canned tomatoes. Food Technol. 13: 418.

Leonard, S.J., Luh, B.S. and Pangborn, R.M. 1960. Effect of sodium chloride, citric acid, and sucrose on pH and palatability of canned tomatoes. Food Technol. 14: 433.

Lopez, A. and Schoenemann, D.E. 1971. Updating developments in acidification of canned tomatoes. Canning Trade 93(19): 8.

Powers, J.J. 1976. Effect of acidification of canned tomatoes on quality and shelf life. Critical Reviews in Food Science and Nutrition, p. 371.

Pray, L.W. and Powers, J.J. 1966. Acidification of canned tomatoes. Food Technol. 20(1): 87.

Rice, A.C. and Pederson, C.S. 1954. Factors affecting growth of Bacillus coagulans in canned tomato juice. 2. Acidic constituents of tomato juice and specific organic acids. Food Research 19: 124.

Sapers, G.M., Panasiuk, O. and Carré, J. 1978a. Effects of thermal processing and salt on the pH and acidity of home canned tomatoes. J. Food Sci. 43: 951.

Sapers, G.M., Phillips, J.G., Panasiuk, O., Carré, J., Stoner, A.K. and Barksdale, T. 1978b. Factors affecting the acidity of tomatoes in home canning. HortScience 13(2): 000.

Sapers, G.M., Stoner, A.K. and Phillips, J.G. 1977. Tomato acidity and the safety of home canned tomatoes. HortScience 12: 204.

U.S. Department of Agriculture. 1975. Home canning of fruits and vegetables. Home and Garden Bull. No. 8. March 1975. Washington, D.C.

York, G.K. 1976. Things to know before you can fruits and vegetables (part 2). (Press release) University of California, Davis, April 19.

Ms received 8/26/77; revised 11/28/77; accepted 12/1/77.

Presented at the 37th Annual Meeting of the Institute of Food Technologists, Philadelphia, PA, June 5-8, 1977.

The authors thank Professors Hugh C. Price and Theodore Wishnetsky of Michigan State University, Professors Milo Burnham and Gale R. Ammerman of Mississippi State University, Theodore C. Torrey and Lois Stringer of the W. Atlee Burpee Co., and Dr. Allan K. Stoner, USDA Beltsville Agricultural Research Center, ARS, for their help in providing tomatoes for our canning studies. We also acknowledge the assistance of Sandra P. Graham, Statistical Clerk at ERRC, and William M. Brooks, Paula Civitillo, Anthony Dixon, and Cindy Oshman, Summer employees.

Reference to a brand or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

MONITORING TECHNIQUE FOR BULK TOMATO PASTE . . . From page 1048

In conclusion, determination of diacetyl and acetylmethylcarbinol production in conjunction with a minimal of traditional bacteriological testing offers a rapid, sensitive, and economical means of monitoring the sterility of an aseptic tomato paste system. Media costs, laboratory technician manpower hours, and obvious savings of tons of finished product almost make this monitoring parameter a necessity in an aseptic system of this type.

REFERENCES

Byer, E.M. 1954. Visual detection of either diacetyl or acetylmethylcarbinol in frozen concentrated orange juice. Food Technol. 8: 173.

Jones, A.H. 1936. A study of organisms causing gaseous spoilage of canned tomato products. Canadian Canners & Food Manufacturer 7: 9.

Pederson, C.S. 1949. The type of organisms found in spoiled tomato products. NY State Agric. Expt. Stat. Tech. Bull. 285.

Ms received 4/7/77; revised 8/7/77; accepted 8/12/77.

The author thanks Dr. Jack Ralls of National Canners Association, Berkeley, CA, for valuable discussions and suggestions throughout the course of this investigation. The author also thanks Dr. Ralls and Mr. Richard Lane for instructions in use of NCA's GLC-Mass Spectroscopy set-up.

Of 387 jars of to
seven showed mi
failure. Of the ren
4.65: otherwise all
as was applied to
the content of a
0.0014. The total
grams malic acid
vacuum of the co

ABOUT 20 YR
pH of tomatoe
Clostridium bot
ucts (Powers,
(Farrow, 1963)
of 14,728 indivi
6% of the toma
4.8. Spores of C.
produce toxin a
In theory, one
can where spor
from the billio
over the years v
much for the o
been subjected
Nelson (1956) a
that the pH ra
spores is narrow

In recent ye
from either ho
1974) and over
and Canada (Po
which may acc
canners as com
home gardeners
these may be hi
Scientific Statu
mercial canners
used at home n
are so many mo
some would fai
tended to cast s
bilities.

Sapers et al.
only the pear t
4.6. Wolf et a
above pH 4.6. t
as the raw tom
tions. Fields et
They found tha

Authors Powers ar
versity of Georgia,