J. Food Sci. Technol., 1993, Vol 30, No.6, 422-428

Thermal Processing of Acidified Vegetables

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Effect of lowering the pH, either by adding acid or lactic fermentation, on thermal process requirements for canned vegetables was investigated. Malic acid was preferred for acidification of canned vegetables. Addition of acid to covering brine was preferable to the blanching in acid solution, as the acidification was uniform, and it reduced the extent of discolouration. Acidification by lactic fermentation, using 2% boiling hot brine to cover the prepared vegetable, reduced the pH to 3.8 in 3 days. Fermentation is initiated by the species of *Leuconostoc* and *Lactobacillus* followed by *Pediococcus* and *Streptococcus*, Process time, based on a sterilisation value of $F_{100}^{8.9}$ = 3.5 min, was adequate to render the canned acidified vegetables (pH $\leq$ 4.0) microbiologically safe. The process time required for 77.8 x 119.1 mm and 103 .2 x 119.1 mm cans, having initial temperature of ~65°C, was 15 min or less in boiling water. Colour of the lactic fermented canned products was superior to canned vegetables acidified with malic acid. Both had texture similar to that of the freshly cooked vegetables. Products acidified by fermentation had minimal sour taste.

Keywords : Acidified vegetables, Fermented vegetables, Canning, Thermal processing, Microbial changes, Storage studies.

Thermal process requirements for low-acid foods (pH > 4.6), especially vegetables, are severe due to the possibility of growth of toxigenic *Clostridium botulinum* and other heat resistant spore - forming bacteria. In earlier studies, the thermal process schedules for okra, potato, yam and drumstick are reported (Saikia and Ranganna, 1992). Acidification, either by addition of acid or by fermentation, to lower the pH as well as process requirements, modifies flavour and chelates trace metals (Anon 1980, 1990; Kozup and Sistrunk 1982).

Blanching in acid solution of pH < 2.0, immersing of blanched vegetable in acid solution or addition of acid to individual containers, are some of the direct acid addition methods for lowering the pH of the vegetables (Anon 1980). In the case of cowpea, blanching is done in hot water in order to get a good quality product by destroying certain enzymes(Ramesh and Nath 1990). Citric, malic, tartaric, lactic and acetic acids are generally used, while phosphoric, adipic, fumaric acids and glucono-delta-lactose (GDL) also find specific uses in the acidification of foods (Anon 1990). 'Salad Bar Fresh' process, developed recently, involves the addition of an ingredient having trade mark 'PHM-1' to the cans. This has been reported to reduce time as well as temperature of processing, and yield products which are similar to freshly cooked vegetables, with respect to colour, texture and flavour (Anon 1986).

Lactic acid fermentation also lowers the pH and, consequently renders the food resistant to pathogenic and spoilage microorganisms as well as inhibits the growth of spores (Anon 1980; Anderson et al. 1990). A number of vegetables are preserved by brining and fermentation. Cabbage and cucumber fermentation are, by far, the most extensively studied. Okra becomes soft and mushy on thermal processing and hence, is acidified, either by addition of acid or by lactic fermentation before canning. *Lactobacillus cellobiosus*, isolated from okra and when used as inoculum, reduces the pH to less than 4.5 after 24 h, and renders the surface of canned okra less mucilagenous and less sloughing (Kotzekido and Roukas 1987a). *L. plantarum*, *L. brevis* and *Pediococcus cerevisiae* have also been used as start cultures in the fermentation of different vegetables (Fleming and McFeeters 1981). Toxigenic amines (1 to 5 mg/kg), formed during fermentation, were considerably lower than the poisonous level (Anderson 1988).

In recent years, there is a renewed interest to reduce the thermal process requirements of low acid (pH > 4.6) vegetables during canning, either by addition of acid (Kozup and Sistrunk 1982; Kotzekidou and Roukas 1987a) or by lactic fermentation (Kozup and Sistrunk 1982; Kotzekidou and Roukas 1987a, b; Edeza and Sanchez 1989; Anderson et al. 1990). Time and temperature conditions, which were made use of in thermal preservation by the authors, were found to vary considerably, and the basis for this has not been investigated. Studies on evolving thermal schedules for canned vegetables, acidified with

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acids or by fermentation, form the subject matter of this paper.

Materials and Methods

Acidification using acids : Fresh vegetables, purchased from the local market, were washed and used. The outer green leaves of cabbage were removed, cored, and shredded. Carrots were peeled and sliced to 1 cm thickness size. The stem of cauliflower was removed and the curds broken into pieces. The green beans were snipped and cut into small pieces of 5 cm length. Green peas were shelled. The two edges of the ivy gourd (*Kundri, Tindora*) were trimmed. Potatoes were peeled, eyes trimmed and cut into halves.

Prepared vegetables and brine (1%) were blended in the ratio of 2:1 in a blender, and the blend was acidified with 10% solution of the acid, to determine the quantity of acid required to get the desired pH.

For acidification, the prepared vegetables were blanched in 3% solutions of lactic, malic, succinic, citric and fumaric acids as also glucono-delta-lactone (GDL), either for 15 min at 70°C as recommended in the canning of cauliflower (Hoogzand and Doesburg 1961) or in boiling solution for 3 min, filled (500 g) into A $2\,^1/_2$ (103.2 x 119.1 mm) plain cans, covered with 2% salt solution, exhausted, sealed and processed in boiling water for 15 min.

Acidification by fermentation : The prepared green beans, cauliflower, peas, carrot and ivy gourd in equal proportions or individually were filled (1.5 kg) into 5 litre jars and covered with hot (97°C), boiled and cooled (45°C), or cold (25°C) brine of 2 to 6% concentrations, containing 0.4 to 0.8% acetic acid or without the acid. The containers were covered with nylon (200 gauge) film and tied with thread. Use of hot brine with acetic acid is somewhat akin to the method followed in Iran to preserve vegetables in the autumn for use in the winter.

Lactic acid bacteria were isolated from the fermenting vegetables at 12, 24 and 48 h intervals, using MRS broth and agar, (NCA 1968), as well as *Lactobacillus-Streptococcus* differential medium (LSDM) (HiMedia 1989). Isolation of pure cultures was done by serial dilution, plating and repeated streaking of single colonies. For biochemical studies, 12 h old cultures of individual isolates were purified by centrifugation. Identification procedure followed was according to Sharpe (1979) and Kandler and Weiss (1986).

After fermentation, the brine was drained, th fermented vegetable rinsed in water, filled (250 g into 77.8 x 119.1 m or (500 g) into 103.2 x 119. mm cans, covered with boiling 1% brine, and th cans were exhausted, sealed and processed a before.

Thermal process evaluation : Heat penetratio studies, using Ecklund plug in needle typ thermocouples and manually operated Leeds an Northrup potentiometer, indicated that the heatin was by convection and the cold point was at abou 1/10th the height of the can. Heat penetratio data, collected at intervals of 1 min with 6 car for each run, was used for calculating the proces time required by equal time interval metho (Patashnik 1953) to inactivate the *Cl. pasteurianu* or heat resistant enzymes.

Inoculated pack studies : Cans filled wit vegetables were inoculated with spores of *Bacillu licheniformis* (7,50,000 spores/can) and/or *C sporogenes* (2,40,000 spores/can). These culture were isolated from canned mango pulp of pH 4. (Azizi and Ranganna 1993). The vegetables we then covered with brine, cans sealed and conten mixed. The inoculated cans were processed a described above and incubated at 37°C Uninoculated cans were used as control.

Storage study : The canned products we stored at room temperature and examined intervals of 3 months. Texture was measured Instron texturometer, using Kramer shear ce (2830 – 018) and plunger assembly (2830 – 01(

Results and Discussion

Vegetables blanched in acid solution for min at 70°C, as recommended for cauliflow (Hoogzand and Doesburg 1961), or in boilin solution for 3 min, did not ensure acidification the interior parts, but caused discolouration. Th brown colour was nearer to the cut surface. Henc acidification by addition of acid to the coverin brine was examined. Concentration of acid require to reduce the pH of the vegetable to 4.0 or le ranged from 0.06 to 0.55%, depending on the ac and the vegetable (Table 1). Sensory evaluation ranking test (Ranganna 1986) indicated that, amo the acids studied, malic acid was the best acidula for canned vegetables in brine, while malic acid GDL made no difference for curried vegetables

The exploratory studies carried out using 2 6% brine, with added acetic acid (0.39 to 0.78 or without acid at different temperatures, indicat

TABLE 1. AMOUNT OF ACID REQUIRED TO REDUCE THE pH OF VEGETABLE BRINE BLEND (2:1)

	Lactic acid		Glucono-delta-lactone		Malic acid		Succinic acid		Citric acid		Fumaric acid	
	%	pH	%	pH	%	pH	%	pH	%	pH	%	pH
Carrot	0.15	3.8	0.22	3.8	0.10	3.9	0.22	3.7	0.13	3.8	0.28	4.1
Cauliflower	0.03	3.5	0.42	3.5	0.17	3.7	0.19	3.9	0.18	3.8	0.31	4.0
Green beans	0.22	4.0	0.16	3.6	0.12	3.8	0.27	3.9	0.01	3.7	0.32	3.7
Ivy gourd	0.19	3.5	0.16	3.7	0.06	3.8	0.12	3.7	0.07	3.7	0.22	3.8
Peas	0.28	4.1	0.55	3.9	0.25	3.8	0.40	3.7	0.27	3.9	0.29	4.0
Potato	0.30	3.7	0.43	3.5	0.17	3.5	0.19	3.6	0.18	3.7	0.31	3.8

that fermentation occurred, when 2% brine at 97°C was used for covering the vegetables. The temperature had decreased to 55 – 58°C on contact with vegetables within about 30 min. The use of hot brine probably destroyed some of the heat sensitive undesirable microorganisms and expelled cellular gases from vegetables. This favoured anaerobic fermentation, enhanced the stability of ascorbic acid as well as natural colour of the vegetables (Steinkraus 1983), and inhibited the activity of enzymes. In the presence of hot brine, the waxy layer on the outer surface of the fresh vegetables got dissolved, thereby causing the natural colour to become bright. The fermentation rendered the vegetables translucent, texture remained firm, and the vegetables as well as brine acquired the typical lactic fermented taste, but the brine was opaque in appearance. The fermented vegetables, produced using hot brine, were better than those involving the use of cold brine.

Vigorous fermentation was found to set in within 16 h of brining, the pH reduced at the end of 24 h to 4.1 – 4.2, and at the end of 90 h to 3.6 – 3.8. There was no change in the pH between 48 and 72 h. Consequently, this period could be considered more as a period of equilibration. After 24 h, the pH was lower, when boiling brine was used as compared to cold brine, but the brine had not penetrated into the interior of vegetables, particularly in those with a hard texture, such as carrot and cauliflower. Hence, fermentation for a minimum of 3 days was considered necessary.

Microbial changes during fermentation : The microbial flora of fermenting vegetables consisted of cocci and rods. The cocci in the first 12 h consisted of *Leuconostoc mesenteroides. L. cremoris* and *L. oenos*, which have the ability to withstand 60°C for 30 min. These produced gas and acid, thereby contributing to anaerobic conditions, besides lowering the pH. Another species, the homofermentative *Lactobacillus delbrueckii* sub sp. *lactis*, produced lactic acid during this period. Besides these microorganisms, during the first 24 h, the flora consisted of *Pediococcus acidilactia, P. damnosus* and *Lactobacillus plantarum*. At the end of 48 h, *Streptococcus lactis* and *S. rabbinolactis*, which produced only acid, dominated. The results show that, when hot brine was used, fermentation was initiated by *Leuconostoc*, which produced CO_2 and created anaerobic conditions. This organism, as well as acid producing lactobacilli, were followed by pediococci between 12 and 24 h. Streptococci come into the picture only after this period. All these microorganisms contributed to the lowering of the pH to about 3.8 at the end of 3 days of fermentation.

pH of canned product : The vegetables fermented for 24, 48, 72 and 96 h, on rinsing and canning in fresh 1% brine, had pH of 4.5, 4.3, 4.0 and 3.6 to 3.8, respectively. The pH of the vegetables, canned after 24h of fermentation, was close to 4.5, and even after 48 h of fermentation, it was just 4.3. As these pH levels are favourable for the growth *B. coagulans* and *B. licheniformis* (Azizi and Ranganna 1993) a fermentation period of 72 or 96 h is recommended, as it will lead to a pH of 4.0 or less in the canned products.

Thermal process requirements for canned products : National Canners Association (NCA 1986) recommended sterilisation $F^{8.9}_{93.3}$ value equivalent to 0.1 min at pH 3.9 or less to 20 min at pH 4.4-4.5. $F^{8.9}_{93.3}$ of 20 min is equivalent to 3.5 min at 100°C. Though the acidified vegetables had pH < 4.0, $F^{8.9}_{100}$ of 3.5 min formed the basis for process evaluation in this study, to accommodate for variations in fill weight of vegetable, net weight, pH and also to impart cooked taste to the canned product. This F value is adequate to destroy *Cl. pasteurianum* (D_{100} = 0.1 to 0.5 min at pH 4.2 to 4.5) and non-spore forming yeasts and moulds (D_{65} = 0.5 to 1.0 min) (Stumbo 1973).

The graphical interpolation curves are given in Figs. 1 and 2. The time required in boiling water ranged from 12 to 15 min, except when the initial temperature was high (Table 2).

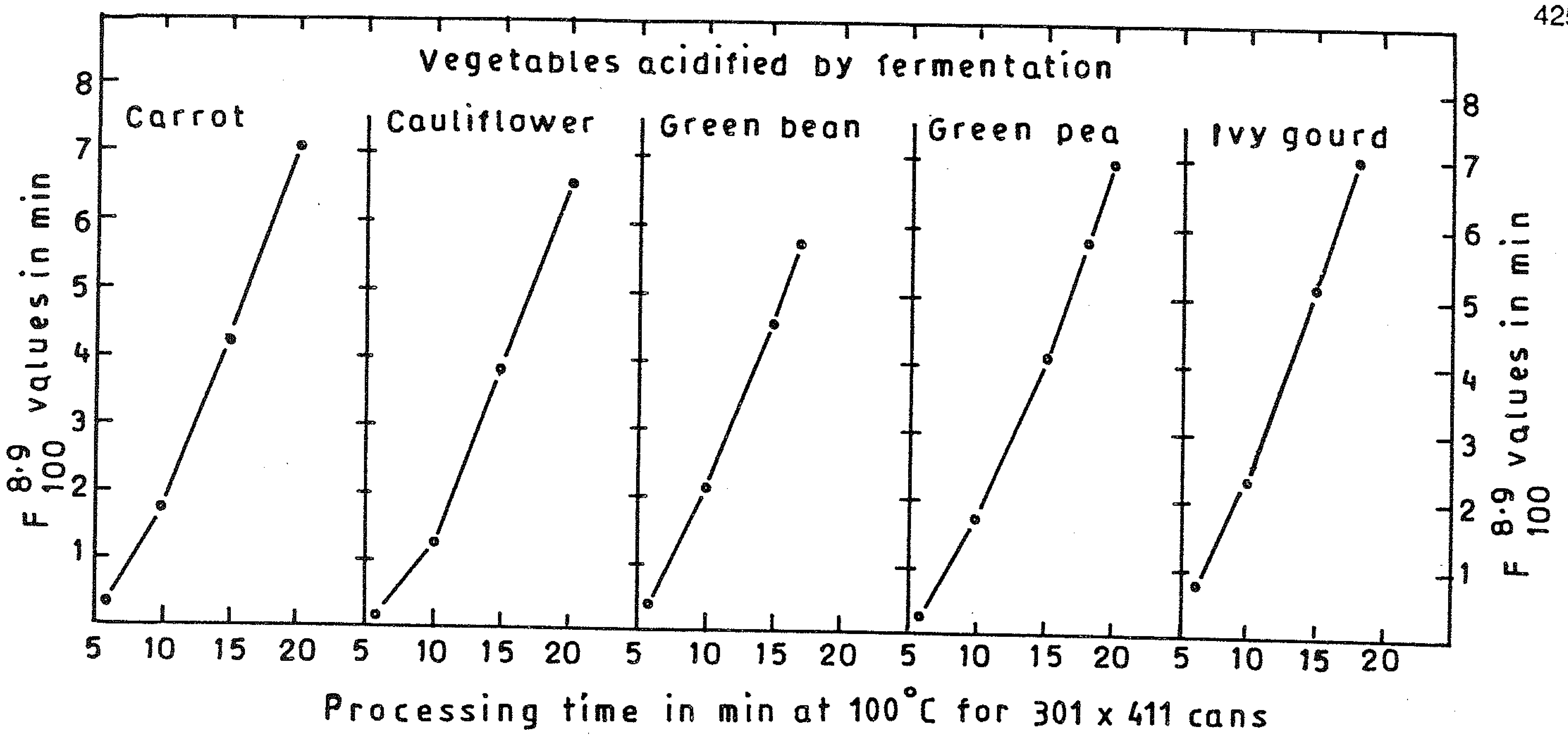

Fig. 1. Graphical interpolation of curves of sterilization values (i.e. $F^{8.9}_{100}$) vs process time for vegetables acidified by fermentation and canned in brine in 77.8 x 119.1 mm cans.

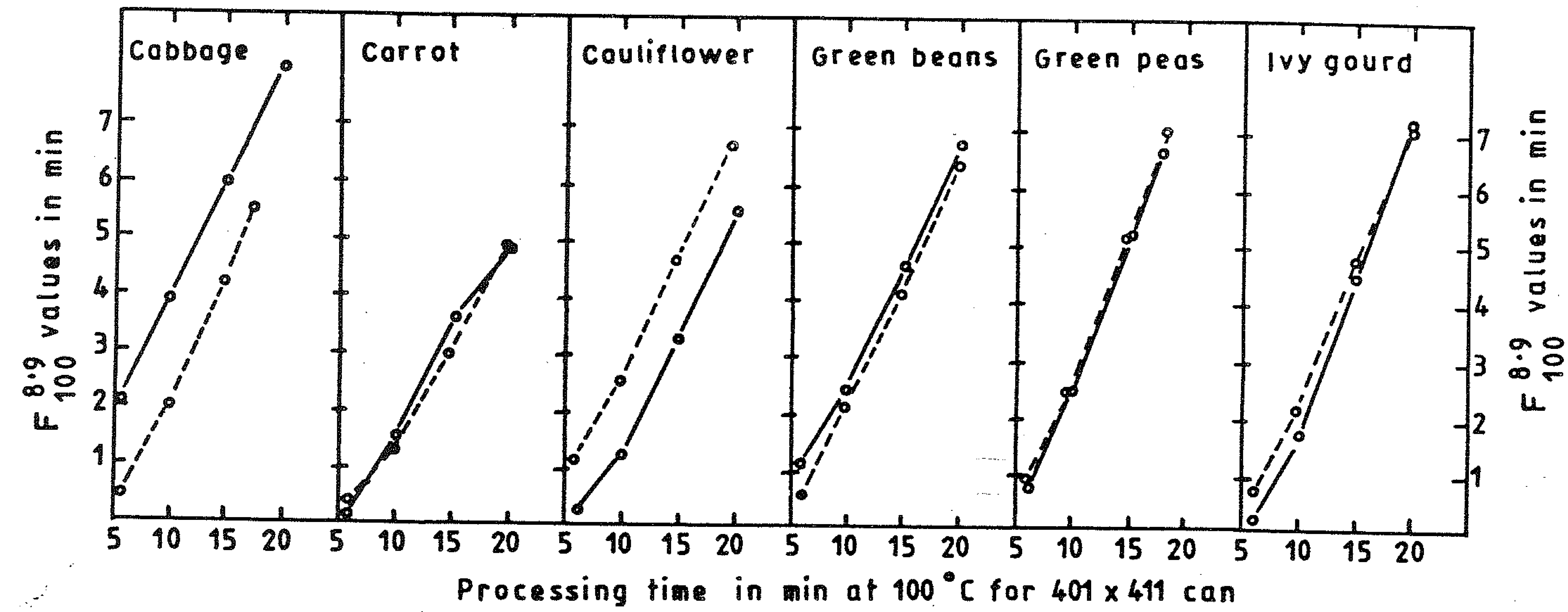

Fig. 2. Graphical interpolation curves of sterilization values vs processing time for fermented vegetables (O——O)) and vegetables acidified with added acid (O------O) and canned in brine in 401 x 411 (103.2 x 119.1 mm) cans.

Peas, French beans, ivy gourd, cauliflower and carrot were found to support the growth of *B. licheniformis*, which elevates the pH, thereby resulting in conditions favourable for the growth of heat resistant *Clostridia* (Azizi and Ranganna 1993). The D_{100} ranged from 2.1 to 2.8 in the vegetables investigated (Table 3). Process time to achieve sterilisation value, corresponding to 5D of *B. licheniformis*, would be considerably higher than the sterilisation value of $F^{8.9}_{100}$ = 3.5 min. The redeeming feature is that the organism grows only at pH 4.2 and above. Hence, if the canned product is acidifed to pH 4.0, with a safety margin of 0.2 units or even lower pH, the possibility of spoilage by this organism is forestalled.

Inoculated pack studies : No spoilage occurred in cans acidified to pH < 4.0, inoculated with spores of *B. licheniformis* and/or *Cl. sporogenes* and processed $F^{8.9}_{100}$ = 3.0 or 3.5 min, but this was not adequate for unacidified canned vegetables, and all such cans spoiled.

Changes during storage of the vegetables acidified using acid : When examined, soon after

TABLE 2 . THERMAL PROCESS REQUIREMENTS AT 97°C FOR CANNED ACIDIFIED VEGETABLES IN BRINE

Acidification	pH	IT °C	77.8 x 119.1 mm cans Processing time (min) corresponding to $F^{8.9}_{100}$ of 3.5 min	5 min	IT °C	103.2 x 119.1 mm cans Processing time (min) corresponding $F^{8.9}_{100}$ of 3.5 min	5.0 min
Acidification using malic acid							
Cabbage	3.7		ND	ND	93	9	13
Carrot	3.9		ND	ND	64	15	18
Cauliflower	4.0		ND	ND	65	15	18
French beans	4.1		ND	ND	65	12	16
Peas	4.0		ND	ND	80	12	15
Ivy gourd	3.8		ND	ND	67	13	16
Acidification by fermentation							
Cabbage	3.6		ND	ND	63	13	15
Carrot	3.8	60	14.0	16.5	66	16	20
Cauliflower	3.8	64	15.0	17.5	66	13	16
French beans	3.8	65	12.5	16.0	66	14	17
Green peas	3.9	65	13.5	17.0	73	12	15
Ivy gourd	3.6	88	12.0	14.8	66	13	16

IT : Initial temperature at cold point of the can at the start of processing time
ND : Not determined. Acidity in the finished product ranged from 0.4 to 0.6%.

TABLE 3. THERMAL RESISTANCE (D) OF *B. LICHENIFORMIS* IN NEUTRAL PHOSPHATE BUFFER AND VEGETABLES

Product	pH	D_{100} value (min)
Natural phosphate buffer	7.0	3.1 ± 0.20
	4.2	2.5 ± 0.08
Peas	4.5	2.5 ± 0.10
French beans	4.2	2.2 ± 0.20
		2.6 ± 0.20
Ivy gourd	4.2	2.2 ± 0.20
	4.5	2.3 ± 0.30
Cauliflower	4.2	2.1 ± 0.90
	4.5	2.8 ± 0.40
Carrot	4.2	2.2 ± 0.20
	4.5	2.5 ± 0.20

canning or after storage for 9 months, the vegetables were negative to heat resistant enzymes like catalase, peroxidase and polyphenoloxidase (Ranganna 1986)

Among the vegetables studied, the green colour of beans, ivy gourd and peas turned yellowish brown during processing mainly due to chlorophyll destruction. This change was further intensified during storage. The natural creamy colour of acidified, canned cauliflower turned to light pink at the end of 3 months of storage and then to brown on further storage. The pink discolouration in cauliflower has been attributed to polymerisation of leucoanthoyanins present in a pseudo-base form (flavorn-4-ol), which is intensified further by the acid (Setty and Ranganna 1972). However, carrot retained the natural colour over the prolonged storage.

The texture of canned acidified vegetables was superior to canned unacidified vegetables processed under pressure, and resembled more closely to fresh cooked product, when examined at the end of 9 months storage (Table 4). Mere blanching of the fresh vegetables, a step in the conventional canning and in the canning of vegetables acidified using acid, considerably reduced the firmness, as seen from the minimum force required to begin extrusion (KN/kg) and the total work done (KJ/kg). Processing of the acidified vegetables in boiling water did not affect the texture further, whereas processing under 10 psig pressure (control) considerably affected the texture.

Acidifed vegetables had perceptible sour taste. In the preparation of curried vegetables in India, acidulants like tomatoes, lime juice, tamarind extract or unripe mango powder (called *amchur*) are added. Hence, slight sour taste should not alter the acceptability much.

Storage changes of canned vegetables acidified by fermentation : Irrespective of the colour of fresh vegetables, the fermented product, on canning, appeared bright and retained the natural colour better. The change in colour during storage even upto 2 years was minimal. Since lactic acid was formed *in situ* from sugar by fermentation, the degradation of chlorophyll in green vegetables was minimal. Hence the colour of the canned product was dull green, but not brown, as in the case of vegetables acidified by acid. Cauliflower did not turn pink and the carrot was bright yellow.

The values of texture properties of the canned fermented vegetables, after storage for 9 months, were lower than those of the fresh vegetable, but

TABLE 4. VALUES OF pH AND TEXTURE OF FRESH, BLANCHED AND CANNED VEGETABLES AFTER STORAGE AT 37°C FOR 9 MONTHS

Attribute	pH	Texture values: Peak force kN/kg	Work done kJ/kg
Carrot			
1. Fresh	5.20	96.86	12.00
2. Blanched	ND	12.16	2.36
3. Acidified	4.00	11.69	2.28
4. Fermented	3.50	30.11	5.98
5. Control	4.85	1.52	0.42
F ratio		312.98	181.14
S.E.		1.81	0.29
Cauliflower			
1. Fresh	6.20	47.25	8.74
2. Blanched	ND	23.52	4.13
3. Acidified	4.50	15.96	2.70
4. Fermented	3.60	30.44	5.12
5. Control	5.00	1.04	0.34
F ratio		81.39	53.09
S.E.		1.60	0.36
French beans			
1. Fresh	5.70	53.46	10.08
2. Blanched	ND	36.24	6.43
3. Acidified	4.30	27.50	5.15
4. Fermented	3.50	46.56	7.20
5. Control	5.00	7.31	2.34
Ivy gourd			
1. Fresh	4.60	53.29	10.28
2. Blanched	ND	39.17	7.20
3. Acidified	3.80	22.20	3.70
4. Fermented	3.60	31.31	4.64
5. Control	4.50	2.38	0.43
F ratio		184.00	168.84
S.E.		1.26	0.26
Green peas			
1 Acidified	3.90	20.60	4.54
2. Control	5.00	7.16	1.28

Blanched : Blanched before canning, Acidified : Canned product acidified with malic acid, Fermented : Fermented vegetable canned, Control : Processed at 116°C for 25 min, F ratio : $P < 0.001$, df : 14 in the case of carrot and cauliflower, and 12 in ivy gourd, ND : Not determined.

higher than those of blanched vegetable. This probably is due to exclusion of blanching in the canning of fermented vegetables (Table 4). The overall quality of the canned fermented vegetable was far superior to the product canned using malic acid or by conventional method without acid, either immediately after canning or after prolonged storage. When made into curry, the lactic fermented note or sour taste was not distinguishable, as reported by the panel members to whom the canned fermented vegetables had been given for preparing the curried product, in their homes for evaluation purposes.

Conclusion

Vegetables acidifed with malic acid, or by lactic fermentation, using 2% boiling brine (the temperature decreasing to 55°C on contact with prepared material) for 3-4 days, to lower the pH to 3.6-3.8, reduced the processing temperature by 15-20°C and also the time. The resulting canned product is microbiologically safe, and similar in texture to fresh cooked vegetable. The sour tinge in taste is not discernible, when made into curry.

Acknowledgement

The authors express their sincere thanks to Dr. B L. Amla for keen interest in this investigation, to Mr. Nagin Chand for help in texture measurement and to Dr. M. C. Varadaraj, as well as to Mr. N. Keshava for their help in identifying the microflora.

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Received 25 November 1992; revised 29 May 1993; accepted 31 May 1993

J. Food Sci. Technol., 1993, Vol 30, No.6, 429-434

Suitability of Indigenously Fabricated Aluminium Cans for Canning of Indian Foods

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Two piece aluminium cans were fabricated in three different sizes, using indigenous 3004 alloy (Mg, Mn and Al), in cooperation with a convertor, and evaluated for suitability to the canning of different Indian foods. The studies indicated the viability of aluminium alloy, as an alternative for tin containers, for eight different types of Indian foods.

Keywords : Rigid container, Aluminium cans, Suitability, Canning of Indian foods, Thermal processing, Lacquering, Storage studies.

Rigid containers have played a very significant role over several years in food processing and build up of consumer acceptance as well as confidence in preserved foods. In India, manufacturing units depend heavily on imported raw materials for fabrication of food cans, thereby necessitating the import of 300,000 tons of tin plate per annum, valued at Rs. 300 crores (TIFAC 1991). This has resulted in constraints with regard to the growth of the can manufacturing and food processing industries. Alternate materials for manufacturing rigid containers, in lieu of tin containers, have long been explored in various parts of the world (Leymarie 1972). The most attractive and viable alternate material in India is aluminium and its alloys. Aluminium is abundantly available in the country, as India possesses 8% of the world's bauxite reserves (Kothari 1986). In addition, aluminium is very light, as it weighs 1/3 that of steel. The corrosion resistance of aluminium is excellent, as compared to that of the conventional low carbon steel, and it also possesses good mechanical properties. Aluminium, when pure, is soft as well as ductile and is capable of attaining high tensile strength by cold working, heat treating and alloying.

Aluminium, in the form of foil, is already being used extensively as an excellent packaging material for processed and fast foods in large catering institutions (Satyanarayana Rao et al. 1990; Padmanabha Reddy and Khan 1993). In the form of collapsible tubes and rigid containers, it finds use in various sectors like pharmaceuticals, beverages, dairy and cosmetic industries (Neider 1986). However, its use in the form of rigid containers for canning processed foods, other than the beverages, is highly limited. Though the energy consumption for extracting the aluminium is high, its excellent recyclability makes it not only environment friendly, but also economically viable. Since armed forces in India is the single largest consumer of processed foods, research and development of two piece aluminium cans, using indigenous materials was undertaken (Jayaraman et al. 1988). Earlier work carried out with cans, fabricated out of 99.5% pure aluminium, has shown that the metal was too soft, and did not possess adequate mechanical strength for thermal processing (Srivatsa et al. 1990). Therefore, an alloy of aluminium (3004) was selected in the present studies. Cans and lids were fabricated out of the same alloy. This paper reports the data on the fabrication of aluminium cans using AA 3304 sheets and their efficacy for canning of eight different Indian processed foods.

Materials and Methods

Aluminium cans : Two piece round aluminium cans were fabricated using aluminium sheets of AA 3004 alloy, equivalent to 4S, (Mn 1.25%, Mg 0.95% and rest aluminium) by drawn, redrawn and ironed (D&I) process, at the premises of a converting firm. The finished cans had an ultimate wall thickness of 0.33 mm. The lids were also of the same thickness and made out of the same alloy. Cans of three different dimensions, fabricated and used in the present studies, are as per the following details :

Dimension (mm)	Capacity (ml)
83 x 50	210
83 x 80	400
130 x 50	450

Lacquering of the cans : Lacquering of the cans and the lids was carried out at the place of the

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