Equilibrium pH of Home Canned Foods Comprising Combinations of Low Acid and High Acid Ingredients

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ABSTRACT

A recipe data bank and method of data processing were developed to classify tomato-based combinations of low and high acid ingredients according to product pH. Information describing the composition and preparation of more than 400 products were entered into the data bank. The extent of variation in ingredient proportions for different product categories was estimated. The ratio of low acid to high acid ingredients specified by the recipe was used as a criterion for selecting representative recipes for preparation and pH determination. High correlations were obtained between this index and product pH. The acidity of 24 common categories of combination products was characterized by the testing of representative recipes.

INTRODUCTION

A RECENT SURVEY conducted by the U.S. Department of Agriculture (Davis and Page, 1979) indicated that about 20% of home canners in the United States prepare "combination" products such as tomato sauce and vegetable mixtures which may be either low or high in acidity, depending on the proportions of low and high acid ingredients used. This distinction is critical to safe canning since low acid foods (pH $>$ 4.6) must be pressure canned while high acid products (pH $\leqslant$ 4.6) may be processed safely in a boiling water bath (IFT, 1977). Published canning instructions for combinations are frequently inconsistent and in some cases may be unsafe (Dragonwagon, 1973; Gewanter and Parker, 1976). Some canning authorities have recommended that combinations be canned by a process appropriate to the highest pH ingredient in the product (IFT, 1977; Anon., 1977). The USDA survey has shown that many home canners are using inappropriate processes for such products. It is possible that some outbreaks of botulism from such combinations as spaghetti sauce and chili (Center for Disease Control, 1979) are a consequence of underprocessing.

Ideally, the choice of canning method for mixtures of low acid and high acid ingredients should be based on the equilibrium pH of the product. However, the number of possible variations in products of this type is very large, and reliable pH data are not generally available. Our objective in this research was to determine whether the equilibrium pH of combination products could be located within a meaningful range from information on product composition compiled in a "recipe data bank" and from representative pH and acidity data so that guidelines for process selection could be developed.

EXPERIMENTAL

Recipe data bank

To compile information on products containing mixtures of low acid and high acid ingredients which might be home canned, we screened recipes found in more than 80 home canning publications and cookbooks. Product categories searched included juices, soups, mixed vegetable dishes, meatless tomato sauces, barbecue sauces, tomato-meat sauces, chilies, and condiments. Recipes from a number of ethnic and regional cuisines were represented. Insofar as possible, we selected recipes on the expectation that some products in each category would fall in the low acid pH range; consequently, we gave certain highly acidic product categories such as relishes and pickled vegetables only a superficial examination.

Information contained in each recipe was coded and entered into a computer for further processing. We converted all ingredient quantities to a weight basis by reference to standard tables (Adams, 1975; Watt and Merrill, 1975; Posati and Orr, 1976; Marsh et al., 1977) or to label declarations for commercial products. When such data were not available, we determined conversion factors experimentally (Sapers, 1981).

Recipe evaluation and comparison

We compared recipes in the data bank on the basis of their specified proportions of low and high acid ingredients. As a criterion for selecting representative recipes for testing, we calculated the ratio of low acid to high acid ingredients on a weight basis without attempting to correct for quantitative differences in acidity between ingredients in the same group. Subsequently, we calculated more exact values of this ratio, based on measurements of ingredient acidity. For this puspose, we titrated duplicate 10g samples of the major ingredients, dispersed in 40 ml distilled H_2O, either with distilled white vinegar (5% acidity) or with 0.1N NaOH, depending on the ingredient pH, to a pH 4.6 endpoint. All raw vegetables were boiled until fully cooked (London, 1972), drained, cooled, and homogenized prior to sampling for this titration. Ground dehydrated ingredients were reconstituted with boiling H_2O and cooled prior to titration. An estimate of the acidity of high acid ingredients in a recipe was obtained by computing the product of the ingredient weight in the recipe (100g basis) and the acidity of the ingredient, expressed as meq NaOH (to a pH 4.6 endpoint) per 100g ingredient, and then summing this product for all high acid ingredients. This process was repeated with low acid ingredients, computing the total quantity of vinegar (meq/100g) required to lower their pH to 4.6. We then calculated the ratio of the total meq vinegar for low acid ingredients to the total meq NaOH for high acid ingredients. We also computed a third "low acid index" from these data: the difference between the total meq of vinegar for low acid ingredients and the total meq of NaOH for high acid ingredients, per 100g of product described by the recipe.

Acidity of representative products

To obtain data on the acidity of representative products, we identified over 100 "benchmark" recipes from each product category for preparation, canning, and analysis. We used extreme values of the ratio of low acid to high acid ingredients (weight basis), unique ingredient combinations, and questionable specifications for acidulation or thermal processing as criteria for recipe selection. Each product was prepared according to recipe instructions and filled hot into pint canning jars, leaving about 3/4-inch headspace. Jars were sealed and processed for 30 min in a boiling water bath or for 60 min at 10 psi in a pressure canner, following procedures described in the USDA's Home and Garden Bulletin No. 8 (Anon., 1975). We processed each product by both canning methods since the pH was not known at the time of canning, and we expected some of the recipes to yield borderline high or low acid products.

All processed samples were equilibrated for 1–3 days before being analyzed; products that had been processed by the water bath method were refrigerated to prevent the spoilage of low acid samples. We analyzed unprocessed samples as soon as they had cooled

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to room temperature. After bringing the refrigerated jars to room temperature, we homogenized samples for 30 sec at high speed in a Waring Blendor and then determined product pH and titratable acidity, following procedures described previously (Sapers et al., 1980). Based on the measured acidity of the first set of "benchmark" products, we selected additional recipes for preparation, canning, and analysis so that each product category could be adequately characterized.

Statistical methods

The pH and titratable acidity data for unprocessed and corresponding processed products were compared by analysis of variance (ANOVA) to determine whether either method of canning altered product acidity.

The pH and titratable acidity values were correlated with the ratios of high acid to low acid ingredients (on both a weight basis and milliequivalent basis) and with the difference between milliequivalents of high acid ingredients and milliequivalents of low acid ingredients. This was done for each product category.

All calculations, file maintenance, and statistical analyses were performed with the Statistical Analysis System (SAS) at the Washington Computer Center of USDA.

RESULTS & DISCUSSION

Distribution of recipes in data bank

From an original compilation of more than 500 recipes for products containing mixtures of low acid and high acid ingredients, we selected 415 tomato-based recipes for inclusion in the data bank. Their distribution according to product category is given in Table 1. Italian, Spanish, Mexican, Creole, Southern and Western United States specialties were included in the compilation, in addition to many North American recipes not associated with a particular region or ethnic group. Approximately 25% of the recipes contained home canning information.

Table 1 — Distribution of recipes for tomato-based combination products in data bank

Product category	Number of recipes			
		Home canning		
	Total	Pressure	Water bath	Open kettle
Juice blends	26	7	9	1
Soups	48	6	1	0
Mixed vegetable dishes	54	24	4	0
Tomato sauces, meatless	165	3	27	2
Barbecue sauces	22	1	3	0
Tomato sauces with meat	54	10	0	1
Chilies	46	6	0	0

Variability within product categories

Individual recipes within each product category varied widely in the specified ingredient proportions (Table 2). The proportion of low acid ingredients varied over a 20-fold range in recipes for such product categories as tomato-vegetable soup and tomato-mushroom sauce. Less variability was seen with the high acid ingredients. However, the ratio of low acid to high acid ingredients (weight basis) varied over a 100-fold range within some product categories. Values of this ratio expressed on an acidity basis, using titration data illustrated by Table 3, were no more

Table 3 — Acidity and buffering properties of some common low acid ingredients of home canned mixtures

Ingredient	Ingredient pH	Titration to pH 4.6[a]
Low acid		With vinegar[c]
Beef (ground)	6.3	6.0
Broth (chicken)	6.3	3.7
Beans (red kidney)	5.8	10.4
Carrots	5.0	1.2
Chili powder[b]	4.6	0
Mushrooms	6.0	3.0
Okra	6.0	6.5
Onions	5.0	1.4
Peppers (green bell)	5.0	1.3
High acid		With 0.1N NaOH
Chili sauce	4.0	5.4
Lemon juice (bottled)	2.9	41.1
Tomatillos (canned)	3.8	6.2
Tomato paste	4.3	4.7
Tomato puree	4.3	2.2
Tomatoes, paste-type	4.4	1.1
Vinegar	2.7	45.0
Wine (red)	3.2	3.0
Worcestershire sauce	3.6	21.2

[a] Milliequivalents of NaOH or acetic acid per 100g ingredient.
[b] Reconstituted with boiling dist. H_2O before analysis
[c] 5% acidity

Table 2 — Variation in the proportions of low and high acid ingredients in recipes for some common combination products

Product category	Number of recipes	Range			Coefficient of variation (%)	
		Low acid ingred.[a]	High acid ingred.[a]	Low acid index[b]	Low acid index	
					Wt basis	Acidity basis
Tomato-vegetable juice	23	3.7–66.7	33.3–95.0	0.04–2.00	136	157
Tomato-vegetable soup	18	3.5–80.0	16.6–93.7	0.04–5.00	110	121
Stewed tomatoes	16	1.3–23.7	66.6–97.6	0.01–0.37	73	62
Tomato-bean combinations	12	18.0–78.4	15.4–69.4	0.42–3.66	60	94
Tomato-okra combinations	12	11.7–77.1	22.6–88.3	0.13–3.40	79	76
Tomato puree	6	16.0–29.4	70.6–83.7	0.19–0.42	31	35
Tomato paste	9	2.5–15.8	84.1–97.1	0.03–0.19	100	98
Tomato sauce, U.S.	32	4.8–47.0	29.7–95.1	0.05–0.91	71	79
Tomato-mushroom sauce	16	3.7–79.5	20.3–95.4	0.04–3.91	130	164
Creole sauce	20	13.6–88.4	10.8–84.7	0.16–8.20	148	123
Mexican tomato-pepper sauce	40	6.0–71.3	6.8–93.9	0.06–2.54	146	134
Barbecue sauce	22	7.8–62.9	35.2–87.5	0.08–1.79	87	137
Spaghetti sauce, meatless	16	5.7–57.3	15.4–88.5	0.10–1.69	128	166
Spaghetti sauce with meat	43	13.9–69.8	15.4–85.2	0.16–2.31	55	110
Chili con carne	34	42.6–91.0	8.7–47.6	1.09–10.45	62	61

[a] Weight percent, fat-free
[b] Low acid ingredients/high acid ingredients (weight basis)

variable than those calculated on a weight basis; coefficients of variation for these indices are included in Table 2.

Any attempt to develop guidelines for processing combinations must take such variability into consideration so that the indicated processing method (pressure or water bath canning) is appropriate for the highest pH product found within any category. Even this constraint may not be sufficient with highly variable product categories because of the probable existence of a recipe exceeding the limits of the data bank. Consequently, blanket recommendations should not be made for such highly variable categories even if all known examples fall in the high acid category.

Acidity of representative products

pH and titratable acidity data were obtained from rep-

Table 4 — Correlation between product pH and indices of recipe acidity

Product category	No. recipes Total	No. recipes Tested	Product pH range[a]	Correlation coefficient Low acid index[b] Wt basis	Acidity basis	Acidity difference
Tomato-vegetable juice	23	4	4.4–5.1	0.95[c]	0.98[c]	0.67
Tomato-vegetable soup	18	4	4.1–4.6	0.85	0.91[d]	0.95[c]
Tomato-mushroom sauce	16	7	4.3–5.0	0.79[d]	0.86[c]	0.84[c]
Spaghetti sauce with meat	43	4	4.6–5.0	0.96[c]	0.98[c]	0.95[d]
Creole sauce	20	8	4.2–5.2	0.97[c]	0.96[c]	0.84[c]
Mexican tomato-pepper sauce	40	10	3.9–4.6	0.15	0.65[c]	0.42
Barbecue sauce	22	4	4.0–4.4	0.86	0.46	0.74

[a] Determined experimentally
[b] As defined in the Experimental section
[c] Significant at 0.05
[d] Significant at 0.10

Table 5 — pH and low acid index of representative combination products

Product category	No. recipes Total	No. recipes Tested	Low acid index range[a] Weight basis All recipes	Weight basis Tested recipes	Acidity basis All recipes	Acidity basis Tested recipes	pH range	Acidity of category[b]
Juice blends								
Tomato-vegetable	23	4	0.04- 2.00	0.47-2.00	0.06- 4.50	0.33- 4.50	4.4-5.1	Low-high
Soups								
Tomato-broth	13	4	0.42- 3.67	0.99-1.66	0.58- 7.29	2.66- 3.05	4.5-4.8	Low-high
Tomato-vegetable	18	4	0.04- 5.00	0.33-2.30	0.10-15.00	0.51- 6.13	4.1-4.6	Low-high
Minestrone	9	1	2.28-14.60	2.28	16.84-41.33	16.84	5.2	Low
Manhattan clam chowder	8	2	1.26- 8.61	1.26-2.15	5.64-78.19	5.64-10.20	5.0-5.3	Low
Mixed vegetable dishes								
Stewed tomatoes	16	3	0.01- 0.39	0.11-0.24	0.02- 0.58	0.20- 0.58	4.4-4.5	High
Tomato-celery	6	2	0.30- 1.00	0.59-1.00	0.84- 2.80	1.52- 2.80	4.5-4.6	High (?)
Tomato-okra	12	4	0.13- 3.42	0.53-3.42	0.86-19.33	2.92-19.33	4.4-4.9	Low-high
Tomato-bean	12	3	0.49- 3.67	0.50-0.96	0.19-27.14	0.19- 6.04	4.9-5.3	Low
Tomato-zucchini	3	3	0.76- 1.35	0.76-1.35	2.41- 4.38	2.41- 4.38	4.7-4.8	Low
Tomato sauce, meatless								
Tomato puree	6	3	0.19- 0.42	0.33-0.42	0.26- 0.65	0.53- 0.65	4.4-4.5	High
Tomato paste	9	1	0.03- 0.19	0.19	0.03- 0.24	0.24	4.4	High
U.S. style	32	6	0.05- 0.91	0.25-0.91	0.08- 1.52	0.44- 1.52	4.4-4.6	High
Spaghetti	16	4	0.10- 1.69	0.16-1.69	0.07- 3.47	0.34- 3.47	4.3-4.5	High
Marinara	7	3	0.05- 0.38	0.17-0.38	0.09- 1.06	0.40- 0.66	4.4-4.5	High
Mexican	40	10	0.06- 2.54	0.17-2.54	0.03- 3.55	0.16- 3.55	3.9-4.6	High (?)
Barbecue	22	4	0.08- 1.79	0.48-1.79	0.02- 1.34	0.13- 1.04	4.0-4.4	High
Tomato-mushroom	16	7	0.04- 3.91	0.29-1.18	0.08-14.72	0.55- 3.14	4.3-5.0	Low-high
Creole	20	8	0.16- 8.20	0.18-8.20	0.19- 9.89	0.23- 9.89	4.2-5.2	Low-high
Spanish	5	2	0.34- 1.44	0.48-1.44	0.42- 3.90	0.82- 3.90	4.3-4.9	Low-high
Tomato-meat sauce								
Spaghetti	43	4	0.16- 2.31	0.16-0.67	0.45-22.27	0.59- 2.90	4.6-5.0	Low
Red clam	5	2	0.29- 0.89	0.29-0.70	3.18- 7.21	3.18- 6.11	4.8-5.1	Low
Chilies								
Chili con carne	34	2	0.88-10.45	1.09-1.24	4.19-44.01	5.71- 8.15	4.9-5.1	Low
Chili without beans	6	1	0.77- 9.21	0.77	3.37-42.04	3.37	5.2	Low

[a] Low acid ingredients/high acid ingredients
[b] Low acid, pH $>$ 4.6; high acid, pH $\leq$ 4.6

resentative products, selected to characterize the acidity of each product category. Treatment of these data by ANOVA indicated that canning had no significant effect on product pH or titratable acidity (F values of 1.06 and 0.49, respectively).

The validity of using values of the low acid indices as criteria for recipe selection and classification was tested by correlating these parameters against product pH data. Significant correlations were obtained between product pH values and the low acid ingredient/high acid ingredient ratios, calculated on both weight and acidity bases, for a number of important product categories (Table 4). However, correlations were poor for Mexican tomato-pepper sauces and for barbecue sauces, probably because of the diversity and high acidulant content of these product categories. The acidity difference was less satisfactory as an index of low acidity than were the ratios.

pH and acidity of product categories

We have used experimentally determined pH values for products representing extreme and intermediate values of the low acid indices to classify the acidity of each product category (Table 5). With some product categories, the least acidic (highest ratio) recipes within the category yielded products with pH values in the high acid range (pH $\leqslant$ 4.6). Stewed tomatoes, tomato-celery combinations, tomato paste and puree, and several meatless tomato sauces (U.S. style, spaghetti, marinara, Mexican, and barbeque) appear to be high acid product categories. However, because correlations between the low acid indices and product pH values for Mexican sauces were poor, and also because of this category's excessive variability, we do not recommend processing the Mexican-style sauces as a high acid food. The classification of tomato-celery combinations also must be viewed with caution since this borderline high acid product category could easily be confused with other mixed vegetable dishes that are generally low acid products.

With some product categories, the most acidic (lowest ratio) recipes yielded products exceeding pH 4.6. One would infer that all recipes in such categories would yield low acid products. Recipes for tomato-bean combinations, tomato-zucchini combinations, spaghetti sauce with meat, and chili con carne yielded low acid products.

The remaining product categories (juice blends, soups, tomato-okra combinations, tomato-mushroom sauces, creole sauces, and Spanish-style sauces included recipes yielding products with pH values above and below 4.6. In the absence of a foolproof means of predicting the pH of individual products within these categories, and in the interest of consistency, one must assume that all such products are low acid foods.

These results may be used as a guide in screening published home canning recipes (or recipes submitted for publication) to assure that appropriate processing methods have been specified. Of course the adequacy of specific processing recommendations (pressures, times) would have to be verified experimentally. The approach one could take in recipe assessment would be first to locate the recipe type within our classification scheme of product categories. If the recipe falls within the scope of our data bank, one would then calculate a value of the low acid index, probably the ratio of low acid ingredients to high acid ingredients, expressed on a weight basis. By comparison of this value with the range of ratios reported in our study, one could confirm that the recipe could be represented by our pH and acidity data. If this is the case, the recipe could then be classified according to whether it would yield a high acid product or a low acid product (including borderline or ambiguous cases). Water bath or steam canning methods would be appropriate for the former situation, while pressure canning methods would be required for the latter situation.

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