Glycine Derivatives as the Source of Carbon Dioxide in Cake Formulations[1]

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ABSTRACT

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Two glycine derivatives—N-carboxyglycine disodium salt (CAS 35783-03-0) and its glycine salt—were studied as alternative sources of CO_2 for leavening cakes. The release of CO_2 from these products was governed by the same pK_a value as that for sodium bicarbonate. When used in combination with fast, moderately fast, or slow leavening acids, the volumes of the final products prepared with glycine derivatives compared well with those of cakes prepared with sodium bicarbonate. Thus, the glycine derivatives appeared equal to sodium bicarbonate in this respect. The products prepared with the different CO_2 sources all appeared similar except for crust color, which was pleasantly darker in the cakes with the glycine derivatives.

In chemically leavened products, the classic source of CO_2 is sodium bicarbonate. When it is used in combination with stoichiometric quantities of acid salts of appropriate dissolution and, therefore, reactivity rates, proper leavening results.

Other CO_2 sources, such as ammonium bicarbonate and sodium carbonate have only limited applications, if any. Because of the moist crumb of cakes, ammonia may be retained from ammonium bicarbonate, and the carbonate results in products with high alkalinity (Hoseney 1986).

The present research was undertaken to study the potential use of two glycine derivatives, N-carboxyglycine disodium salt (Galat 1968) and its glycine salt (Fig. 1) in cake recipes. We also wanted to determine whether differences exist between the leavening action of different CO_2 sources.

MATERIALS AND METHODS

Chemicals

Sodium bicarbonate and sodium carbonate were obtained from Janssen Chimica (Beerse, Belgium) and UCB (Ghent), respectively; both glycine derivatives were supplied by F. Gils, NV Tessenderlo (Belgium) Chemie.

Citric acid was from UCB, and coated monocalcium phosphate and acidic sodium aluminum phosphate (V-90 and Levair) were obtained from Stauffer Chemical Co., Westport, CT.

Determination of pK_a Values

The pK_a values were determined from pH titration curves of

the four compounds studied. The titration curves were determined with 0.3 mmol of the compounds in 30 ml of 0.1 M sodium chloride titrated at room temperature with a 0.01 M solution of hydrochloric acid in 0.1 M sodium chloride. The pH was measured with a Consort pH meter. The experimental pK_a values were used to construct plots of the relative amounts of the different species present as a function of pH.

Cake Baking—Belgian Recipe

Ingredients. The ingredients were four eggs (total weight, 225 g), granulated sugar (225 g), flour (225 g), margarine (160 g), vanillin sugar (10 g), and a leavening system. The leavening system consisted of sodium bicarbonate (2.25 g) and the stoichiometric or recommended corresponding quantity of the leavening acid (1.72 g of citric acid, fast; 2.81 g of V-90, moderately fast; and 2.25 g of Levair, slow). When the glycine derivatives were used as the CO_2 source, we added the theoretical amounts necessary to generate the same quantity of CO_2 (i.e., 4.37 g for N-carboxyglycine disodium salt and 6.38 g for its glycine salt). As shown by the titration experiments, the amounts of leavening acids needed to generate the leavening gas from these derivatives are twice the amounts needed for sodium bicarbonate. Experiments also were conducted to determine whether or not the glycine derivatives needed a proton donor to release the leavening gas. This was done by omitting the leavening acids from the recipe.
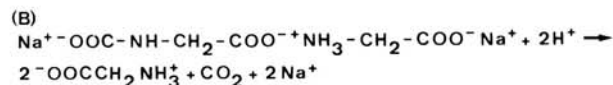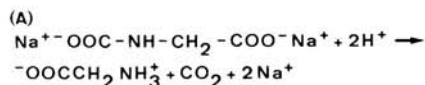
(A)
$$Na^{+\,-}OOC-NH-CH_2-COO^-Na^+ + 2H^+ \longrightarrow$$
$$^-OOCCH_2\,NH_3^+ + CO_2 + 2Na^+$$

(B)
$$Na^{+\,-}OOC-NH-CH_2-COO^{-\,+}NH_3-CH_2-COO^-Na^+ + 2H^+ \longrightarrow$$
$$2\,^-OOCCH_2\,NH_3^+ + CO_2 + 2Na^+$$

Fig. 1. Structural formula of (A) N-carboxyglycine disodium salt, (B) its glycine salt, and their reaction to CO_2 on addition of acid.

Cake Baking. The batter was prepared by mixing the margarine and the egg yolk with the sugar in a Kenwood mixer (2 × 2 min, with intermediate scraping of the sides of the mixing bowl). Half the flour weight (to which the leavening chemicals had been added) and half the whipped egg whites (separately whipped for 2 min with a Philips egg-white mixer) were added, and the batter was mixed for 2 min. The remaining flour and egg whites were added and the resulting mixture beaten for 2 min. Samples of cake batter (300 g) were transferred to Shogren-type baking pans (TMCO-National Manufacturing, Lincoln, NE), and the cakes were baked at 170°C for 50 min in a reel-type oven (TMCO-National).

Cake Baking—AACC Procedure

AACC Method 10-90 (AACC 1983) was used to bake high-ratio white layer cakes. In place of the baking powder, N-carboxyglycine disodium salt, its glycine salt, and sodium bicarbonate were used as sources of CO_2 in the formulations. They were used alone and in combination with citric acid, coated monocalcium phosphate (V-90), and acidic sodium aluminum phosphate (Levair). Molar ratios of the different leavening-system compounds used in the recipe were the same as those used in the Belgian formula. The cakes were baked in 8-in. pans in a reel-type oven (TMCO-National) at 191°C for 23 min.

Cake Batter—pH and Density

The pH of the batter was determined by direct immersion of a pH electrode in the batter at room temperature. The specific gravity of the cake batter was calculated as the ratio of the weight of a volume of batter (approximately 50 cm^3) to that of the same volume of 25°C water.

TABLE I
pKₐ Values from Literature (l) and Experiments (e)

Product	pKₐ Value	
	1	2
Sodium bicarbonate (l) (Vogel 1961)	6.37	...
Sodium bicarbonate (e)	6.36	...
Sodium carbonate (l) (Vogel 1961)	6.37	10.33
Sodium carbonate (e)	6.37	10.22
CGS (e)[a]	6.38	9.43
CGGS (e)	6.37	9.12
Glycine (l) (Roberts and Caserio 1977)	2.34	9.60
Glycine (e)	n[b]	n

[a] CGS = N-carboxyglycine disodium salt, CGGS = glycine salt of N-carboxyglycine sodium salt.
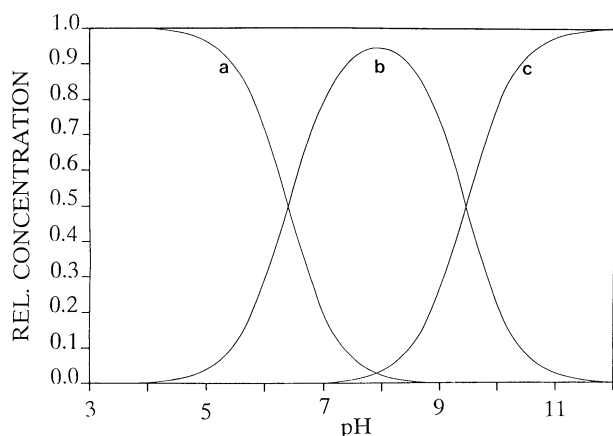[b] Cannot be observed under the experimental conditions described in the text.

Cake Volume

Volume was determined by rapeseed displacement; the cakes were wrapped in plastic foil before they were measured.

RESULTS AND DISCUSSION

Determination of pKₐ Values

The values for sodium bicarbonate and sodium carbonate determined in this work correspond well with those previously reported (Table I). The higher of the two pKₐ values of the glycine derivatives was lower than the highest pKₐ value of sodium carbonate, an agent too alkaline for application in bakery products.

With the experimental pKₐ data obtained from the titration curves, we constructed plots showing the relative concentration of the different species present as a function of pH (Figs. 2–4). These plots do not include the different forms of glycine generated (Roberts and Caserio 1977).

How the reactions proceed is unclear. However, the plots and the pKₐ values indicate that the release of CO_2 from the glycine derivatives is governed by the same pKₐ value as that for sodium bicarbonate. This could indicate that the release of CO_2 occurs very readily from both compounds under alkaline (Roberts and
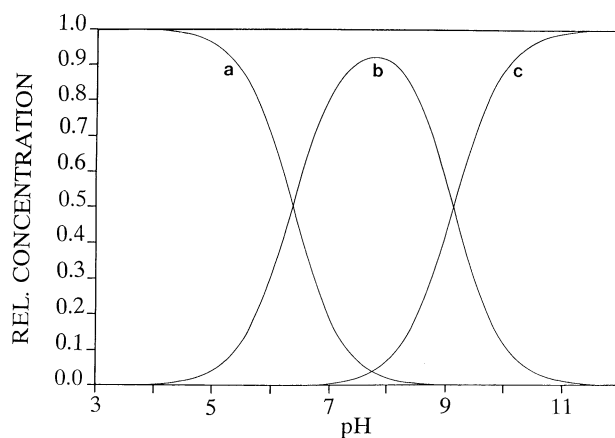

Fig. 3. Relative concentrations of the different species of compounds containing CO_2. a = CO_2, b = presumably sodium bicarbonate (see text), c = glycine salt of N-carboxyglycine sodium salt, present as a function of pH for solutions of the glycine salt of N-carboxyglycine sodium salt in water.

Fig. 2. Relative concentrations of the different species of compounds containing CO_2. a = CO_2, b = presumably sodium bicarbonate (see text), c = N-carboxyglycine disodium salt, present as a function of pH for solutions of N-carboxyglycine salt in water.

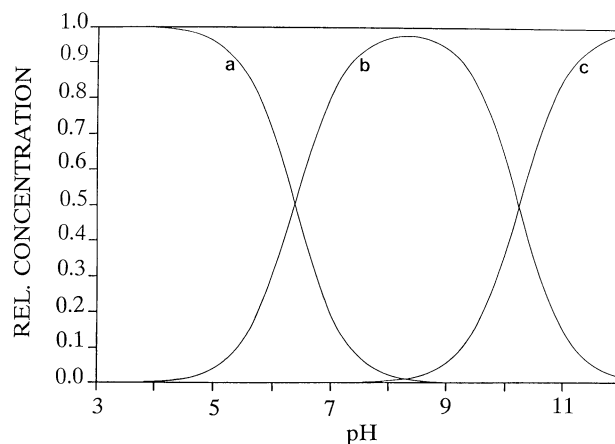**Fig. 4.** Relative concentrations of the different species of compounds containing CO_2. a = CO_2, b = sodium bicarbonate, c = sodium carbonate, present as a function of pH for solutions of sodium bicarbonate in water.

TABLE II
Specific Gravity and pH of Batters
Prepared with Different Leavening Acids
and Carbon Dioxide Sources (Belgian Recipe)

	Leavening Acid			
Carbon Dioxide Source	None	Citric Acid	V-90[a]	Levair
Batter specific gravity				
None	1.074	...	...	...
Sodium bicarbonate	1.054	1.044	0.933	0.992
CGS	1.054	1.045	0.953	1.026
CGGS	1.037	1.049	1.007	1.022
Batter pH				
None	6.14	...	...	...
Sodium bicarbonate	7.59	6.07	6.44	7.21
CGS	9.22	5.83	6.58	8.28
CGGS	9.02	6.25	8.12	8.28

[a] V-90 = Stauffer coated monocalcium phosphate, Levair = Stauffer acidic sodium aluminum phosphate, CGS = N-carboxyglycine disodium salt, CGGS = glycine salt of N-carboxyglycine sodium salt.

TABLE III
Volumes (cm^3) of Cakes Prepared with Belgian Recipe
and Different Leavening Acids and Sodium Bicarbonate, CGS, or CGGS[a]

	Leavening Acid			
Carbon Dioxide Source	None	Citric Acid	V-90	Levair
None	490 ± 2	...	...	...
Sodium bicarbonate	632 ± 2	670 ± 1	736 ± 4	775 ± 9
CGS	533 ± 0	627 ± 3	730 ± 9	747 ± 6
CGGS	587 ± 8	653 ± 5	745 ± 17	766 ± 2

[a] CGS = N-carboxyglycine disodium salt, CGGS = glycine salt of N-carboxyglycine sodium salt, V-90 = Stauffer coated monocalcium phosphate, Levair = Stauffer acidic sodium aluminum phosphate. All results are the average of at least duplicate determinations ± SD.

TABLE IV
Volumes (cm^3) of Cakes Prepared with AACC Formula
and Different Leavening Acids and Sodium Bicarbonate, CGS, or CGGS[a]

	Leavening Acid			
Carbon Dioxide Source	None	Citric Acid	V-90	Levair
None	595 ± 14	...	...	...
Sodium bicarbonate	625 ± 0	685 ± 7	745 ± 0	795 ± 7
CGS	545 ± 0	645 ± 0	750 ± 7	755 ± 7
CGGS	550 ± 7	680 ± 21	755 ± 14	770 ± 14

[a] CGS = N-carboxyglycine disodium salt, CGGS = glycine salt of N-carboxyglycine sodium salt, V-90 = Stauffer coated monocalcium phosphate, Levair = Stauffer acidic sodium aluminum phosphate. All results are the average of at least duplicate determinations ± SD.

Caserio 1977) as well as acidic (Carey and Sundberg 1977) conditions. That is, at these pH values, N-carboxyglycine and its salts are immediately converted to sodium bicarbonate. As the titration proceeds, the sodium bicarbonate would then be converted to CO_2.

If the above were true, it would seem important to determine whether or not the rapid release of CO_2 from the carbamic acid would still occur under the conditions of a cake batter. If not, the derivatives could be used to control the release of CO_2 during cake production.

Cake Baking—Belgian Recipe

Table II lists the density of the cake batter and the pH readings for cakes prepared with different leavening acids and CO_2 sources; Table III lists the corresponding cake volumes.

The data show that for all three CO_2 sources used, the magnitude of the pH drop was highly correlated with the dissolution rate of the leavening acid. When no leavening acid was used, the order of the pH readings coincided with the respective pK_a values.

At first glance, the high density readings for the cake batters prepared with the fast-acting leavening acid (citric acid) are rather surprising. However, the CO_2 was probably released before the cake structure could hold the formed leavening gas, thereby resulting in higher density readings. In the case of the two slower agents, the density of the batter could be predicted quite well from the dissolution rates.

The data in Table III clearly indicate that the glycine derivatives need a proton donor to release the leavening gas. The bicarbonate system produced some gas without use of a leavening acid because of a lower batter pH (Table II). For all three CO_2 sources, the volume of the cake depended on the dissolution rate of the leavening acids used, with the slowest agent giving cakes of largest

volume. The pH and volume readings also clearly indicate that dissolution of the slower leavening acids occurs mainly during baking.

Cake Baking—AACC Procedure

The pH and specific gravity measurements for the AACC batter followed the same trends as reported for the Belgian formula; therefore, the data are not presented. Cake volumes for the AACC formula (Table IV) generally agreed with those reported for the Belgian formula (Table III).

The use of glycine derivatives as alternatives for sodium bicarbonate leads to equivalent products, except that the crust color of cakes prepared with the Belgian and AACC procedures became darker in the following order (lightest to darkest): sodium bicarbonate, N-carboxyglycine disodium salt, glycine salt of N-carboxyglycine sodium salt. Adding glycine to cakes leavened with sodium bicarbonate (AACC procedure) also resulted in a darker color. This can be attributed to the participation of glycine in the Maillard reaction.

CONCLUSIONS

The classic source of CO_2 in chemical leavening is sodium bicarbonate. Because this salt dissolves rapidly, the rate of the release of CO_2 is controlled by choosing leavening acids with appropriate dissolution rates. Our work shows that the release of the leavening acid from the two glycine derivatives is governed by the same mechanism as that for CO_2.

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