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Relative reactivities of glucose and galactose in browning and pyruvaldehyde formation in sugar/glycine model systems

Su-Lin Chen [a,*], Shu-Yi Jin [a], Chia-Song Chen [b]

[a] School of Nutrition, Chung-Shan Medical University, 110, Sec., 1, Chiangkuo North Rd., Taichung, Taiwan, ROC
[b] Kuang Wu Primary School, Kaohsiung, Taiwan, ROC

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Abstract

Glucose/glycine and galactose/glycine model systems were incubated at 45 and 60 °C for the studies of Maillard browning, sugar consumption, and pyruvaldehyde formation. The results showed that, at pH 8, rates of browning followed pseudo-zero-order kinetics. Sugar consumption followed two-staged first-order kinetics with a lower rate constant at the second first-order stage when initial sugar concentration was 2.4% w/v and higher. The yield of pyruvaldehyde followed a third-ordered function of time. Although galactose/glycine system browned at a faster rate, glucose consumed faster than galactose in model systems. The yield of pyruvaldehyde was higher in galactose/glycine systems than in glucose/glycine systems at 45 °C, but inverted at 60 °C.

Keywords: Maillard reaction; Pyruvaldehyde; Glucose; Galactose; Glycine

1. Introduction

Maillard reaction is one of the most important reactions between reducing sugars and amino compounds during food processing and in living bodies (Nishi, Miyakawa, & Kato, 1989). Products of Maillard reaction (MRPs) can be either desirable or undesirable. In addition to brown pigment, some MRPs become flavors or off-flavors in foods (Amrani-Hemaimi, Cerny, & Fay, 1995; Hwang, Hartman, Rosen, Lech, & Ho, 1994; Hwang, Hartman, & Ho, 1995; Keyhani & Yaylayan, 1996; Van Boekel, 1998), some are antioxidative or antimutagenic (Bailey, 1988; Bedinghaus & Ockerman, 1995; Yen, Chau, & Lii, 1993), while others might be potentially toxic to human beings (Kitts, Wu, Stich, & Powrie, 1993; Nursten, 1986; Shibamoto, 1982).

Among these MRPs, pyruvaldehyde, also named as methylglyoxal, has caused much attention of medical scientists because of its potential mutagenecity (Cajelli, Canonero, Martelli, & Brambilla, 1987; Kasai et al., 1982; Shipanova, Glomb, & Nagaraj, 1997; Yim, Kang, Hah, Chock, & Yim, 1995). Fortunately, since puruvaldehyde is a compound of high activity, it reacts readily with other compounds to form volatiles such as butanedione, methylpyrazines, pyrazinones (Chiu, 1994; Keyhani & Yaylayan, 1996; Weenen et al., 1994), and brown pigments (Hayashi & Namiki, 1986). Thus pyruvaldehyde can be beneficial to sensory quality of foods through the formation of flavors and melanoidin, meanwhile reduce its toxicity through consuming pyruvaldehyde itself. Therefore, it is interesting to see how the concentration of pyruvaldehyde varies during food processing and storage. Optimizing the yield of pyruvaldehyde in food would be a challenge to food chemists.

* Corresponding author. Tel.: +886 424730022x1860; fax: +886 423248188/75.
E-mail address: slc@csmu.edu.tw (S.-L. Chen).

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In this study, glucose and galactose were used to react with glycine in model systems to study the kinetics of browning rate, sugar consumption, and change of pyruvaldehyde concentration.

2. Materials and methods

2.1. Glucose/glycine model system

Glucose and glycine solutions were prepared by dissolving α-D(+)-glucose (Sigma Chemical Co., USA) and L-glycine (Sigma Chemical Co., USA) in de-ionized water then incubated separately. Concentrations of glucose solution thus prepared were 2.4, 4.8, and 9.6% w/v, respectively, where that of glycine solution was 10.0% w/v. In the beginning of experiments, equal volume of glucose solution and glycine solution at the same temperature were mixed, adjusted pHs to 8.0 using 0.5 N NaOH and 0.5 N HCl solutions, then incubated at 45 °C or 60 °C immediately. Concentrations of glucose and glycine in the mixtures would be half of the original solutions. One hundred and ten milliliter mixture was sampled at intervals for the determination of pH (model SP-71, Suntex Inc., Taiwan), Maillard browning, concentration of sugar and pyruvaldehyde.

2.2. Galatose/glycine model system

Experiment procedures were the same as glucose/glycine model system with α-D(+)-galactose (Sigma Chemical Co., USA) instead of α-D(+)-glucose.

2.3. Measurement of color change

The color change of model systems was measured using two parameters: absorbance at wavelength 420 nm (A_{420}) and Hunter L, a, b value. Instrument for determining A_{420} was a spectrophotomerer (U-1100, Hitachi, Japan), while that for Hunter L, a, b was a colorimeter (U-3000, Hitachi, Japan).

2.4. Determination of sugar concentration

Sugar concentration of sample solution was determined using HPLC. After filtration, 10 μl sample was fractionated in a NH_2 column (4 mm ID × 250 mm, 5 m particle size; Lichrosorb NH_2, Merck, Germany) using acetonitrile/water (80/20) as mobile phase eluting at a rate of 1.2 ml/min. Sugar peaks were detected by a RI detector (L-3500 RI-monitor detector, Hitachi, Japan), and calculated using a software (D-6000 Chromatography Data Station Software, Hitachi, Japan) installed in an IBM compatible PC (Acer Inc., Taiwan).

2.5. Determination of pyruvaldehyde

Pyruvaldehyde is a water soluble, highly active compound. It reacts readily with compounds primary amine, acetaldehyde and so on. That makes direct GC analysis of pyruvaldehyde very difficult. Hayashi and Shibamoto (1985) developed a method involving derivation of pyruvaldehyde with cysteamine. In the current study, determination of pyruvaldehyde followed their procedure with some modification because of its very low concentration in our model systems.

For qualitative analysis of pyruvaldehyde, cysteamine hydrochloride (0.75 g) was added to 100 ml of de-ionized water that contained 2.5μl pyruvaldehyde (Sigma Chemical Co., USA). The mixture was then adjusted to pH 6.0 using 0.1 N NaOH, stirred for 30 min at room temperature, and extracted by dichloromethane for 6 hr in a liquid-liquid extractor. The extract was dehydrated by anhydrous sodium sulfate overnight in a refrigerator, and then concentrated in 65 °C water bath to a volume less than 0.5 ml. The concentrate was then fractionated in a DB-Wax fused silica capillary column (30 m × 0.25 mm, J&W Scientific, USA) installed in a GC (model Autosystem, Perkin–Elmer, USA), using helium carrier gas at a flow pressure of 7.6 psi. The setting conditions for GC analysis were: oven temperature held at 80 for 5 min, programmed at 3 °C/min to 200 °C and held for 10 min. Chemical structures of these fractions were detected using a Mass Spectrometer (Q-Mass 910, Perkin–Elmer, USA) equipped with NIST data library. Analytical conditions for mass spectrometry were set as follow: helium carrier gas flowed at pressure 7.6 psi, the temperature of ion source was 150 °C, and ion voltage was 70 eV.

For quantitative analysis, sample concentrate was prepared from 100 ml of sample solution, added with 500 μl internal standard (20% w/v *N*-methylacetamide). The sample concentrate was then fractionated and detected using the same GC equipped with a FID. The relative amounts of fractionated peaks were calculated using an integrator (model 1020, Perkin–Elmer, USA).

2.6. Data analysis and statistical method

Absorbance at wavelength 420 nm (A_{420}) and difference of color index (ΔE) were used to indicate browning of the model systems. Values of ΔE were calculated using the following equation (Zamora & Hidalgo, 1992):

$$\Delta E = \{(\Delta a)^2 + (\Delta b)^2 + (\Delta L)^2\}^{1/2}. \quad (1)$$

Rates of reaction including browning and sugars consumption were calculated using equation:

$$v = -d[\mathrm{R}]/d\mathrm{t} = k[\mathrm{R}]^n \quad (2)$$

where v was reaction rate in h^{-1}, [R] was reactant concentration in % w/v, t was time in hour, k was reaction constant, and n was the order of reaction.

All experiments were done in triplicate. Stepwise regression analysis, on the basis of least sum of square of residuals and visual examination on distribution of residuals, was used to describe the reaction rate.

3. Results and discussions

Model systems containing merely sugars and water did not develop any color change in this study, it could therefore be sure that the contribution of caramelization could be negligible and Maillard reaction was the major cause of browning.

3.1. Changes of pH

System pH values went from 8.0 down slightly to 7.8 around in the first hour of Maillard reaction (Fig. 1). During this period of time, no significant differences on pH changes between galactose/glycine and glucose/glycine systems were observed; neither were systems at 45 and 60 °C. However, pH changes differentiated between system temperatures thereafter. In the following hour, systems pHs at 60 °C went steeply upward over the original values to a peak ranging between 8.4 and 9.8, then setback to values between 8.2 and 8.6 at hour 4; while those at 45 °C kept going slowly down till hour 4. After that, pH values went slowly down throughout the experiment in systems at 60 °C. While in systems at 45 °C, pH values went upward then turned downward between hour 4 and 108. The mechanisms that system pHs decreased in the earlier stage might be due to the loss of the basic amino groups as de Man (1999) indicated. But in the later stages, after Amadori rearrangement, products with various acidities (e.g., glyoxal, pyruvaldehyde, and furfural etc) became distinguished that might be influential on system pH.

Few literatures had discussed pH change during Maillard reaction. Reyes, Poocharoen, and Wrolstad (1982) studied Maillard reaction in sugar/glycine model systems at 60 °C, and indicated. that no change in pH was observed. In their studies, Reyes et al. monitored system pH every 3 h during the first 12 h. In the current study, whereas, we found that tremendous pH fluctuation accomplished in the first 3 h. It might be the reason that Reyes et al. (1982) did not observe obvious pH change in their studies.

Temperature and pH are two of the major factors that influence Maillard reaction. In the current study, we found that temperature further influenced pH change in sugar/glycine model systems. It is clear that there should be synergistic effect between temperature and pH on Maillard reaction.

3.2. Rate of browning

Changes of absorbance at 420 nm and color index followed similar trend as shown in Figs. 2 and 3, which indicated that browning reactions of glucose/glycine and galactose/glycine systems followed pseudo-zero-ordered kinetics. These results were accordant with the studies of Baisier and Labuza (1992). The browning rates in glucose/glycine systems were significantly lower than galactose/glycine systems as showed in Figs. 2 and 3.

Table 1 summarizes the rate constants of the zero-ordered period during browning of the systems. According to this table, rate constants of absorbance for galactose/glycine systems averaged 8.5- and 1.9-folds of glucose/glycine systems at 45 and 60 °C, while those of color index averaged 5.7- and 1.4-folds, respectively. Maillard (1912) noted the reactivities of sugars in Maillard reaction was declining in the orders of D-xylose, L-arabinose, hexoses, and disaccharides, but the author did not mention the difference among all hexoses. Reyes et al. (1982) reported that fructose/glycine systems browned at a rate faster than glucose/glycine and sucrose/glycine systems

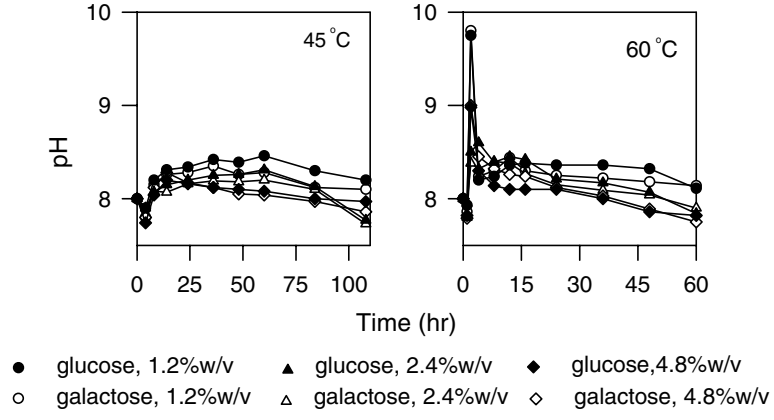

Fig. 1. pH change of glucose/glycine and galactose/glycine systems at 45 and 60 °C.

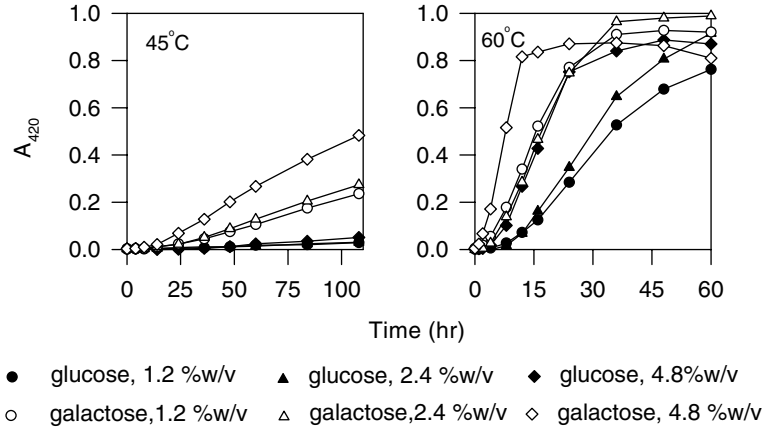

Fig. 2. Changes of absorbance at 420 nm in model systems at 45 and 60 °C.

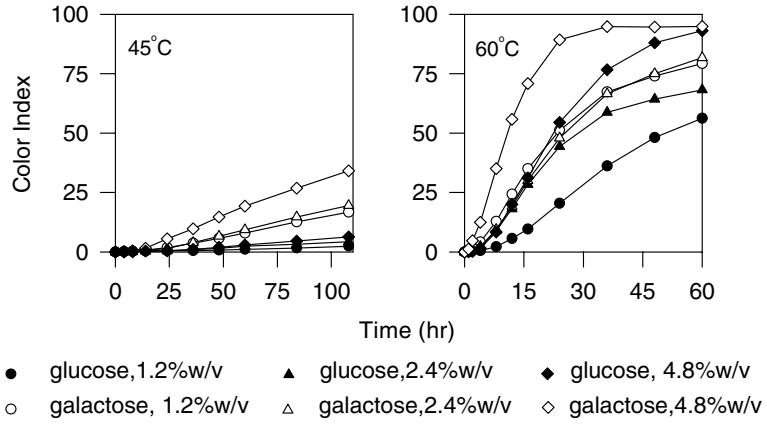

Fig. 3. Changes of color index in model systems at 45 and 60 °C.

Table 1
Zero-order rate constant for browning in glucose/glycine and galactose/glycine systems

Sugar	Treatment		Rate constant	
	Temp. (°C)	Concentration (% w/v)	$k_{A_{420}}$	$k_{\Delta E}$
Galactose	45	1.2	0.00248	0.1806
		2.4	0.00292	0.2179
		4.8	0.00493	0.3418
	60	1.2	0.03711	1.5965
		2.4	0.03834	2.3463
		4.8	0.07683	4.9019
Glucose	45	1.2	0.00027	0.0236
		2.4	0.00034	0.0462
		4.8	0.00062	0.0715
	60	1.2	0.01826	1.3254
		2.4	0.02303	2.1594
		4.8	0.04058	2.7038

at initial stage. Similar relative reactivity was reported by de Man (1990), who indicated that the order of relative reactivity was mannose > galactose > glucose. In this study, more precisely numerical data validated the relationship between galactose and glucose on the browning rate reported by de Man (1999).

Further calculation of data in Table 1 indicated that rate constants of absorbance for systems containing glucose and galactose at 60 °C were 65.6–68.0- and 13.1–15.6-folds of systems containing same sugars at 45 °C. These were equivalent to Q_{10} values 16.3–16.7 and 5.6–6.2 for glucose/glycine and galactose/glycine systems; while those of color index were 11.3–14.7 and 4.3–5.9, respectively. Petriella, Resnik, Lozano, and Chirife (1985) studied browning rate in glucose/lysine systems and indicated Q_{10} values ranged from 3.5 to 6.0 at 35 to 55 °C and pH 5–7. In the current study, Q_{10} values more than 10 in glucose/glycine systems at 45–60 °C and pH 8 were much higher than those reported by Petriella et al. (1985). These results revealed a synergistic effect between pH and temperature on browning rate.

Effects of initial sugar concentration on the browning rate constant followed the linear semi-logarithmic equation:

$$log(k_{A_{420}}) = \mathrm{A}[\mathrm{sugar}] + \mathrm{B}. \quad (3)$$

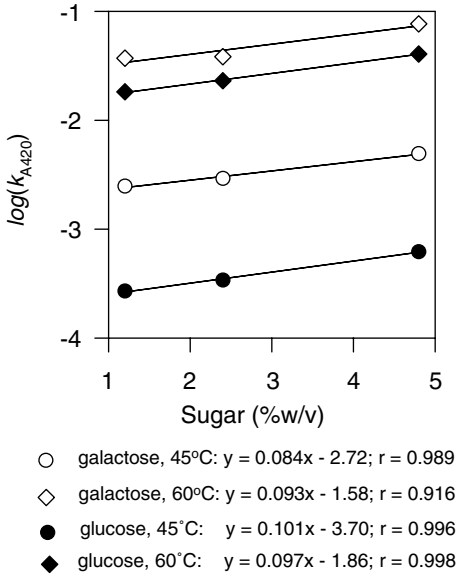

Fig. 4. Effects of initial sugar concentration on the rate constants of Maillard browning measured with absorbance at 420 nm.

Fig. 4 shows the linear relationship between the browning rate constant measured by absorbance and initial sugar concentration. The slopes showed no significant difference between temperature at 60 and 45 °C, revealing no significant synergistic or inhibitory effects between initial sugar concentration and temperature on the browning rate.

3.3. Sugars consumption

Baisier and Labuza (1992) indicated that consumption of sugar in glucose/glycine systems followed first-ordered kinetics. In the current study, systems containing 1.2% w/v glucose or galactose followed similar kinetics as shown in Fig. 5. However, in systems containing higher sugars, i.e., 2.4 and 4.8% w/v, we found there were second first-ordered phases with lower rate constants. To materialize the relationship between these two phases, the term "turning point" was defined as the time when regression lines of these two phases intersected with each other. The rate constants and turning points of sugar consumption were summarized in Table 2.

The mechanism for two-staged kinetics of sugar consumption was not clear. Baisier and Labuza (1992) indicated that in model systems, consumption of glycine was more complicated than sugar. It also has been known that reducing sugars only participate in the first step of Maillard reactions while amino acids will further participate in later reactions such as Strecker's degradation, etc. Was it the higher consumption rate of glycine in the later period that lowered amino acid concentration and further slowed down the sugars consumption rates? Or there might be another mechanism. That requires further studies.

Table 2
First-order consumption rate constants of glucose and galactose in sugars/glycine systems

Sugar	Treatment		Rate constant		R		T (h)
	Temp. (°C)	C	k_1	k_2	k_1	k_2	
Galactose	45	1.2	0.0022	–	0.969	–	–
		2.4	0.0032	0.0004	0.948	0.996	12.2
		4.8	0.0028	0.0019	0.802	0.961	15.8
	60	1.2	0.0056	–	0.983	–	–
		2.4	0.0110	0.0019	0.972	0.95	23.0
		4.8	0.0137	0.0029	0.963	0.993	20.9
Glucose	45	1.2	0.0024	–	0.919	–	–
		2.4	0.0046	0.0016	0.892	0.972	8.3
		4.8	0.0067	0.0019	0.975	0.982	12.2
	60	1.2	0.0059	–	0.961	–	–
		2.4	0.0154	0.0048	0.988	0.987	16.7
		4.8	0.0196	0.0095	0.94	0.953	13.1

Note. k_1 is the first first-order phase of reaction; k_2 is the second first-order phase of reaction; C is the initial sugar concentration in (%w/v); R is the correlation coefficient; T is the turning point between two first-order phases.

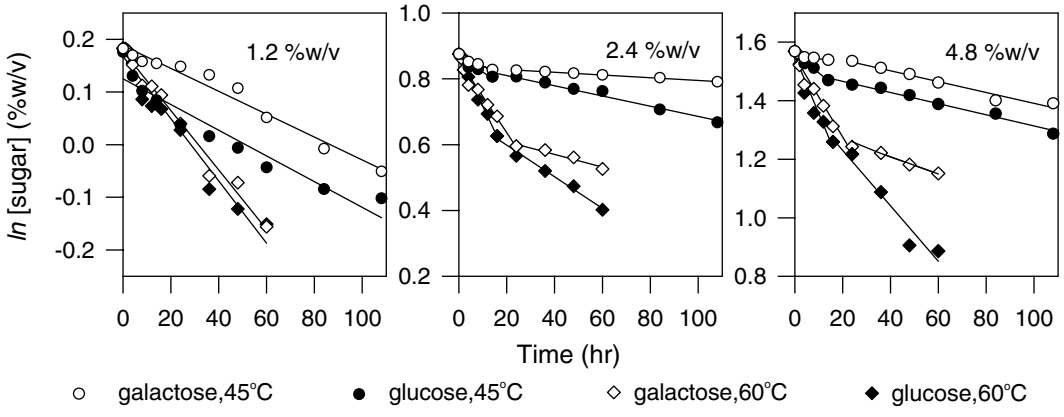

Fig. 5. Consumption of glucose and galactose in model systems at 45 and 60 °C.

Consumption rates of glucose were higher than galactose in the first first-order phases (Table 2). From the data shown in Table 2, we figured that at 45 °C, rate constant of galactose consumption in the first first-ordered phase (k_1) ranged from 0.92 down to 0.42-folds of glucose consumption as sugar initial concentration increased from 1.2 to 4.8% w/v. And at 60 °C, it ranged from 0.95 down to 0.70-folds as sugar initial concentration increased from 1.2 to 4.8% w/v. The facts that galactose consumed slower than glucose seemed to conflict with the results that galactose browned faster than glucose as mentioned previously. According to Hodge (1953), there were four pathways involving in the formation of melanoidins. Furthermore, Reinefeld, Bliesener, and Kunz (1978) indicated that although fructose reacted more rapidly in the formation of glyceraldehyde, methyl glyoxal and deoxyhexosuloses, glucose converted into hexoseamine more rapidly than did fructose. It therefore would be reasonable to conclude that in Maillard reaction, sugars consumed at higher rate did not necessarily brown faster.

Effects of temperature on sugar consumption was more significant in galactose/glycine systems than in glucose/glycine ones. On dividing k_1 values at 60 °C by those at 45 °C, we figured ratios averaged 3.6 in galactose/glycine systems and 2.9 in glucose/glycine systems. That was equivalent to Q_{10} values 2.3 and 2.0, respectively. These results implied that effect of temperature fluctuation on sugar consumption rate was higher for galactose/glycine than glucose/glycine at temperature between 45 °C and 60 °C.

Effects of initial sugar concentration on its rate constant sugar consumption followed a linear semi-logarithmic equation, except the 45 °C galactose/glycine system:

$$k_i = A\,log[\text{sugar}] + B. \quad (4)$$

Fig. 6 shows the relationships and their regression parameters between the rate constant and logarithm of the initial sugar concentration. For galactose/glycine systems at 45 °C, as shown in Table 2 and Fig. 6, the rate constants, with an average value of 0.0027, were no significantly different among the initial sugar concentrations. The slope of glucose at 60 °C shown in Fig. 6 was 0.0227, more than 3-folds of that at 45 °C, revealing a synergistic effect between sugar concentration and temperature on the rate constant of sugar consumption. At 60 °C, the slope of glucose was higher than that of galactose (Fig. 6), revealing a greater effect of sugar concentration on rate constant in glucose/glycine than galactose/glycine systems.

3.4. Yield of pyruvaldehyde

Fig. 7 is the gas–liquid chromatogram of dichloromethane extract from the reaction products of pyruvaldehyde and cysteamine. Among these products, the peak

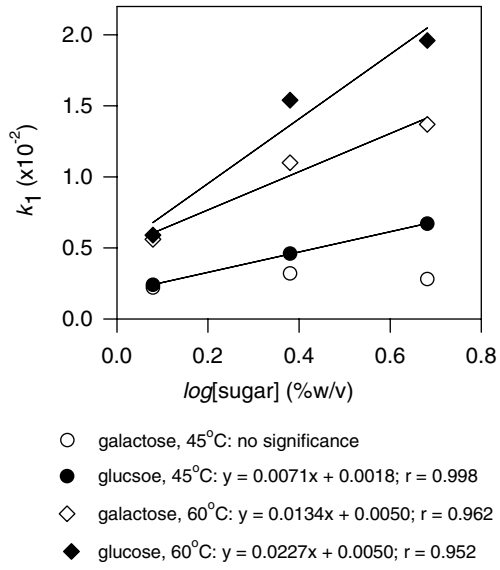

Fig. 6. Effects of initial sugar concentration on the rate constant of sugar consumption.

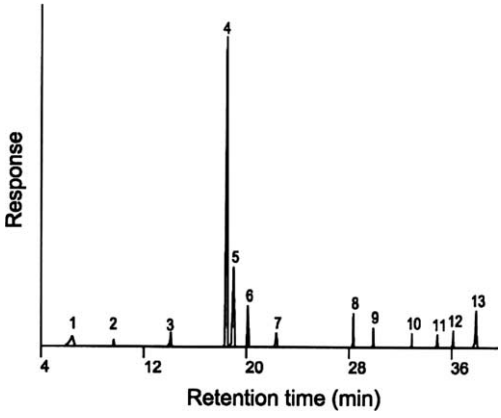

Fig. 7. GC chromatogram of dichloromethane extract from products of reaction between pyruvaldehyde and cysteamine. 1: *N*-Methylamide (internal standard); 2: thiazoline; 3: 2,4,5-trimethylthiazole; 4: 2-acetyl-2-thiazoline; 5: unknown; 6: *N*-nitrosothiazolidine; 7: unknown; 8: 3-acetyl-2-methylene thiazolidine; 9–13: unknown.

of 2-acetylthiazoline took average 81% of total area, and was used as the indicator of pyruvaldehyde. Fig. 8 shows the mass spectrum of 2-acetylthiazoline.

Fig. 9 shows the yield of pyruvaldehyde in sugar/glycine systems at 45 and 60 °C. Since pyruvaldehyde is not a primary product of Maillard reaction, there was an induction period before it was formed. Length of the induction period was dependent upon temperature and sugars. In the glucose/glycine systems at 45 °C, pyruvaldehyde was not detectable until hour 84 (Fig. 9) and the data obtained were not enough for regression analysis. While in galactose/glycine systems at 45 °C, some pyruvaldehyde was detected at hour 36, 48 h earlier than glucose/glycine ones. For systems at 60 °C, pyruvaldehyde became detectable at hour 8, and increased to the max-

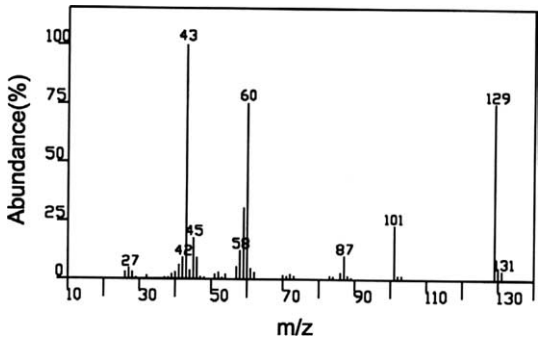

Fig. 8. Mass spectrum of 2-acetyl-2-thiazoline.

imum between hour 36 and 60 °C then went down. At 45 °C, yield of pyruvaldehyde in galactose/glycine systems was higher than that in glucose/glycine system. However, production inverted at 60 °C where pyruvaldehyde concentration in glucose/glycine systems exceeded the other ones (Fig. 9). Stepwise regression analysis showed that changes of pyruvaldehyde concentration followed an empirical third-ordered equation (5), except that in glucose/glycine system at 45 °C:

$$Y = b_o + b_1X + b_2X^2 + b_3X^3 \quad (5)$$

where Y was concentration of pyruvaldehyde in % w/v and X was time in hour. Table 3 summarizes all the regression parameters. From the regression parameters, pyruvaldehyde concentration increased to the maximum in 80 and 40 h around for galactose/glycine systems at 45 and 60 °C, respectively; while it took 50 h around for pyruvaldehyde to get to the maximum in glucose/glycine at 60 °C. The induction period of pyruvaldehyde formation in glucose/glycine systems at 45 °C was so long that we could not see the maximum values during the experiment. The maximum pyruvaldehyde concentrations in glucose/glycine systems at 60 °C decreased from 0.0179 to 0.0116% w/v as glucose initial concentration increased; while those in galactose/glycine systems at 45 and 60 °C increased from 0.0017 to 0.0043 and 0.0042

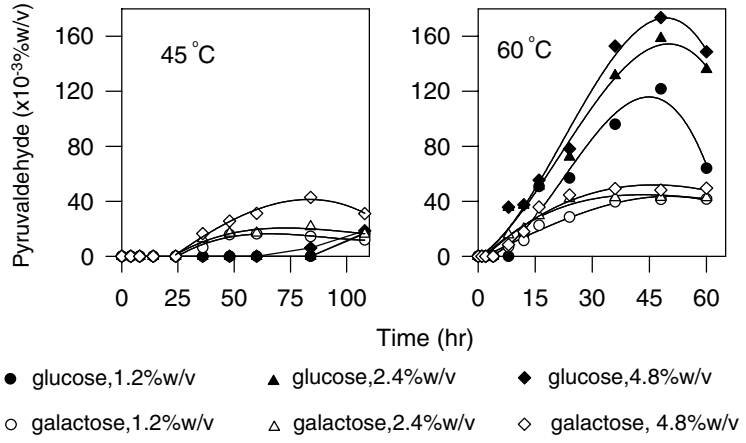

Fig. 9. Changes of pyruvaldehyde concentration in model systems at 45 and 60 °C.

Table 3
Regression coefficients of yield of pyruvaldehyde vs. time in sugars/glycine systems

Sugar	Treatment		Regression parameters					MC ($\times 10^{-3}$)
	Temp. (°C)	C	b_0	b_1	b_2	$b_3(\times 10^{-3})$	R	
Galactose	45	1.2	−67.5	3.422	−0.044	0.18	0.957	17.3
		2.4	15.3	−0.377	0.011	−0.07	0.941	21.1
		4.8	18.5	−0.876	0.030	−0.19	0.984	42.6
	60	1.2	−12.1	2.590	−0.040	0.20	0.986	42.0
		2.4	−11.9	3.830	−0.086	0.61	0.975	43.8
		4.8	−32.7	6.130	−0.147	1.13	0.962	50.0
Glucose	45	1.2	–	–	–	–	–	–
		2.4	–	–	–	–	–	–
		4.8	–	–	–	–	–	–
	60	1.2	29.8	−2.935	0.256	−3.30	0.986	179.3
		2.4	51.4	−4.134	0.297	−3.40	0.986	160.7
		4.8	48.6	−4.079	0.326	−3.80	0.987	116.5

Note. b is regression coefficient; C is initial concentration of sugars in %w/v; MC is the calculated maximum concentration of pyruvaldehyde in %w/v; R is the correlation coefficient.

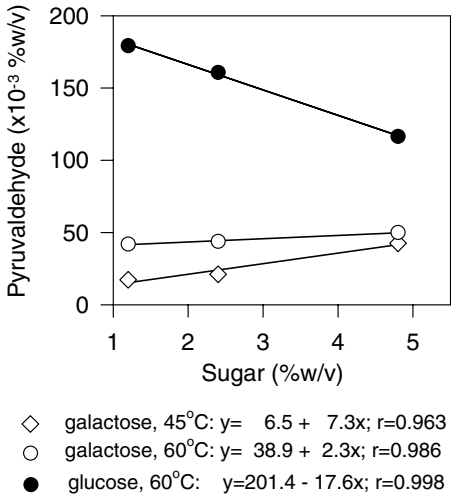

Fig. 10. Effects of initial sugar concentration on the maximum concentration of pyruvaldehyde in sugar/glycine systems.

to 0.0050% w/v, respectively, as galactose initial concentration increased (Fig. 10).

There were several pathways involving the formation of pyruvaldehyde in Maillard reaction: (1) through retroaldolization of 2,4-diketobutanol and deoxayglucosone, which were produced from Amadori compounds (Keyhani & Yaylayan, 1996; Weenen et al., 1994); (2) through conversion of glyceraldehyde in the presence of amino compounds (Keyhani & Yaylayan, 1996); (3) through aldol condensation followed by deamination of glyoxal with glycine (Keyhani & Yaylayan, 1996). Once pyruvaldehyde was formed, it reacted readily with other compounds to produce volatiles such as pyrazine containing methyl group (Chiu, 1994; Hwang et al., 1994; Weenen et al., 1994), 2,3-butanedione (Keyhani & Yaylayan, 1996), trimethylpyrazinones (Keyhani & Yaylayan, 1996), and melanoidins (Hayashi & Namiki, 1986). These may explain the complexity of pyruvaldehyde concentration changes in this study.

4. Conclusion

The changes of pyruvaldehyde concentration in sugar/glycine systems followed the third-ordered equations during the experiment period. The maximum values of pyruvaldehyde varied with sugar, temperature, and their interaction. The trends of maximum value depended upon sugars. In glucose/glycine, the maximum values of pyruvaldehyde decreased linearly as the initial sugar concentration of glucose/glycine increased; while it increased linearly as the initial sugar concentration of galactose/glycine increased.

Rate constant of the first-ordered kinetics of sugar consumption changed after the so-called "turning point". These results might be partly because of the complexity of amino acid reaction with other MRPs in the later stage. Even so, we could still figure the rate constants of first-ordered reaction in the very early stage. Glucose consumed more rapidly than did galactose at temperature below 60 °C. However, since Q_{10} value of sugar consumption in galactose/glycine was higher than that in glucose/glycine, the consumption rate of galactose would exceed that of glucose at some temperature above 60 °C. Effects of the initial sugar concentration on its consumption rate followed a linear semi-logarithm equation. The fact that slopes at 60 °C was larger than those at 45 °C indicated a synergistic effect of initial sugar concentration and temperature on the sugar consumption.

In contrast to sugar consumption rate, in which glucose/glycine reacted faster, galactose/glycine browned at a higher rate than did glucose/glycine at temperature between 45 and 60 °C. Color development of Maillard browning reactions followed the pseudo-zero-ordered kinetics. The Q_{10} values of browning rate in glucose/glycine were more than 2-folds of those in galactose/glycine. These results showed that browning rate of glucose/glycine would exceed that of galactose/glycine at some temperature above 60 °C. Effects of the initial sugar concentration on browning rate constant browning followed a linear semi-logarithm equation. There was no significant synergistic or inhibitory effect between temperature and initial sugar concentration on the browning rate constant.

Few literatures concerned the pH changes in Maillard reaction. However, since the reaction proceeded at the expense of amino acids which were high in buffering capacity and, at the same time, producing chemicals that might be influential on pH, it would be necessary that we monitor pH changes in Maillard reaction. Not mentioning the fact that pH was quite a critical factor in Maillard reaction. The results here could only present a descriptive curve, yet far away from developing any inferential model, on pH changes in the reaction. Still much more experimental data were required for the development of empirical models for pH changes in Maillard reaction.

MRPs are quite a group of compounds with quite a variety of structure and diversity of role in foods. Consequently, how to optimize the production of special MRPs, i.e., to maximize their beneficial effects meanwhile to minimize the negative effects, will be a challenge for food technologists.

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