Effects of Phosphates Differing in P_2O_5 Contents on Firming Rate of Cooked Rice

I. H. KIM[1] and S. K. KIM, Department of Food and Nutrition, DanKook University, Yongsan-Ku, Seoul, Korea

ABSTRACT

Cereal Chem. 61(2):91-94

The effect of phosphates having P_2O_5 contents of 33.5–68% on the firming rate of nonwaxy and waxy cooked rice stored at 21°C was studied. Phosphates having P_2O_5 contents of 59.3 and 68% decreased the firming rate of the cooked nonwaxy rice, and the effect exerted by 68% P_2O_5 phosphate was more pronounced. The 68% P_2O_5 phosphate reduced the firming rate of nonwaxy cooked rice by 25–40%, depending on the rice variety. Phosphates had no effect on the firming rate of cooked waxy rice. Kinetic studies indicated that the primary effect of phosphates in decreasing the firming rate of cooked nonwaxy rice was to reduce the amount of starch components available for crystallization.

Rice is the staple food in Korea. In 1970, high-yielding rice varieties were introduced so that Korea could attain self-sufficiency in terms of its food grains. Amylose content plays a prime role in determining the eating quality of cooked rice (Juliano 1982). In Korea, the high-yielding Indica varieties generally have poorer eating quality than the traditional Japonica varieties, even though the amylose contents for both types are comparable. In comparing an Indica and a Japonica type rice, Chung et al (1982) demonstrated that starches had different physical properties even though the amylose contents were similar.

Phosphates have been widely used in food processing (deMan and Melnychyn 1971, Ellinger 1972). Little information is available, however, for the use of phosphates in starchy food products. Nara et al (1964) showed that sodium pyrophosphate markedly retarded the swelling of potato starch granules and thus depressed the viscosity of the starch pastes.

The purpose of this article is to investigate the firming rate of cooked rice (Indica and Japonica type nonwaxy rices, and a waxy rice) in the absence or presence of phosphates differing in P_2O_5 contents.

[1] Present address: Seo-Do Chemical Co., Ltd., Bukchang Dong, Chung-Ku, Seoul, Korea.

MATERIALS AND METHODS

Materials

Nonwaxy varieties of a Japonica type (Akibare) and an Indica type (Milyang 30) and a waxy variety of rice were dehulled and abrasively polished (8%, d.b.).

Phosphates employed in this experiment (Table I) were obtained from Seo-Do Chemical Co., Ltd., Seoul. The phosphorus content of the phosphates was weighed as $Mg_2P_2O_7$ and reported as P_2O_5 (AOAC 1980).

Cooking of Rice

The cooking apparatus was a brass vessel 12 mm (i. d.) × 28 mm that was able to endure inner pressure at 140°C when a packing was inserted and sealed with a screw cap.

One gram of rice and 1.4 ml of water were placed in the vessel and soaked for 30 min. The rice was then cooked in an oil bath (100°C) for 20 min and cooled for 1 min in ice water (Cheigh et al 1978). The concentrations of phosphates employed were 0.2, 0.25, and 0.3% (d.b.). Phosphates were dissolved in water before use.

Aging of Cooked Rice

The cooked rice in the vessel was stored at 21°C for up to five days. The firmness of cooked rice grain was tested using a Texturometer (Zenken Co., Ltd., Tokyo, Japan) at 0, 1, 2, 3, and 5 days; 10–20 cooked rice grains were measured, and the average was taken. The experiment was repeated once. The limiting modulus was obtained from the cooked rice stored at 2° C for six days. The values of E_0, E_1, E_2, E_3, and E_5, which represent the firmness of cooked rice at 0, 1, 2, 3, and 5 days, respectively, were used in Avrami analysis (Avrami 1939, 1940, 1941) to determine the rate constant (k) and the Avrami exponent (n) according to Cornford et al (1964) and McIver et al (1968):

$$\theta = \frac{E_L - E_t}{E_L - E_0} = \exp(-kt^n) \qquad (1)$$

Thus:

$$\log(-\log_e \frac{E_L - E_t}{E_L - E_0}) = \log k + n \log t \qquad (2)$$

Where θ is the fraction of uncrystallized material at time t, and E_L is the limiting modulus. The reciprocal of the rate constant (that is, $1/k$) is termed time constant. A detailed explanation of these various terms was given previously (Cornford et al 1964, McIver et al 1968).

The Avrami exponent was obtained from the gradient of a graph of equation 2, and the rate constant was determined from a graph of $\log_e(E_L - E_t)$ vs t (McIver et al 1968).

TABLE I
Composition and P_2O_5 Contents of Phosphates

Phosphate	Composition (%)		P_2O_5 Content (%)
Polygel-RW	Sodium polyphosphate	30	33.5
	Sodium metaphosphate	30	
	Sodium carbonate	10	
	Potassium carbonate	30	
Polygel-RM	Sodium polyphosphate	50	50.7
	Potassium polyphosphate	10	
	Potassium carbonate	15	
	Disodium phosphate	25	
Polygel-RMG	Sodium polyphosphate	55	51.5
	Sodium metaphosphate	10	
	Potassium polyphosphate	10	
	Potassium carbonate	25	
Polygel-RMF	Sodium polyphosphate	60	55.9
	Sodium metaphosphate	25	
	Disodium phosphate	10	
	Dipotassium phosphate	5	
Polygel-RR	Sodium polyphosphate	60	59.3
	Sodium metaphosphate	20	
	Sodium pyrophosphate	10	
	Potassium metaphosphate	10	
Polygel-XP	Sodium polyphosphate	60	68.0
	Sodium metaphosphate	25	
	Potassium metaphosphate	15	

RESULTS AND DISCUSSION

The results of the Avrami analysis on the aging of cooked rice stored at 21° C are shown in Figs. 1 and 2. The Avrami exponents for Akibare, Milyang 30, and waxy rice were 1.0434, 1.0225, and 0.9863, respectively (Fig. 1). The same value ($n = 1$) was reported for rice starch gels (Chung et al 1982, Kim et al 1978). When the aging of starch gel is applied, the value of unity for the Avrami exponent indicated that the mechanism of starch crystallization is instantaneous nucleation followed by rodlike growth of crystals (Sharples 1966). The Avrami exponents for cooked rice (Fig. 1), therefore, indicate that the basic mechanism of the firming of cooked rice involves changes analogous to starch crystallization. A

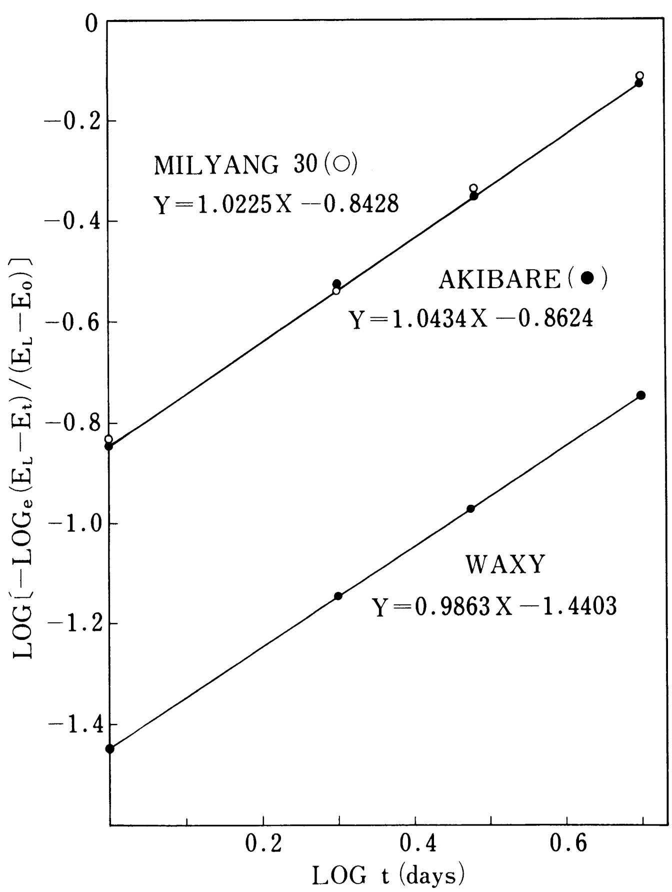

Fig. 1. Plot of log ($-\log_e \frac{E_L - E_t}{E_L - E_o}$) against log t for cooked rice stored at 21°C.

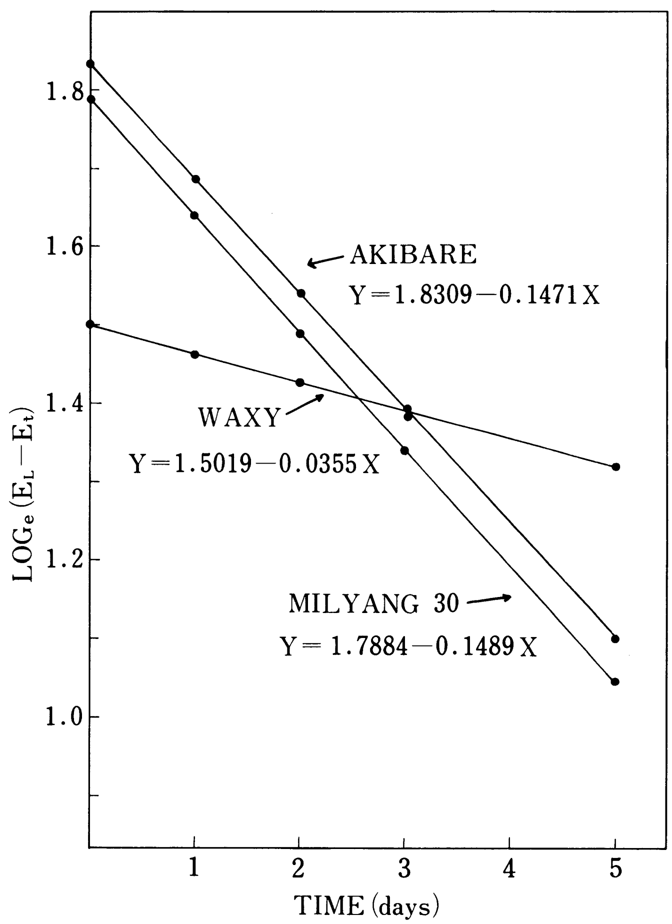

Fig. 2. Plot of $\log_e (E_L - E_t)$ against time for cooked rice stored at 21°C.

similar result was reported by Kim and Pyun (1982).

The Avrami exponents of cooked rice in the presence of phosphates differing in P_2O_5 contents are given in Table II. The values for the Avrami exponent showed unity in all cases, indicating that the basic mechanism of aging of cooked rice is not affected by the presence of phosphates.

The values of the rate constant for Akibare, Milyang 30, and waxy rice corresponded to 0.1471, 0.1489, and 0.0355 reciprocal days (Fig. 2), giving time constants of 6.80, 6.71, and 28.17 days (Table II). The time constant for Akibare starch gels stored at 21°C was reported to be 6.72 days (Chung et al 1982). This is in good agreement with that for cooked rice (6.80 days). It is known that the time constant of starch gels was inversely related to the amylose content (Kim et al 1976). The amylose contents for Akibare and Milyang 30 starch were 18.5 and 18.9%, respectively.

The time constants for cooked nonwaxy rice were about two times greater than those for wheat starch gels (Colwell et al 1969, Kim and D'Appolonia 1977a, McIver et al 1968) and for bread (Axford et al 1968, Cornford et al 1964, Kim and D'Appolonia 1977b). The amylose content for wheat starch was reported to be about 25% (Medcalf and Gilles 1965).

The values for the time constant for cooked rice in the presence of various phosphates are given in Table II. The time constant of cooked nonwaxy rice containing 0.2–0.3% of Polygel-RW, Polygel-RM, Polygel-RMG, or Polygel-RMF, the P_2O_5 content of which was less than 56% (Table I), was essentially the same as that of the control. Polygel-RR (59.3% P_2O_5) and Polygel-XP (68% P_2O_5) considerably increased the time constants of cooked nonwaxy rice, however. Although the time constants of cooked rice at 0.2–0.3% phosphate level were comparable, cooked rice at 0.3% phosphate concentration showed good texture and eating quality.

The time constants for Akibare and Milyang 30 were 1.17 and 1.26 times greater, respectively, in comparison with the control, in the presence of 0.3% Polygel-RR (Table II). At the same phosphate concentration, Polygel-XP increased the time constants for Akibare and Milyang 30 by 1.32 and 1.65 times, respectively. The results in Table II thus suggest that phosphates having more than 59% P_2O_5 are effective in retarding the firming rate of cooked nonwaxy rice, and that the higher the P_2O_5 content of phosphates, the less the rate of firming cooked nonwaxy rice. The time constant for cooked waxy rice remained unchanged in the presence of various phosphates (Table II).

Table III shows the data on firmness of cooked nonwaxy rice in the absence or presence of phosphates at 0.3% concentration, based on raw rice. In the case of Akibare, the total material available for crystallization on aging (E_L-E_0) was 6.24. The portion of material that crystallized during storage at 21°C for five days (E_5-E_0) was 3.25. The ratio of E_5-E_0 over E_L-E_0 was 0.52; that is, 52% of the total material was crystallized during storage. Polygel-RW, Polygel-RM, Polygel-RMC, or Polygel-RMF decreased the values for E_5-E_0 and E_L-E_0 by about 50% compared with those for the control (Table III), indicating that phosphates having less than 56% P_2O_5 content reduced the total material available for crystallization as well as the material that changed on aging of cooked Akibare rice. However, the ratio of E_5-E_0 over E_L-E_0 of cooked rice in the presence of these phosphates was similar to that of the control

TABLE II
Avrami Exponent (n) and Time Constant ($1/k$) For Cooked Rice in the Absence or Presence of Phosphate

Rice	Phosphate Concentration[a] (%)	Akibare n	Akibare $1/k$	Milyang-30 n	Milyang-30 $1/k$	Waxy n	Waxy $1/k$
Control	···	1.0434	6.80	1.0121	6.71	0.9863	28.17
P-RW	0.20	1.0155	7.21	1.0138	6.68	1.0076	29.48
	0.25	0.9963	7.18	0.9997	6.45	0.9888	29.90
	0.30	0.9997	7.06	1.0175	6.48	0.9986	29.42
P-RM	0.20	1.0295	7.10	1.0342	7.32	0.9918	26.91
	0.25	0.9797	7.03	1.0539	7.13	0.9907	28.58
	0.30	0.9791	7.10	0.9908	7.10	0.9755	26.76
P-RMG	0.20	0.9940	6.73	0.9967	6.70	0.9854	28.72
	0.25	0.9957	7.16	1.0243	6.66	0.9861	28.17
	0.30	0.9868	7.43	1.0040	6.80	0.9856	28.60
P-RMF	0.20	1.0427	7.00	0.9960	6.62	0.9947	28.17
	0.25	1.0337	6.50	0.9923	6.51	1.0034	28.02
	0.30	1.0240	6.70	1.0103	6.75	0.9858	28.39
P-RR	0.20	1.0814	7.77	1.0508	8.48	0.9951	27.90
	0.25	0.9908	7.71	1.0435	8.12	0.9868	27.76
	0.30	0.9910	7.96	0.9991	8.48	0.9954	27.76
P-XP	0.30	0.9866	8.99	0.9237	11.05	1.0336	29.08

[a] Based on raw rice weight.

TABLE III
Data on Texturometer Firmness of Cooked Rice in the Absence or Presence of Phosphate[a]

Cooked Rice		Firmness[b] Control	P-RW	P-RM	P-RMG	P-RMF	P-RR	P-XP
Akibare	E_0	6.08	6.03	5.66	5.87	6.04	5.62	5.71
	E_5	9.33	7.72	7.38	7.51	7.77	7.14	7.02
	E_L	12.32	9.36	9.13	9.22	9.33	8.88	8.78
	E_5-E_0 (A)	3.25	1.69	1.72	1.64	1.73	1.52	1.31
	E_L-E_0 (B)	6.24	3.33	3.47	3.35	3.29	3.26	3.07
	A/B × 100	52.08	50.75	49.57	48.90	52.58	46.63	42.67
Milyang-30	E_0	6.06	6.00	5.97	5.97	5.90	5.97	5.96
	E_5	9.20	7.93	7.83	8.04	7.90	7.69	7.27
	E_L	12.04	9.59	9.65	9.87	9.60	9.83	9.56
	E_5-E_0 (A)	3.14	1.93	1.88	2.07	2.00	1.72	1.31
	E_L-E_0 (B)	5.98	3.59	3.68	3.70	3.70	3.86	3.60
	A/B × 100	52.51	53.76	51.09	55.95	54.05	44.56	36.39

[a] Phosphate concentration was 0.3% (W/W).
[b] E_0 and E_5 represent the firmness of cooked rice at 0 and 5 days at 21°C, respectively. E_L is the limiting modulus.

(Table III), giving the same time constant as the control (Table II). In the presence of Polygel-RP or Polygel-XP, the value for E_5-E_0 and E_L-E_0 in the presence of Polygel-RR and Polygel-XP were 0.47 and 0.43, or 90 and 82%, respectively, of that for the control.

The effects of phosphates on the firmness data for cooked Milyang 30 rice was similar to those for cooked Akibare rice (Table III). The effects exerted by Polygel-RR and Polygel-XP were more pronounced, however; the ratios of E_5-E_0 *over* E_L-E_0 in the presence of the former and the latter corresponded to 0.45 and 0.36, or 85 and 69% of that for the control. As indicated in Table II, phosphates had no effect in retarding the firming rate of cooked waxy rice, and in reducing the values for E_5-E_0 and E_L-E_0 (date not shown).

From the results in Tables II and III, it can be concluded that all phosphates employed in these experiments reduced the starch components available for crystallization of cooked rice, except in waxy rice, but only Polygel-RR and Polygel-XP were effective in retarding the firming rate of cooked nonwaxy rice. It is unknown why cooked nonwaxy rice firms more slowly in the presence of Polygel-RR or Polygel-XP. In studies of the effect of wheat flour pentosans on the process of firming of wheat starch gels, Kim and D'Appolonia (1977a) demonstrated that the crystallization of starch gels was characterized by the retrogradation of both amylose and amylopectin over the first day of storage, and thereafter amylopectin alone controlled the retrogradation process. Collins (1968) suggested that in a concentrated paste or gel, the amylose and amylopectin were intermixed and would probably retrograde together in regions where amylose molecules and outer branches of amylopectin were suitably oriented for hydrogen-bond formation. Since Polygel-RR or Polygel-XP had no effect on retarding the firming rate of cooked waxy rice (Table II), it seems probable that their action is to impede retrogradation of the amylose fraction.

As mentioned previously, the amylose content of Akibare (18.5%) was close to that of Milyang 30 (18.9%). The reason for the effect of Polygel-RR or Polygel-XP being more pronounced for Milyang 30 than for Akibare in reducing the firming rate remains to be explained.

LITERATURE CITED

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1980. Official Methods of Analysis. 13th ed. The Association, Washington, DC.

AVRAMI, M. 1939. Kinetics of phase change. I. J. Chem. Phys. 7:1103.

AVRAMI, M. 1940. Kinetics of phase change. II. J. Chem. Phys. 8:212.

AVRAMI, M. 1941. Kinetics of phase change. III. J. Chem. Phys. 9:177.

AXFORD, D. W. E., COLWELL, K. H., CORNFORD, S. J., and ELTON, G. A. H. 1968. Effect of loaf specific volume on the rate and extent of staling of bread. J. Sci. Food Agric. 19:95.

CHEIGH, H. S., KIM, S. K., PYUN, Y. R., and KWON, T. W. 1978. Kinetic studies on cooking of rice of various polishing degrees. Korean J. Food Sci. Technol. 10:52.

CHUNG, H. M., AHN, S. Y., and KIM, S. K. 1982. Comparison of physicochemical properties of Akibare and Milyang 23 rice starch. J. Korean Agric. Chem. Soc. 25:67.

COLLINS, R. 1968. Starch retrogradation. Page 1 in: Starch and Its Derivatives. J. A. Radley, ed. Chapman & Hall, Ltd., London.

COLWELL, K. H., AXFORD, D. W. E., CHAMBERLAIN, N., and ELTON, G. A. H. 1969. Effect of storage temperature on the aging of concentrated wheat starch gels. J. Sci. Food Agric. 20:550.

CORNFORD, S. J., AXFORD, D. W. E., and ELTON, G. A. H. 1964. The elastic modulus of bread crumb in linear compression in relation to staling. Cereal Chem. 41:216.

DeMAN, J. M., and MELNYCHYN, P. 1971. Symposium: Phosphates in Food Processing. The Avi Publishing Co., Westport, CT.

ELLINGER, R. H. 1972. Phosphates in food processing. Page 617 in: Handbook of Food Additives. T. E. Furia, ed. The Chemical Rubber Co., Cleveland, OH.

JULIANO, B. O. 1982. An international survey of methods used for evaluation of the cooking and eating qualities of milled rice. IRRI Research Paper Series No. 77. The International Rice Research Institute, Manilla, Philippines.

KIM, S. K., CIACCO, C. F., and D'APPOLONIA, B. L. 1976. Kinetic study of retrogradation of cassava starch gels. J. Food Sci. 41:1249.

KIM, S. K., and D'APPOLONIA, B. L. 1977a. Effect of pentosans on the retrogradation of wheat starch gels. Cereal Chem. 54:150.

KIM, S. K., and D'APPOLONIA, B. L. 1977b. Bread staling studies. I. Effect of protein content on staling rate and bread crumb pasting properties. Cereal Chem. 54:207.

KIM, S. K., HAHN, T. R., LEE, Y. H., and D'APPOLONIA, B. L. 1978. Physicochemical properties of Tongil (Indica type) and Paldal (Japonica type) rice starch. Korean J. Food Sci. Technol. 10:157.

KIM, S. K., and PYUN, Y. R. 1982. Staling rate of cooked rice stored at 21 and 72°C. Korean J. Food Sci. Technol. 14:80.

McIVER, R. G., AXFORD, D. W. E., COLWELL, K. H., and ELTON, G. A. H. 1968. Kinetic study of the retrogradation of gelatinized starch. J. Sci. Food Agric. 19:560.

MEDCALF, D. G., and GILLES, K. A. 1965. Wheat starches. I. Comparison of physicochemical properties. Cereal Chem. 42:558.

NARA, S., MAEDA, I., and TSUJINO, T. 1964. Effect of monoglycerides on the viscosity and swelling of starch granules. Nippon Nogei Kagaku Kaishi 38:356.

SHARPLES, A. 1966. Introduction to Polymer Crystallization. Edward Arnold Ltd., London.

[Received June 24, 1983. Accepted September 21, 1983]