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Short communication

Relationship between pasting parameters and length of paste drop of various starches

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ABSTRACT

When a starch paste stretches and breaks during dropping under gravity, the length of fully stretched paste drop is considered as an important flowing characteristic of starch. The length of paste drop (LPD) often determines eating quality of the starch-containing foods. The relationship between pasting parameters measured using a rapid visco-analyzer and LPD of various starches from different botanical sources was investigated at different starch concentrations (50, 70 & 90 g/kg). Starch content in the paste mainly affected the single pasting parameters ($p < 0.05$), whereas the type of starches such as genotype, botanical source, cereal/root *vs* tuber, and variety affected the LPD ($p < 0.05$). Pasting parameters such as peak viscosity, breakdown, final viscosity, peak viscosity/final viscosity, and peak viscosity-final viscosity exhibited significant correlations with LPD ($p < 0.05$) regardless of starch source. Especially for cereal starches, the correlation coefficient values between the 2nd order pasting properties (breakdown/setback, peak viscosity-final viscosity, and peak viscosity/final viscosity) and LPD were relatively high ($r = 0.81–0.93$).

1. Introduction

The rheological behavior of a liquid food is considered as one of the most important physical properties for determining its eating quality and acceptance by consumers (Szczesniak, 1972; Szczesniak & Kahn, 1971). It is also useful for obtaining important data for the process design and development of new products (Borwankar, 1992). Texture and rheological attributes are typically detected using mechanical, tactile, visual and auditory receptors (Borwankar, 1992; Szczesniak, 2002). Rheology represents the flow and deformation behaviors of foods, however, it is typically determined by measuring the force and deformation level as a function of time (Tabilo-Munizaga & Barbosa-Cánovas, 2005).

Starch is one of the major components in foods and often used as an additive to contribute to textural and rheological properties of foods. When a starch is subjected to a thermal process in the presence of sufficient water, the starch granules swell and rupture releasing starch chains resulting in the formation of a viscous paste (Dzuy Nguyen, Jensen, & Kristensen, 1998). The rheological properties of the paste determine the potential and practical application for the starch. The rheological behavior of starch paste depends on the starch chain structure, botanical source, starch concentration, and pasting procedure (Dzuy Nguyen et al., 1998). Numerous types of analytical techniques such as rotational rheometer, mixer viscometer, and starch-specific empirical devices have been employed to characterize the viscosity and rheological changes of starch during pasting (Lagarrigue & Alvarez, 2001). One of the starch-specific empirical devices is the rapid visco-analyzer (RVA), which is a rotational viscometer analyzing the viscosity during pasting under a controlled temperature change and shear speed.

One of the simple ways to characterize the flowing behavior of a starch paste is to measure the length of paste drops (LPD) (Morgan & Vaughn, 1943). Typically, a long paste exhibiting high stringiness induces slimy mouthfeel, with a high tendency to coat a surface. Whereas, a short paste generates cohesive drop that readily separate from each other, which is commonly favored for desserts, such as pie fillings and puddings (BeMiller, 2007). Although these flowing characteristics of starch paste provide practical information, instrumental analysis of the length of starch paste drop is still unclear till now.

In this study, the LPD of various starches from different sources at different concentrations were compared and then statistically

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correlated with the pasting parameters obtained from RVA viscograms.

2. Materials and methods

2.1. Materials

Potato starch, sweet potato starch, tapioca starch, normal corn starch, waxy corn starch, normal rice starch, waxy rice starch, and normal wheat starch were obtained from Samyang Genex Company (Seoul, Korea). Rice varieties harvested in Korea in 2010, including Goami-3, waxy Dongjin, waxy Aranghyang, Younganbyeo, Barkjinjoo, Aromatic, and Chunchuang were obtained from the Rural Development Administration in Suwon, Korea. Rice starches were isolated from the flours of those rice varieties according to the method described by Lim, Lee, Shin, and Lim (1999). The ash, crude protein, crude lipid, and amylose content of all starches used in this study were provided in supplementary Table 1.

2.2. Pasting viscogram of starch

The pasting viscogram of different starches was obtained using a RVA (Newport Scientific Inst. Ltd., Warriewood, Australia) with starch dispersions prepared at different concentrations (50, 70 & 90 g/kg, dry solids). The starch slurry was equilibrated at 50 °C for 1 min under continuous mixing at 960 rpm, then heated to 95 °C at 13 °C/min, held at 95 °C for 3 min, cooled to 50 °C at 13 °C/min, and held at 50 °C for 4 min at 160 rpm. From the viscograms, the pasting parameters such as pasting temperature (PT), peak viscosity (PV), breakdown (BD), trough (T), setback (SB), and final viscosity (FV) were obtained. The viscograms of all starches used in this study were provided in supplementary Fig. 1, 2 and 3.

2.3. Length of paste drop (LPD)

As shown in Fig. 1, the LPD of starch was determined using a simple tool. The tool consisted of a conical tube (20 mm diameter, 15 mL volume) with an outlet hole (5.0 mm diameter). Without the cooling step (95–50 °C), a hot starch paste (95 °C) prepared using the RVA was transferred into a water bath (80 °C). After equilibrating for 5 min, the starch paste (15 mL) was transferred into the conical tube and then allowed to drop through the hole. The dropping process was recorded by a digital camera (iPhone 6, Apple Inc., Cupertino, CA), and the length of each drop was measured.

2.4. Statistical analysis

All analyses were conducted at least in triplicate. The normality of all analytical data was assessed using the Shapiro-Wilk test ($\alpha < 0.05$) (Shapiro & Francia, 1972). Because some data exhibited a non-normal distribution pattern, all experimental data were analyzed using a nonparametric Kruskal-Wallis test (McKight & Najab, 2010). Pearson's correlation analysis was used to examine the relationship between the LPD and starch pasting properties ($p < 0.05$). The results were analyzed using SPSS 12.0K for Windows (SPSS Institute Inc., Cary, NC).

3. Results and discussion

3.1. Pasting properties and LPD

The pasting properties of a starch are impacted by its genotype (Dang & Copeland, 2004), botanical source (Singh, Singh, Kaur, Sodhi, & Gill, 2003) and variety (Zhong et al., 2009). Starch concentration and mechanical process used for pasting also affect the physical properties of paste. The level of significance for the effects of starch concentration (50, 70 & 90 g/kg) and starch type in terms of genotype (waxy, normal, and high-amylose starches), cereal vs. root and tuber (corn, rice and wheat vs. potato, tapioca, and sweet potato starches), and botanical source (corn, rice, wheat, potato, tapioca, and sweet potato starches) on the LPD and pasting parameters was analyzed by using Kruskal-Wallis test. As shown in Table 1, LPD was significantly affected by the genotype, cereal/root and tuber, and the botanical source whereas it was not much affected by the starch concentration. On the other hand, the concentration significantly affected the single pasting parameters, such as PV, BD, SB, T, and FV. With different rice starches, the level of significance was also determined. In this case, similar results were observed showing that the genotype and variety of rice affected the LPD. Both the concentration and starch source affected at least one of the 2nd order pasting parameters, such as PV/FV or PV-FV, regardless variable of samples. As discussed above, these observations suggested that the pasting parameters of starch were mainly affected by starch concentration, whereas the LPD was mainly affected by the source of starch.

3.2. Correlation between pasting parameters and LPD

Table 2 exhibits the correlation coefficients between the LPD and pasting parameters as a function of variables (starch concentration or source [genotype, cereal/root and tuber, and botanical source]) used for statistical analysis. In the starch samples tested, LPD was significantly correlated with all pasting parameters, except SB, T, and SB/PV ($p < 0.05$), suggesting that the flowing behavior of starch paste was affected by the viscosity profile during pasting. At a given concentration of starch (50 or 70 g/kg), PV, BD, FV, PV/FV, and PV-FV values exhibited significant correlations with LPD (at $p < 0.05$), regardless of starch source. However, for the 90 g/kg starch paste, the FV, PV/FV, and PV-FV values did not exhibit a meaningful correlation with LPD. The correlation between the LPD and pasting parameters seemed to have become less obvious when starch concentration increased in the paste. When a large quantity of starch molecules exists in a paste, it seems that the chain interaction became excessive and thus the functions of individual starch chains on the flowing behavior might be reduced (Evans & Lips, 1992).

In the case of normal and waxy starches, the LPD exhibited a significant correlation with BD, BD/PV, PV/FV, and PV-FV ($p < 0.05$). Statistical analysis for high-amylose starch was not possible in this study because of the limited number of starch samples. In the case of cereal starches, the correlation between the LPD and pasting parameters appeared similar to that measured with total starch samples. However, the r values of the 2nd order pasting parameters (BD/SB, BD/PV, PV/FV, and PV-FV) for cereal starches were much higher than those for the total starch samples. The lower correlation values for total starch samples were because the tuber and root starch samples tested did not exhibit significant correlations. It was noticeable that the statistical analysis for the rice samples showed higher correlation values than did the analysis for the total cereal samples. It indicates that a structural homogeneity might exist among the rice starches of same botanical origin. Other botanical groups (normal wheat, potato, sweet potato, and tapioca starches) were ruled out in the correlation due to insufficient number of samples tested ($n = 3$) for the statistical analysis.

It is noticeable that, among the cereal and rice samples, LPD exhibited significant correlation values ($p < 0.05$) with all 2nd order pasting parameters (BD/SB, BD/PV, SB/PV, PV/FV, and PV-FV), while, only two single pasting parameters (PV and BD) had significant correlation with LPD ($p < 0.05$). This result suggests that the flowing behavior of starch paste, as represented by the LPD in this study,

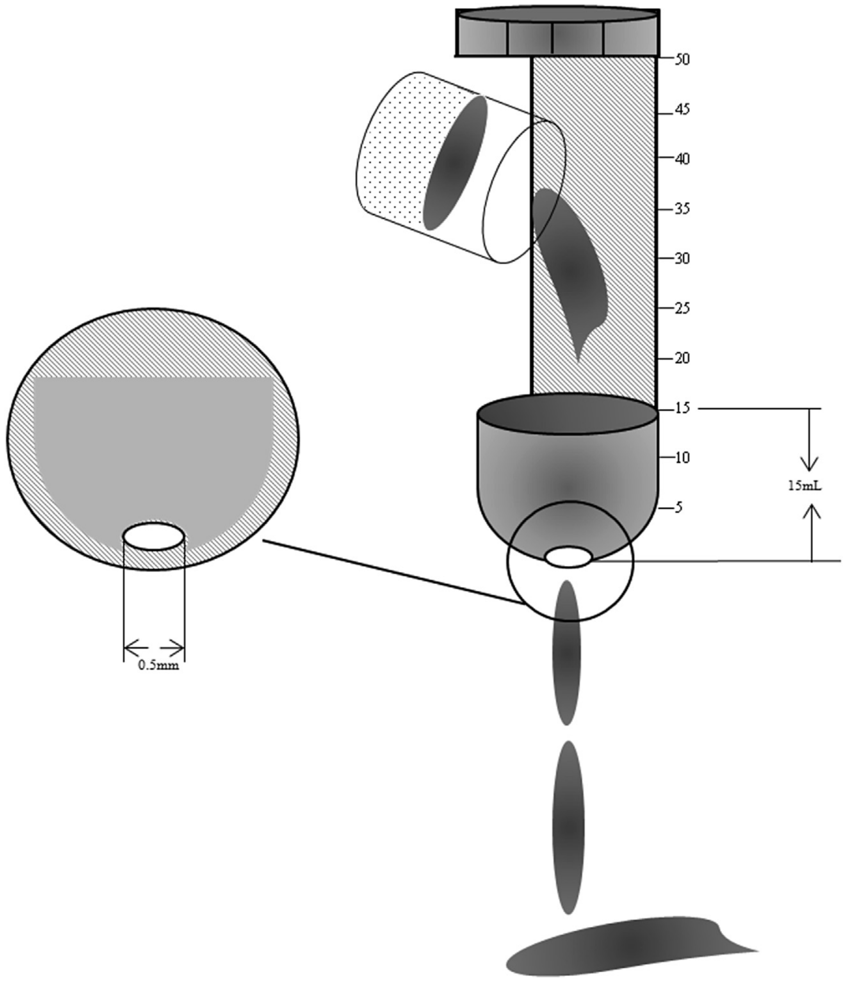

Fig. 1. Schematic drawing of the simple tool used to determine length of paste drop.

cannot be explained by the single pasting parameters. The single parameters on the viscogram represent the flowing behavior of starch paste which was kinetically explained. However, the LPD is a morphological behavior which may be affected by the interactions among the starch chains in the paste, possibly at a higher degree compared to the single pasting parameters (Debet & Gidley, 2007; Morgan & Vaughn, 1943). It indicates that the interactions among the constituents in the pastes could be more strongly related to the 2nd order parameters than the single parameters. For example, the FV (obtained after cooling the paste) and the PV (related to the

Table 1
Level of significance[a] for the effects of concentration and source of starch samples on length of paste drop and pasting viscosity parameters of the starches via Kruskal-Wallis test.

Population	Parameter	df	*p*-value										
			Length	Pasting parameters[b]									
				PV	BD	SB	T	FV	BD/SB	BD/PV	SB/PV	PV/FV	PV-FV
Total samples	Concentration[c]	2	0.153	<0.001*	0.001*	<0.001*	<0.001*	<0.001*	0.545	0.336	0.996	0.301	0.007*
	Genotype[d]	2	0.008*	0.698	0.112	0.004*	0.495	0.394	0.002*	0.068	0.018*	0.001*	0.010*
	Cereal/T&R[e]	1	0.002*	0.016*	0.018*	0.004*	0.043*	0.022*	0.323	0.050	0.391	0.025*	0.013*
	Botanical source[f]	5	0.005*	0.065	0.024*	0.015*	0.246	0.202	0.002*	0.012*	0.001*	0.037*	0.038*
Rice samples	Concentration[c]	2	0.166	<0.001*	0.005*	0.001*	<0.001*	<0.001*	0.491	0.275	0.765	0.313	0.038*
	Genotype[d]	2	0.004*	0.833	0.074	0.053	0.723	0.575	0.004*	0.057	0.133	0.002*	0.008*
	Variety[g]	8	0.006*	0.979	0.205	0.332	0.974	0.900	0.013*	0.058	0.132	0.010*	0.061

[a] Asterisk denotes statistical significance ($p < 0.05$) and all data represent data represent the mean of triplicate.
[b] PV: pasting viscosity; BD: breakdown; SB: setback; T: trough; FV: final viscosity.
[c] Concentration: 50, 70, and 90 g/kg (dry basis).
[d] Genotype: normal, waxy and high amylose starches.
[e] Cereal/T&R: corn, rice, wheat/potato, tapioca, and sweet potato starches.
[f] Botanical source: corn, rice, wheat, potato, tapioca, and sweet potato starches.
[g] Variety of rice: commercial normal and wary rice starches, and rice starches isolated form different varieties: Goami-3, waxy Dongjin, waxy Araghyang, Younganbyeo, Barkjinjoo, Aromatic, and Chunchuang.

Table 2
Correlation coefficient values[a] between length of paste drop and pasting parameters[b] in different concentration and source of starch samples according to group for statistical analysis.

Population		n	PV	BD	SB	T	FV	BD/SB	BD/PV	SB/PV	PV/FV	PV-FV
Total starch samples		45	0.543***	0.621***	0.248	0.294	0.320*	0.471**	0.659***	−0.153	0.662***	0.567***
Concentration	50 g/kg	15	0.584*	0.540*	0.549*	0.630*	0.601*	0.468	0.383	−0.262	0.631*	0.561*
	70 g/kg	15	0.563*	0.603*	0.284	0.309	0.541*	0.516*	0.714*	−0.954	0.592*	0.573*
	90 g/kg	15	0.532*	0.673*	0.064	0.080	0.049	0.429	0.764**	−0.001	0.525	0.565
Genotype[c]	Normal	30	0.543*	0.612***	0.307	0.311	0.355	0.505*	0.709***	−0.143	0.585**	0.552*
	Waxy	12	0.544	0.785*	0.283	0.115	0.127	0.469	0.754**	0.181	0.801*	0.780*
Cereal/T&R[d]	Cereal	36	0.517**	0.835***	−0.102	0.057	0.021	0.816***	0.753***	−0.549**	0.928***	0.852***
	T&R	9	0.237	0.314	0.040	0.177	0.237	0.232	0.655	0.008	0.242	0.218
Botanical source[e]	Corn	6	0.751	0.891*	0.474	0.329	0.319	0.900*	0.846*	−0.398	0.940*	0.896*
	Rice[f]	27	0.456*	0.808***	−0.339	−0.004	−0.049	0.847***	0.719***	−0.567*	0.930***	0.829***

All data represent the mean of triplicate.
[a] Statistical significance denoted as follows:$^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$.
[b] PV: pasting viscosity; BD: breakdown; SB: setback; T: trough; FV: final viscosity.
[c] Genotype: normal, waxy and high amylose starches.
[d] Cereal/T&R: corn, rice, wheat/potato, tapioca, and sweet potato starches.
[e] Botanical source: corn, rice, wheat, potato, tapioca, and sweet potato starches.
[f] Rice: commercial normal and wary rice starches, and rice starches isolated form different varieties: Goami-3, waxy Dongjin, waxy Araghyang, Younganbyeo, Barkjinjoo, Aromatic, and Chunchuang.

degree of stiffness of the swollen starch granules) did not have any meaningful r values with LPD, whereas the ratio of FV and PV exhibited the strongest correlation with the LPD in the rice samples. In addition, the PV-FV and BD/SB for cereal corn and rice samples also exhibited significant correlations with LPD. In short, PV/FV, PV-FV, and BD/SB appeared to be useful pasting parameters for predicting the flowing behavior of starch paste.

The PV typically refers to the capability of granular swelling whereas FV is the viscosity after cooling which positively relates to the chain association induced by cooling. These primary parameters provided limited data of paste viscosity at given temperatures. The 2nd order parameters, PV/FV as an example, however, provide the information on how starch granules develop to a paste, which relates to the chain behavior during pasting. As an example, a high value of PV/FV may indicate that the granular swelling of starch is high, but the starch chains released from the swollen granules have a low tendency of association. Based on the speculated information, it was expected that the low degree of chain association made the paste not cohesive and exhibit a long flowing behavior.

4. Conclusions

In this study, a simple method was introduced to determine the length of paste drop of various starch pastes to understand the relationship between the LPD and pasting parameters. The LPD is a visual indicator of the flowing behavior of starch paste, which was strongly affected by starch source and also statistically correlated with some of the pasting parameters obtained from viscograms. For the cereal starch samples, the 2nd order pasting parameters such as BD/SB, PV/FV, and PV-FV were highly correlated with the LPD, and thus useful for predicting the LPD. The relationship between the LPD and pasting parameters will play a key role in predicting the behavior of starch paste and development of new starchy products. However, the correlation between the LPD and pasting parameters became less obvious when starch concentration increased.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.lwt.2016.11.004.

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