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RESEARCH NOTE

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In vitro Digestibility of Cooked Noodle Products

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Abstract The *in vitro* digestive properties of 6 domestic noodle products (spaghetti, *somyeon, ramyeon, dangmyeon, naengmyeon,* and *jjolmyeon*) were compared after cooking under the manufacture's recommended cooking conditions. The kinetic constant (k), representing the rate of hydrolysis at the initial digestion stage, was highest in the *somyeon* noodles (0.1151), followed by *naengmyeon* (0.0954), and was lowest in the spaghetti (0.0421). However, the concentration of starch (C_∞) hydrolyzed over 2 hr was not different between the spaghetti (96.22) and the *somyeon* (96.40), indicating that different digestion behaviors occurred in each type of noodle, even though the amounts of digested starch were similar. The *ramyeon, dangmyeon,* and *naengmyeon* noodles showed relatively lower C_∞ values than the spaghetti and the *somyeon* noodles. The spaghetti had the highest amount of slowly digestible starch (SDS, 43%) and the lowest glycemic index (GI, 87.8), whereas the *somyeon* had the lowest SDS value (9.6%) and the highest GI (93.0). The digestibility differences among the noodles were attributed to differences in their flour compositions and manufacturing processes.

Keywords: noodle, digestibility, slowly digestible starch, cooking

Introduction

In Korea, there are several kinds of noodles each with its own manufacturing process, and based on the type of noodle, the main ingredients vary, and may consist of wheat flour, buckwheat, arrowroot, or various kinds of cereal starch. Each type of noodle may be consumed in several ways such as with cold soup (in summer) or with hot soup (in winter), or just mixed with other ingredients and no broth. Depending on the kind of noodle, the dimensions of the strands vary (1). The noodle types are divided into several groups: dry noodles, fresh noodles, boiled noodles, and instant noodles (2). Noodles were introduced as one of the primary foods to replace traditional rice, and today instant noodles (*ramyeon*) have become popular. In the year 2000, the domestic production of these noodles was 748,953 tons, in which 83.3% was *ramyeon*, followed by *somyeon* (10%), *naengmyeon* (3.6%), and *dangmyeon* (2.9%). Noodle manufacturing possesses problems, not with the technical issues, but rather with satisfying the changes of dietary life, which include simplicity, convenience, and the creation of new tastes. Also, increasing concerns for healthier lifestyles have resulted in the production of functional noodle products containing various healthful ingredients (3-6).

The most common materials for noodles are wheat or rice flours, or pure starch. Therefore, the major component in noodles contributing to calorie is starch. Starch can be classified into 3 groups according to its digestion behavior: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (7). These are defined as digestion within the first 20 min for RDS, digestion from 20 to 120 min for SDS, and the non-digestible fraction is RS. Individuals with type II diabetes may especially benefit from foods that contain high levels of SDS because it does not produce hyperglycemia followed by hypoglycemia. In addition, SDS may prolong satiety, and could be incorporated into food products marketed for weight-loss. SDS may also be beneficial in products utilized by athletes, since it provides a more consistent and lasting source of glucose (8). Glycemic index (GI) is the classification of foods according to their effects on blood glucose (sugar) levels, and it correlates strongly with the rate of digestion and absorption of carbohydrate in the small intestine (9). It is well known that all foods with a high SDS content have a low GI. Several studies have reported on lowering the digestion rate and extent (i.e., the glycemic response in noodles) by adding barley β-glucan to durum wheat pasta (10), as well as by adding 20% guar gum to pasta (11). Because many varieties of noodles are consumed as major sources of dietary carbohydrate in several Asian countries, including Korea, it is important to know the digestive behaviors of the noodles that are commercially available. In this study, the *in vitro* digestive properties of commercial noodles were compared under the cooking conditions recommended by the manufactures.

Materials and Methods

Materials Six different kinds of noodles (spaghetti, *somyeon, ramyeon, dangmyeon, naengmyeon,* and *jjolmyeon*) were purchased from a local grocery market in Seoul, Korea. The spaghetti was produced with durum wheat semolina flour, whereas the *somyeon* was from soft wheat flour. The *ramyeon, naengmyeon,* and *jjolmyeon* contained both wheat flour and starches of different origins (potato, sweet potato, and corn starch, respectively). The *dangmyeon,* however, consisted only of pure sweet potato starch.

***In vitro* digestibility** Each noodle sample (10 g, dry solid

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basis) was cut into a length of 1 cm, and cooked in boiling distilled water (200 mL) for its individual recommended cooking time (8 min for spaghetti; 6 min for *dangmyeon*; 4.5 min for *ramyeon*; and 3 min for *somyeon*, *naengmyeon*, and *jjolmyeon*). Digestibility was determined using the method described by Chung *et al.* (12).

Determination of RDS, SDS, and RS Based on their digestion rates, different fractions of starch were quantified (7): rapidly digestible starch (RDS), and slowly digestible starch (SDS) were the starch fractions hydrolyzed in 20 and 120 min of incubation, respectively. The resistant starch was the fraction that remained unhydrolyzed after 120 min.

Glycemic index (GI) The glycemic indexes of the samples were estimated using the method of Goñi' *et al.* (13) with white bread as the reference. The hydrolysis curve of each noodle product followed the first order equation, $[C=C_\infty(1-e^{-kt})]$. The k value, representing the digestion rate at time t, was obtained using the equation, where C and C_∞ were the concentrations at time t and at equilibrium, respectively. The glycemic indices of the samples were estimated according to the following proposed equation (13): $GI=39.71+0.549\ HI$, in which HI was the hydrolysis index calculated as the percentage of total glucose released from the samples based on that from white bread.

Statistics Statistical analyses were carried out using Duncan's multiple tests to determine the significance of the differences among the data.

Results and Discussion

***In vitro* digestibility** Based on the enzymatic digestion profiles (data not shown), the digestion kinetic constant (k), indicating the digestion extent per unit time, and C_∞, the equilibrium concentration of the hydrolyzed starch, are shown in Table 1. All of the samples were hydrolyzed over 50% at 20 min of digestion. For spaghetti, the digestion curve reached a plateau near 100 min of digestion; however, the *somyeon* plateaued after approximately 45 min of incubation, although there were no significant differences in their C_∞ values (Table 1). This suggests that although similar amounts of starch were digested, the digestion rate or extent was different. The other noodles (*ramyeon, dangmyeon, naengmyeon,* and *jjolmyeon*) reached their plateaus near 60 min of digestion.

Table 1. Digestion parameters (k and C_∞) and estimated glycemic index (GI) values of commercial noodles

	k	C_∞	GI
Spaghetti	0.042$^{e1)}$	96.22^{a}	87.83^{c}
Somyeon	0.115^{a}	96.40^{a}	93.0^{a}
Ramyeon	0.0663^{cd}	91.9^{c}	88.63^{bc}
Dangmyeon	0.0739^{c}	92.12^{c}	89.30^{b}
Naengmyeon	0.0954^{b}	92.73^{c}	90.40^{b}
Jjolmyeon	0.0619^{d}	94.05^{b}	89.3^{b}

[1)]Different superscript letters within one column mean statistically significant differences ($p<0.05$).

The *somyeon* had the fastest digestion rate, namely, the highest k value, and spaghetti had the lowest, indicating that the *somyeon* was digested fastest, and the spaghetti slowest among the noodles tested. Judging from the digestive parameters such as k, C_∞, and GI, the noodles can be classified into 4 groups according to their digestibility: *somyeon*>*naengmyeon*>*dangmyeon, ramyeon, jjolmyeon*>spaghetti. The differences in digestibility among the noodles were derived from their raw materials and manufacturing processes. Spaghetti is different from Asian noodles in its ingredients; it is prepared with durum wheat semolina, which has a high amount of gluten. In addition, spaghetti is extruded through a metal die under pressure at high temperatures (>80°C) to shorten the drying time, which makes the lines more compact and provides superior cooking quality (14). The high temperature drying increases the extent of protein denaturation (15), which promotes cross-linking of the 2 gluten proteins, glutenin and gliadin, increasing the rigidity of the protein network (16). Also, high temperature drying reduces starch swelling and amylose solubilization in the outer zone of the hydrated pasta strand, resulting in a high cooking time and low water uptake, as well as increased firmness and low surface stickiness (17). *Somyeon*, which has a similar nutritional composition as spaghetti, is simply prepared using wheat flour mixed with salt and water, and is then dried at room temperature (18). Therefore, when compared to spaghetti, *somyeon* has much less rigidity in the noodle matrix.

Naengmyeon is also prepared by the extrusion process with dough made of wheat flour and starch. According to Kwon and Lee (19), *naengmyeon* is usually made as a wet noodle by local manufacturers, using wheat flour and potato starch. Dried *naengmyeon* products sold in grocery stores contain sweet potato starch added to wheat flour to make the dough. According to Lee *et al.* (20), the addition of buckwheat induced a slower digestion rate when fed to rats. The *naengmyeon* tested in this study was the dry type containing sweet potato starch and buckwheat. It showed a slower digestion rate (k) than the *somyeon*, but had a higher k and GI than the other noodles.

The *ramyeon, dangmyeon*, and *jjolmyeon* could be classified into one group, having similar k and GI values. These values are larger than the values for spaghetti, but lower than those of the *somyeon* and *naengmyeon*. Unlike the other noodles, the *ramyeon* and *dangmyeon* were precooked products. However, both noodles showed slower digestion rates than the *somyeon*. The *ramyeon* was fried after steam-cooking, and then dried (21). It not only contained a high amount of oil (14%), but also formed resistant starch (RS) via starch-lipid complexes which may be produced during cooking and frying processes, resulting in slower digestion. *Dangmyeon* is a traditional type of noodle in Korea, with sweet potato starch as its main ingredient. In its manufacturing process, starch is mixed with water to form a paste, which is dropped and then cooked in boiling water (22). The noodle strands are cooled in cold water, and then frozen. During the cooling process, the gelatinized starch becomes recrystallized (retrogradation) (23). Russel *et al.* (24) has also reported that resistant starch (RS) can be formed in starch during the cooling and freezing processes. Because *jjolmyeon* is sold as a wet noodle product, the carbohydrate content of the *jjolmyeon* we tested was lower (56%) than that of the other noodles (67-82.8%). Although, the manufacturing process of *jjolmyeon* has not been reported, it is supposed that *jjolmyeon* is prepared from wheat flour by extrusion, and alcohol is added to the processing, which might affect its digestion behavior.

The GI value, which indicates the relative amount of absorbed glucose, was lowest for the spaghetti and highest for the *somyeon*. The low digestibility of the spaghetti that we observed in this study agrees with the findings of several researchers (25, 26), although our GI value was relatively higher than the value previously reported for spaghetti (27). During the digestion test, the spaghetti samples remained relatively intact even after 60 min of digestion, whereas the *somyeon* samples disappeared in 60 min (figure not shown). This observation suggests that the digestion resistance of the spaghetti was mainly from the structural rigidity of the noodle matrix.

RDS, SDS, and RS portions in each noodle The starch fractions (RDS, SDS, and RS) of the noodles after cooking are shown in Fig. 1. All the noodles tested contained a much higher content of RDS than SDS or RS, indicating that the cooked noodles were readily digestible. However, there was still some RS (less than 10%) in the noodles, indicating the noodles were not completely digestible. The *ramyeon, dangmyeon*, and *naengmyeon* contained relatively higher amounts of RS than the other noodles. These 3 types of noodles were manufactured with a mixture of wheat flour and different kinds of starch, and the starch in the noodles may have retrograded during manufacture, which would include frying, freezing, and drying processes. Finally, the spaghetti contained the highest amount of SDS, whereas the *somyeon* had the lowest SDS content. The digestion kinetic constant (k) appeared to be positively correlated to the SDS content. In addition, the lowest GI value occurred with the spaghetti, and may have resulted from its high SDS content. The composition and processing methods for the noodle products tested in this study might not be identical among the manufactures. However, the differences are not expected to be significant because these noodle products are commercially manufactured by relatively standardized procedures.

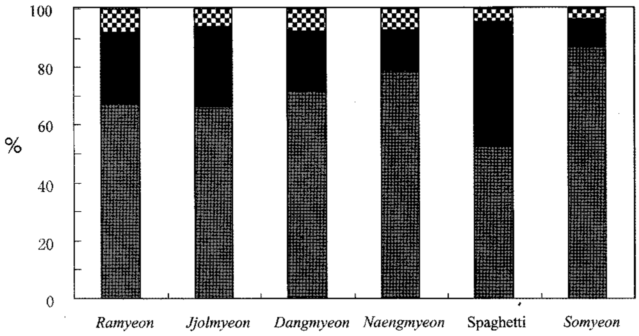

Fig. 1. Rapidly digestible starch (RDS, ▦), slowly digestible starch (SDS, ■), and resistant starch (RS, ▩) contents of commercial noodles after cooking.

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