Cabbage Core Powder as a New Food Material for Paste Preparation with “Nata Puree”

Ken Tokuyasu, Kenji Yamagishi, Yasumasa Ando, and Nobuya Shirai

Abstract: Cabbage core (CC) is regarded as a waste part of the vegetable, despite being edible and containing various nutritional and functional compounds. We investigated the properties of CC powder with particle sizes < 1 mm as a new food material. CC powder was more resistant to structural deformation than leaf-derived powder, particularly CC powder with particles ≥ 0.3 mm in size. To examine the application of CC powder in 3D printed foods, we investigated the effects of “nata puree,” a disintegrated nata de coco made with tamarind seed gum (NPTG), on paste made with CC powder. NPTG promoted stable binding of paste made using CC powder, which was successfully extruded using a syringe to form a bar with a granular structure. Thus, CC powder possesses unique textural/structural properties for its application in next-generation foods.

Key words: cabbage core powder, structural deformation, nata puree, granular structure, 3D printed foods

Conventionally discarded parts of vegetables are regarded as potentially edible resources with nutritional and functional compounds when they are recovered using appropriate food management. In Japan, cabbage core (CC) is regarded as a rejected part of the vegetable, despite being edible and containing various nutritional/functional compounds, such as carbohydrates, amino acids, dietary fiber, vitamin C, vitamin U, phosphorus, potassium, calcium, chlorogenic acid, quercetin glycoside, and p-coumaric acid. However, it is discarded or used as animal feed due to its short shelf life and low applicability for foods. Therefore, upgrading CC to a food material has attracted increasing interest to promote a sustainable society.

The pulverization of vegetables to prepare dry powders could yield a promising solution to the problems of their applications by extending their shelf lives, transforming heterogenous materials into homogeneous powders, and maintaining their unique components, colors, flavors, and tastes. Powders can be easily and stably formulated in processed foods without resembling their sources or original shapes. Additionally, homogeneous powders can guarantee highly reproducible cooking using three-dimensional (3D) food printing as form of next-generation cooking. In general, the powder is mixed with water to form a paste for extrusion to the stage of the printer. Interaction of the powder with other components in the paste, such as carbohydrates, proteins, and food hydrocolloids, could help construct unique textures and stabilize the manipulation of the 3D printed foods since in many cases, the original texture of the vegetable is lost by pulverization into an homogeneous powder. Such bottom-up techniques for pastes would be a breakthrough for next-generation cooking and would be ideal if the original texture could be maintained after pulverization since the texture of the fresh vegetable is one of the most important factors determining its palatability.

The present study focused on the rejected parts of vegetables, such as CC, broccoli stalk, and cauliflower stalk, since they are often discarded due their hardness compared with the edible parts of the vegetable. We hypothesized that pulverization to reduce the size of the rejected parts of the vegetables would retain the original hard texture depending on the particle size. Furthermore, the resultant powders would possess unique textures and structures, hopefully resembling the original vegetables, for use in 3D food printing technology.

White cabbages were obtained from a local market. For the preparation of leaf powders, the outer leaves were removed and the leaves from the middle layers were used for the study. The leaves were cut into 3-cm squares using a knife and immersed in tap water. Drained samples were then blanched in boiling water for 2 min and immediately cooled in iced water. For the preparation of core powders, the cabbage was divided vertically in half, and the core part was cut out with a knife and blanched in boiling water for 1 min. After blanching, the core was immediately cooled in iced water and drained then cut into approximately 6 mm × 6 mm × 6 mm cubes. The samples were dried in a dryer (SM4S-EH, Kihara Works Co. Ltd., Yamaguchi, Japan) for 5 h at 60 °C.
until the mass change became constant.

The dried leaves and core were milled using a cutter-mill machine (MF10.1, IKA Japan, Osaka, Japan) with a 2-mm pore size screen. The powders were milled again using the same machine and passed through a 1-mm pore size screen to obtain leaf (L0) and core (C0) powders. The C0 powder (2.00 g) was sequentially passed through two screens with pore sizes of 0.5 and 0.3 mm to recover the following fractionated powders: C1, 0.5–1.0 mm (0.35 g); C2, 0.3–0.5 mm (0.79 g); and C3, < 0.3 mm (0.88 g).

Structural deformation was examined by spreading the powder (10 mg) on a disk-shaped mass with a diameter of approximately 8 mm at the center of a transparent slide glass for microscopic analysis on a paper comprising 2.12-mm grids. Tap water (20 µL) was dropped onto the powders and the wet powder was left to settle for 5 min. Another slide glass was carefully placed over the wet powder on the former slide glass. The sample between the glass slides was left to settle for 5 min and the structural deformation was measured using a photograph taken from above as the area occupied by the wet powder (S1). A 500-g weight was then placed on the upper slide glass and the layered object was left to settle for 3 min. The weight was removed and after 1 min settlement the area occupied by the deformed powder (S2) was measured using a photograph taken from above. Deformation was calculated as the ratio of S2 to S1 and expressed as a percentage.

Nata puree (NP) was prepared as previously described with modifications. Tamarind seed gum (TG) was prepared by dissolving tamarind seed gum (Tamarind gum, Tokyo Chemical Industry Co., Ltd., Tokyo, Japan) in water and autoclaving at 121 ºC for 15 min prior to its use as a water-soluble polysaccharide for disintegration of nata de coco (Morinaga nata de coco plain, Morinaga Milk Industry Co., Ltd., Tokyo, Japan) for preparation of NP (NPTG).

The physical properties of paste samples were investigated using a rheometer (CR-500DX, Sun Scientific Co., Ltd., Tokyo, Japan). The powders (7.2 g) were mixed with 16.8 g of water (L0W and C0W) or a 1:1 (w/w) mixture of water and NPTG (C0NP), and the pastes were placed in stainless dishes (diameter, 40 mm; height, 15 mm). The firmness peak and adhesiveness areas were calculated as previously described. Calculation for statistical analysis using Tukey’s test was performed with the software KyPlot 6.0 (KyensLab Incorporated, Tokyo, Japan). Differences were considered significant at p < 0.01 (**). The structural deformation ratios of the powders were compared between leaves (L0) and stems (C0) prepared as a mesh-passing fraction with a pore size of 1 mm, and between the fractionated powder samples of C0 (C1–C3) as well. C0 showed a significantly smaller ratio than that of L0 (Fig. 1). Light-green tube-like organs were observed in the L0 powder after pressurization and release, whereas the dark-green and white particles were heavily crushed (Figs. 2A, B, and Fig. S1B2; see J. Appl. Glycosci. Web site). On the other hand, C0 maintained the granular structures of the white and
were 17.3, 39.1, and 43.6 % for C1, C2, and C3, respectively. The weight proportions of the three fractionated C0 powders could be also affected by the part of the vegetable used. The findings from our study suggest that the mechanical strength between the fractionated pastes. The broken into smaller particles, whereas the harder parts vegetable and the parts that can be milled should be readily may be preferences in reducing the size of the organs of a mechanical strength of the paste could be attributed to the size of the powder particles. As they mentioned, there the mechanical strength of C0 may be attributed to differences in the properties of the particles, which were > 0.3 mm in size (i.e., the particles recovered in the C1 and C2 fractions).

Lee et al. prepared a series of fractionated spinach powder samples and examined the differences in the properties of powders and pastes to reveal their various properties, such as the bulk density of the powder, water holding capacity of the powder, extruded hardness of the paste, and shape stability of the paste. They showed that larger powders exhibited better stability as a food ink for 3D printing, suggesting that the mechanical strength of the paste could be attributed to the size of the powder particles. As they mentioned, there may be preferences in reducing the size of the organs of a vegetable and the parts that can be milled should be readily broken into smaller particles, whereas the harder parts should remain larger, which may result in differences in mechanical strength between the fractionated pastes. The findings from our study suggest that the mechanical strength could be also affected by the part of the vegetable used. The weight proportions of the three fractionated C0 powders were 17.3, 39.1, and 43.6 % for C1, C2, and C3, respectively, whereas the weight proportions for the L0 powders, which were subjected to the same fractionation procedures as C0, were 7.9, 43.8, and 48.3 % for powders with particles of 0.5–1.0, 0.3–0.5, and < 0.3 mm in size, respectively (data not shown). Although the weight proportions of the corresponding sizes for C0 and L0 were not identical, the similar trends in the size distributions support our hypothesis that differences in the structural deformation ratios of L0 and C0 may be attributed to differences in the properties of the individual parts of the vegetable.

We then examined the rheological properties of the following paste samples: L0 with water (LOW); C0 with water (C0W); and C0 with NPTG (C0NP). The addition of NP affected the firmness peak value the adhesiveness area value in previous experiments using potato paste samples. There were no significant differences in firmness peak values between the samples (Fig. 3A). The adhesiveness area of C0W was smaller than that of L0W (Fig. 3B), demonstrating that CC powder may be a new food material that exhibits a lower adhesiveness than cabbage leaf powder (L0). The adhesiveness areas of C0W and C0NP were not significant, suggesting that the effect of NPTG on the modification of adhesiveness is limited in C0 paste because the adhesiveness of C0W itself was low.

The use of NP in the preparation of vegetable powder pastes could help broaden the range of applications for 3D food printing by dispersing particles in the suspension and binding the particles to improve the firmness. NP exhibits an excellent particle-binding activity at a low concentration (0.71 %), which is much lower than that (10 %) for xanthan gum and hydroxypropyl methylcellulose applied in the previous study. Present study examined the effects of NPTG supplementation in C0 paste on paste properties, which is an important factor in 3D food cooking. As expected, C0 powder was successfully dispersed in both NPTG and a 1:1 mixture of water and NPTG (Fig. S2; see J. Appl. Glycosci. Web site). Examination of the particle-binding activity revealed that paste containing NPTG could be shaped into a ball immediately after its preparation (Fig. 4A) and the paste could be formed into a ball after 5 min (Fig. 4B). Meanwhile, paste made with water only was unable to form a ball structure (Fig. 4C). The ball-forming properties were likely reduced due to rapid water absorption by the particles (Fig. 4D). Thus, NPTG exhibits the activities of the binding particles of C0 powder, which could enable stable extrusion of the paste for 3D food cooking. Paste made using C0 powder with NPTG as a powder-binding agent was extruded to prepare a bar-shaped food with a taste of sauerkraut. The paste was successfully extrud-
C0 powder in next-generation cooking by binding or dispersing powder. The addition of NPTG broadens the applicability of powder containing particles > 0.3 mm in size, has a higher friction, and the coarse surface could promote the fragmentation and product becomes coarse depending on the proportion of C0, whereas that of a 1:1 mixture was stably extruded (Fig. S3; see J. Appl. Glycosci. Web site). The surface of the extruded bar product with C0 powder provides a unique structure as well as the nutritional values of CC.

In the meanwhile, a coarse surface of the bar-shaped food implied that paste of this formulation might be broken into fragments when it is extruded through a nozzle of 2 mm in diameter, a standard size used in a 3D food printer. In our preliminary test by manual extrusion of paste from a syringe with a nozzle of 2 mm in internal diameter, a paste of a 1:3 mixture of commercially-available cabbage powders (< 0.3 mm in diameter) and C0 was broken during extrusion, whereas that of a 1:1 mixture was stably extruded (Fig. S3; see J. Appl. Glycosci. Web site). The surface of the extruded product becomes coarse depending on the proportion of C0, and the coarse surface could promote the fragmentation and nonlinear, unstable extrusion.

In summary, C0 powder made from CC, especially powder containing particles > 0.3 mm in size, has a higher tolerance against structural deformation compared with leaf powder. The addition of NPTG broadens the applicability of C0 powder in next-generation cooking by binding or dispersing wet C0 powder. The granular structure and hardness of C0 powder in foods could yield nutritional, functional, and textural values, and pulverization could promote the use of rejected parts of vegetables, such as CC and broccoli and cauliflower stalks, to reduce food waste and provide novel values for food used in next-generation cooking.

**CONFLICTS OF INTEREST**

The authors declare no conflict of interests.

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**REFERENCES**

1. C. Bas-Bellver, C. Barrera, N. Betoret, and L. Segui: Turning agri-food cooperative vegetable residues into functional powdered ingredients for the food industry. *Sustainability*, **12**, 1284 (2020).
2. T.B.N. Brito, L.R.S. Lima, M.C.B. Santos, R.F.A. Moreira, L.C. Cameron, A.E.C. Fai, and M.S.L. Ferreira: Antimicrobial, antioxidant, volatile and phenolic profiles of cabbage-stalk and pineapple-crown flour revealed by GC-MS and UPLC-MS. *Food Chem.*, **339**, 127882 (2021).
3. M. Kudo, A. Koizumi, R. Yamamoto, K. Kurata, M. Chiyoda, M. Arizumi, and M. Mineki: Unused cabbage core components and their utilization in dumplings. *J. Home Econ. Jpn.*, **72**, 664–672 (2021) (In Japanese).
4. Y. Kitagawa: Distribution of vitamin C as related to the growth of edible herbs. *J. Jpn. Soc. Food Nutr.*, **26**, 551–557 (1973) (In Japanese).
5. G.-H. Kim: Determination of vitamin U in food plants. *Food Sci. Technol.,* **9**, 316–319 (2003).
6. H. Kitamura, T. Matsuda, M. Hara, and T. Yano: The mineral contents according to part in rice, cabbage, onion and carrot. *Jpn. J. Soil Sci. Plant Nutr.*, **86**, 114–119 (2015) (In Japanese).
7. M.C. Karam, J. Petit, D. Zimmer, and E.B. Djantou: Effects of drying and grinding in production of fruit and vegetable powders: A review. *J. Food Eng.,* **188**, 32–49 (2016).
8. T. Pereira, S. Barroso, and M.M. Gil: Food texture design by 3D printing: A review. *Foods,* **10**, 320. doi.org/10.3390/foods10020520 (2021).
9. H.W. Kim, J.H. Lee, S.M. Park, M.H. Lee, I.W. Lee, H.S. Doh, and H.J. Park: Effect of hydrocolloids on rheological properties and printability of vegetable inks for 3D food printing. *J. Food Sci.,* **83**, 2923–2932 (2018).
10. K. Nishinari: Texture and rheology in food and health. *Food Sci. Technol.,* **15**, 99–106 (2009).
11. K. Tokuyasu, K. Yamagishi, J. Matsuki, D. Nei, T. Sasaki, and M. Ike: “Nata puree,” a novel food material for upgrading vegetable powders, made by bacterial cellulose gel disintegration in the presence of (1,3)(1,4)-β-glucan. *J. Appl. Glycosci.,* **68**, 77–87 (2021).
12. F. Hayakawa, A. Fukui, J. Matsuki, and H. Yano: Effect of
glutathione on the physical properties of soy dough. *Bull. NARO, Food Res.*, 1, 1–7 (2017) (In Japanese).

13) I. Park, S.-H. Kim, I.-M. Chung, I.-H. Kim, C.F. Shoemaker, and Y.-S. Seo: Comparison of a dynamic test to analyze the texture of cooked rice with a classic compression–extension test. *Starch/Stärke*, 66, 998–1004 (2014).

14) K. Kohyama, T. Sasaki, and T. Azuma: Patterns observed in the first chew of foods with various textures. *Food Sci. Technol. Res.*, 7, 290–296 (2001).

15) J.H. Lee, D.J. Won, H.W. kim, and H.J. Park: Effect of particle size on 3D printing performance of the food-ink system with cellular food materials. *J. Food Eng.*, 256, 1–8 (2019).