

Effect of γ -irradiation on some physiochemical properties of konjac glucomannan

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Abstract

Konjac glucomannan (KGM) was irradiated at 5, 20, 50 and 100 kGy and the effects of γ -irradiation on some physiochemical properties of KGM were studied by using viscosimeter, colorimeter, gel permeation chromatography (GPC), Fourier transform infrared (FT-IR) spectroscopy, ultraviolet (UV) spectroscopy, thermal gravimetric (TG) analysis and scanning electron microscopy (SEM). γ -irradiation led to significant degradation of KGM according to the significant reduction of the weight-average molecular weight (M_w). The apparent viscosity of KGM decreased with increasing dose, while the viscosity stability was improved after irradiation. The colour of KGM became more intense brown with increasing dose up to 20 kGy. FT-IR spectra indicated that γ -irradiation introduced no significant changes into the structure but UV spectra showed a distinct absorption peak at about 265 nm, increasing with irradiation dose, which was attributed to the formation of carbonyl groups or double bond. High irradiation dose (100 kGy) caused a small decrease of thermal stability but presented no visible fissures or splitting of KGM granules according to the TG analysis and SEM microphotographs.

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1. Introduction

Konjac glucomannan (KGM) is a high molecular weight water-soluble non-ionic polysaccharide extracted in high yield from the tubers of *Amorphophallus konjac* plant (Dave, Sheth, McCarthy, Ratto, & Kaplan, 1998; Li, Xie, & Kennedy, 2006). It has a β -(1 \rightarrow 4) linked D-glucose (G) and D-mannose (M) residues as the main chain with branches joined through C-3 carbon of both G and M (Maeda, Shimahara, & Sugiyama, 1980) or C-6 of glycosyl units with the side chains linked β -(1 \rightarrow 6) at the glycosyl units (Katsuraya et al., 2003). The M:G ratio is typically reported to be approximately 1.6:1 with a low degree of acetyl groups (approximately 1 acetyl group per 17 resi-

dues) at the C-6 position (Kato & Matsuda, 1969; Maeda et al., 1980).

KGM is regarded as a non-calorie food, the role of which has been displayed in weight loss and cholesterol reduction (Yamada et al., 2003). In addition, the characters of high viscosity, excellent film-forming ability and good biocompatibility, biodegradability, as well as gel-forming properties entitle KGM to be a novel polymer material, which has been used in various fields like food additives, packing and preservatives material, control release material and wood adhesives (Yu, Huang, Ying, & Xiao, 2007; Zhang, Xie, & Gan, 2005). However, with the development of new application of KGM, modification has been applied widely to improve its functional properties, such as physical modification (Li, Xia, Wang, & Xie, 2005), chemical modification (Cheng, Karim, & Seow, 2007; Shinsaku, Shigetomo, Naruhiro, & Yoshinory, 2002; Xie, Feng, Cao, Xia, & Lu, 2007) and biologic modification (Zhang & Jiang, 2004).

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γ -Irradiation is an ionic, no-heat process that continues to receive attention as a preservation and functional modification agent in polymer research and application (Abu, Duodu, & Minnaar, 2006). It was considered as one of the physical modification methods of nature polysaccharide (Hai, Diep, Nagasawa, Yoshii, & Kume, 2003; Relleve et al., 2005; Rombo, Taylor, & Minnaar, 2004). In comparison with other physical modification methods, such as microwave, UV, ultrahigh hydrostatic pressure and hydrothermal treatment, γ -irradiation treatment is rapid, convenient and more extensive because ionizing energy penetrates through the polysaccharide granule rapidly (Bao, Ao, & Jane, 2005).

In this paper, γ -irradiation was taken place on KGM and some physiochemical properties, including apparent viscosity, viscosity stability, weight-average molecular weight, chemical structure, thermal property and granule structure, were measured before and after irradiation. The purpose of this work is to determine whether γ -irradiation is useful for enlarging the application of KGM.

2. Materials and methods

2.1. Materials

KGM was purchased from commercial konjac flour (San Ai Konjac Food Co., Yibin City, China), which had been purified by washing with aqueous methanol solution before air-drying. The other chemicals used in the experiment were analytical grade.

2.2. Preparation and γ -irradiation of KGM

KGM powder (100 g) was sealed in polyethylene bags and irradiated at Radiation Center of Guangdong Province with a ^{60}Co source at room temperature. The target doses were 5, 20, 50 and 100 kGy. Samples were stored in desiccator for further use.

2.3. Apparent viscosity

KGM samples were dissolved in distilled water to a certain concentration and then used a rotating viscosimeter (NDJ-8S, Shanghai, China) to determined the apparent viscosity at 30 ± 0.5 °C every 30 min, the peak viscosity was defined as the final viscosity of KGM.

2.4. Gel permeation chromatography

The weight-average molecular weight (M_w) and polydispersity index (M_w/M_n) of KGM were determined by using a 515-gel permeation chromatography (GPC, Waters, USA). Samples were dispersed with distilled water to a concentration of 0.3% (w/v) and stirred for 5 h, then filtrated with a membrane (aperture: 0.54 μm). The filtrate (10.0 μL) was injected into the Ultrahydrogel column and

a solution made of distilled water containing 0.1 mol/L NaCl was used as eluent at a flow rate of 0.6 mL/min.

2.5. Colour

The colour of KGM was measured using a commercially available light reflectance spectrophotometer (CM-2600D, Minolta, Japan) and expressed on the L , a and b tristimulus scale as in the method described by Nnanna, Phillips, McWatters, and Hung (1990).

2.6. Spectrometry

Fourier transform infrared (FT-IR) measurement of the KGM was carried out using a Vetor33 FT-IR spectrometer (Bruker, Germany). KGM samples were prepared as KBr pellets and were scanned against a blank KBr pellet background. Ultraviolet (UV) spectrum of KGM was obtained using a UV-2550 spectrometer (Shimadzu, Japan). Samples were dispersed with distilled water to a concentration of 1.0% (w/v) and stirred for 5 h, then centrifugated at 6000 r/min for 10 min. The supernate was collected and used for scanning.

2.7. Carbonyl content

The carbonyl content of KGM was measured by following the titrimetric method of Kuakpetoon and Wang (2006).

2.8. Thermal analysis

Thermogravimetric analysis of KGM was conducted with a Netzsch TG 209 (Germany) under air atmosphere with a flow capacity of 20 mL/min. The scan was carried out at a heating rate of 10.0 °C/min from 20 °C to 550 °C. The sample weight was about 6.0 mg.

2.9. Scanning electron microscopy

KGM samples were fixed on a cylindrical microscope stub covered with carbon strip and coated with a thin layer of gold, followed by observation under a scanning electron microscope (XL-LAB630, Philips, Holand).

3. Results and discussion

3.1. Molecular weight

Fig. 1 shows the GPC elution curves of KGM irradiated at 0, 5 and 100 kGy, and data of the weight-average molecular weight (M_w) and polydispersity index (M_w/M_n) are presented in Table 1. Clearly, the M_w decreased significantly with increasing dose, and is 48.06×10^4 , 37.03×10^4 and 3.99×10^4 for 0, 5 and 100 kGy irradiated KGM, respectively. Polysaccharides are typical degradable materials under ionizing radiation based on the reduction

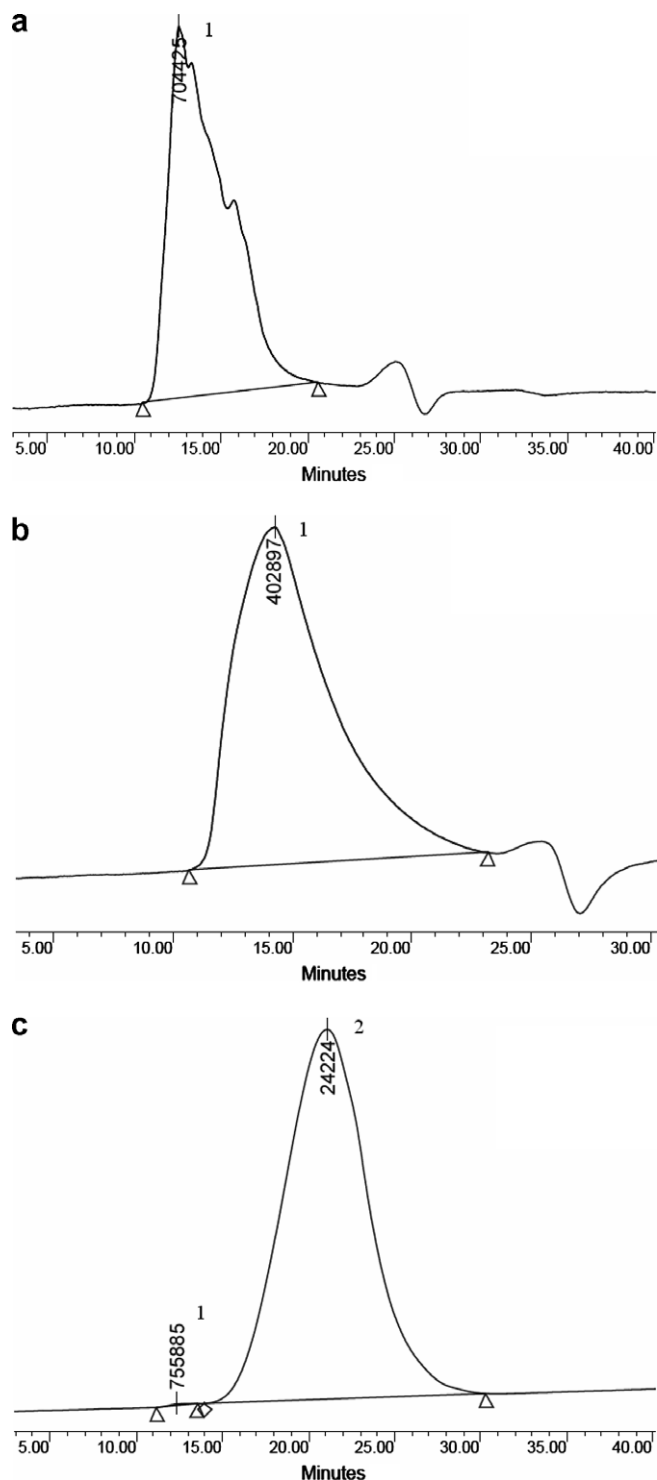


Fig. 1. GPC elution curves of KGM irradiated at 0 (a), 5 (b) and 100 (c) kGy.

Table 1
Weight-average molecular weight (M_w) and polydispersity (M_w/M_n) of KGM irradiated at different dose

Dose (kGy)	Peak	$M_w \times 10^{-4}$	M_w/M_n
0	1	48.06	1.44
5	1	37.03	2.00
100	1	73.28	1.02
	2	3.99	2.97

of molecular weight (Nagasawa, Mitomo, Yoshii, & Kume, 2000), which is attributed to free radical reactions following with chain scission (Ulanski & von Sonntag, 2000). The broadening of the curves (Fig. 1) after irradiation was reflected by an increase of polydispersity index with increasing dose from 1.44 to 2.97 (Table 1), which indicated a random rupture process (Vodenicarova, Drimalova, Hromadkova, Malovikova, & Ebringerova, 2006). Therefore, it can be suggested that the decrease of M_w of KGM by γ -irradiation arose mainly from random chain scission of KGM backbone.

In the case of 100 kGy irradiation, KGM was degraded mostly and remains only 0.09% of undegraded fraction (Fig. 1c). It means that γ -irradiation is convenient for degradation of KGM and might be considered for preparing konjac oligosaccharide, which has been found to have many physiological functions, such as antioxidative ability, lowering plasma glucose and improving immune ability (Xiang, Chen, & Liu, 2004). Choi, Ahn, Lee, Byun, and Park (2002) and Hai et al. (2003) had already reported that γ -irradiation was an effective method for preparing chitosan oligomers.

3.2. Apparent viscosity and viscosity stability

Fig. 2 shows the apparent viscosity of KGM in aqueous solution after irradiated at different dose. The viscosity decreased significantly in a dose-dependent manner. For example, the viscosity of non-irradiated KGM in 1.0% (w/v) aqueous solution is 28.44 Pa s when measured at 30 °C, while the viscosity of irradiated KGM (50 kGy) in 5.0% (w/v) aqueous solution is only 2.129 Pa s. The reduction of apparent viscosity was expected due to the decrease of KGM molecular weight (Kishida, Okimasu, & Kamata, 1978). Similar behaviour had been observed in irradiated carrageenan, starch, guar gum (Abu, Muller, Duodu, & Minnaar, 2005; Kornelia, Stephen, & John, 1996; Relleve et al., 2005).

The relationship between apparent viscosity of KGM in aqueous solution and storage time was determined to study the viscosity stability of irradiated KGM and the results are shown in Fig. 3. As can be seen from the curves, the apparent viscosity of non-irradiated KGM increased

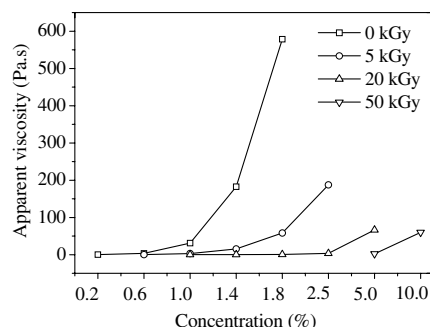


Fig. 2. The apparent viscosity of KGM irradiated at different dose.

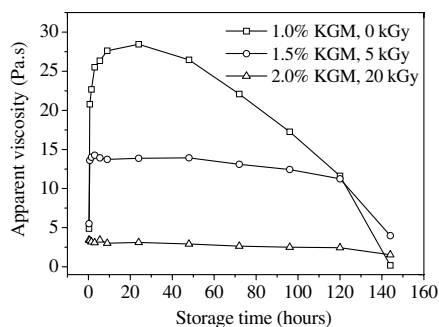


Fig. 3. The viscosity stability of KGM irradiated at different dose.

slightly at first and exhibited a maximum value at about 24 h and then decreased gradually with the increase of storage time. Tian, Gong, and Xie (2005) also observed a similar phenomenon. Compared to the non-irradiated KGM, the viscosity of irradiated KGM exhibited a maximum value rapidly and then kept at a steady level for a long time, which implied that the viscosity stability of KGM in aqueous solution was improved. It might attribute to the scission of main chain, KGM with low molecular mass is easily to form stable conformation with water molecule through hydrogen bond.

3.3. Colour

The L , a and b values for irradiated KGM are shown in Table 2. The colour of KGM did not significantly change when the irradiation dose was lower than 5 kGy, but it changed to a more intense brown with the increasing dose up to 20 kGy. The change might attribute to the formation of carbonyl groups or double bond during γ -irradiation. Prawitwong, Takigami, and Phillips (2007) also reported that the colour of KGM changed from off-white to more yellow with increasing of absorbed dose. Colour is an important quality index of KGM, off-white is more acceptable in commercial use. The colour change of KGM during γ -irradiation is negative. However, it seemed to be avoidable, Nagasawa et al. (2000) reported that little colour change was observed on γ -irradiation of sodium alginate in the present of oxygen, probably due to the decolouration

Table 2
Effect of γ -irradiation, at different dose, on colour (L , a , b values) of KGM

Dose (kGy)	L	a	b
0	87.78 ^a (0.03)	−0.59 ^a (0.02)	9.75 ^a (0.03)
5	87.47 ^a (0.02)	−0.53 ^b (0.04)	10.05 ^a (0.01)
20	86.29 ^b (0.01)	−0.51 ^b (0.01)	13.29 ^b (0.03)
50	85.10 ^c (0.03)	−0.65 ^c (0.02)	18.99 ^c (0.03)
100	81.58 ^d (0.01)	1.80 ^d (0.03)	30.22 ^d (0.01)

Values are means and standard deviations (in parentheses) of three determinations ($n = 3$). Values followed by the same superscript letter in a column are not significantly ($p > 0.05$) different from each other. L = Lightness (0 = black, 100 = white), $+a$ = redness, $-a$ = greenness, $+b$ = yellowness, $-b$ = blueness.

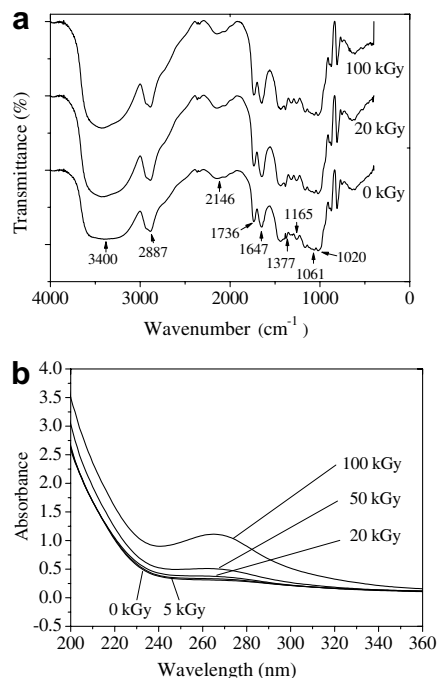


Fig. 4. The FT-IR spectra (a) and UV spectra (b) of KGM irradiated at different dose.

of ozone formed during irradiation in the present of oxygen.

3.4. Chemical structure

Chemical structure change of irradiated KGM was measured by FT-IR and UV spectroscopy. Fig. 4a shows the FT-IR spectra of non-irradiated and irradiated KGM. The non-irradiated KGM, stretching vibration modes of O—H groups is a broad band and occurs at about 3400 cm^{-1} . The band at 2887, 1376 and 1061 cm^{-1} assigned to the stretching vibration of $-\text{CH}_2-$ groups (Yu et al., 2007). The peak at 1736 cm^{-1} is due to the C=O groups in KGM. The intense peak at 1647 cm^{-1} is attributed to the in-plane deformation of the water molecule (Zhang et al., 2001), and the dominant peaks at 1020 cm^{-1} can be assigned to C—O. In the case of irradiated KGM, no significant new chemical groups were intro-

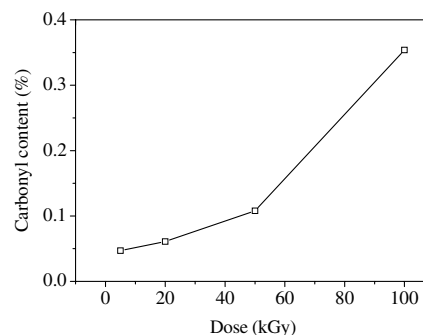
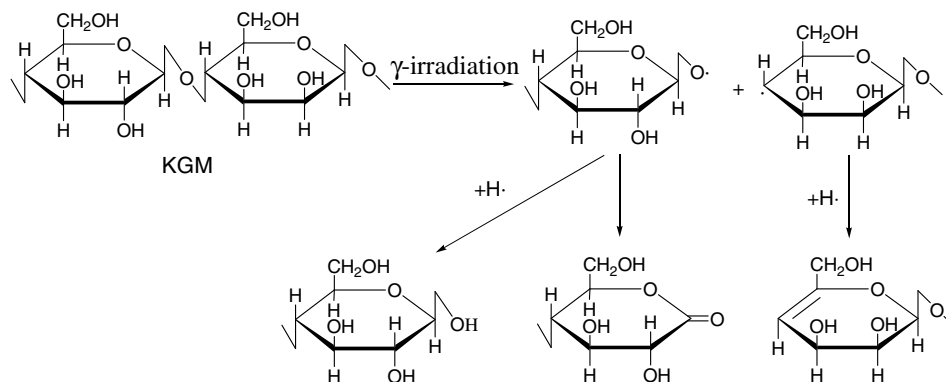


Fig. 5. The carbonyl content of KGM irradiated at different dose.

Scheme 1. The probable degradation mechanism of KGM by γ -irradiation.

duced into the structure. It seemed to be no obvious effect of γ -irradiation on main transmittance peaks of KGM. The result was similar to the report of Prawitwong et al. (2007).

UV spectrum of irradiated KGM was determined and the changes are presented in Fig. 4b. An absorption band at about 265 nm of irradiated KGM had appeared and its intensity increases with irradiation dose. Wasikiewicz, Yoshii, Nagasawa, Wach, and Mitomo (2005) also observed a similar formation of peaks between 250 and 280 nm of irradiated sodium alginate. It was explained that this peak can be ascribed to carbonyl groups or double bond formed after the main chain scission of the polymer followed by the ring opening. Fig. 5 shows the relationship between the carbonyl content of KGM and irradiation dose, which was consistent with the results of UV spectra.

How did the carbonyl groups or double bond form during γ -irradiation? It might mostly due to the scission of main chain of KGM. Scheme 1 shows the probable mechanism of degradation of KGM by γ -irradiation. As illustrated in the scheme, KGM underwent breakage of glycosidic bond during irradiation. After scission, the $\cdot O$ radical may give an end group by combining with hydrogen or form of carbonyl groups by rearrangement. Hydrogen of C_5 is probably abstracted indirectly by $\cdot OH$ radical or macroradical, as a result, a double bond between C_4 and C_5 is formed. The mechanism might be reasonable to explain the change of chemical structure and browning of KGM.

3.5. Thermal property

The characteristic TG and DTG curves for non-irradiated KGM and 100 kGy irradiated KGM are presented in Fig. 6. Both of samples involved four steps of degradation, after the first stage loss of moisture at low temperature, the major weight loss occurred. As can be seen from Table 3, non-irradiated KGM began to decompose at about 250 °C, rapidly loses 61.11% of its weight up to 363 °C and then left about 0.53% up to 550 °C. The maximum rate of weight loss occurred at 296 °C. In the case of irradiated KGM (100 kGy), the decomposition in the major step of weight loss commenced at about 229 °C

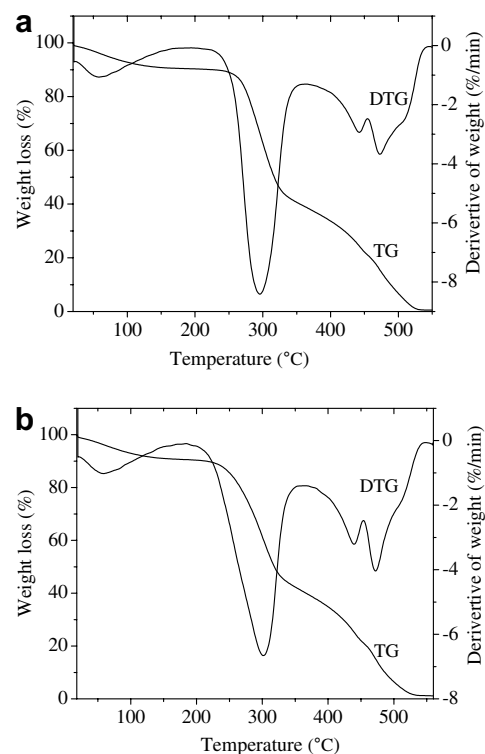


Fig. 6. The TG and DTG curves of KGM irradiated at 0 (a) and 100 (b) kGy.

Table 3
Thermogravimetric (TG and DTG) data of 0 and 100 kGy irradiated KGM

Dose (kGy)	Decomposition stage	Temperature range (°C)	Weight loss (%)	DTG maximum (%/min)	DTG maximum (°C)
0	1	23–189	9.59	−1.06	58
	2	250–363	61.11	−8.41	296
	3	363–455	79.05	−2.94	442
	4	455–550	99.47	−3.68	473
100	1	21–184	9.41	−1.02	58
	2	229–365	59.88	−6.66	301
	3	365–453	78.87	−3.21	439
	4	453–550	98.79	−4.04	471

and the temperature at the maximum rate of weight loss was 301 °C. The overall degradation left about 1.21% residue at 550 °C.

The result of TG analysis indicated that the initial decomposition temperature (T_i) of irradiated KGM is lower than that of non-irradiated KGM, and in the major step of weight loss, the rate of weight loss of irradiated KGM is slightly slower than that of non-irradiated KGM. It meant that the thermal stability of KGM decreased slightly after irradiated at high dose, which might cause by the chain scission or ring opening of KGM during irradiation. Yu et al. (2007) pointed out that the weight loss of KGM during heating could be attributed to a complex process including degradation of the saccharide rings and disintegration of macromolecule chains of KGM.

3.6. Granule structure

Because of the high reduction in apparent viscosity coupled with the belief that KGM degradation occurred with irradiation, we took microphotographs of KGM granules from control (0 kGy) and irradiated (100 kGy) KGM using scanning electron microscopy (SEM) at 500 magnification

for evidence of KGM granular fissures or splitting. SEM microphotographs (Fig. 7) show that KGM granules are made up of erose shapes. γ -Irradiation apparently does not cause fissures or splitting in KGM granules. Abu et al. (2006) and Sokhey and Hanna (1993) also reported the absence of evidence of physical damage to starch granules by γ -irradiation. Perhaps, irradiation damage to KGM granules might exist only in the form of changes to the structure of KGM molecules (Bhatti & Macgregor, 1988).

4. Conclusions

γ -Irradiation caused a dose-dependent degradation of KGM and resulted in significant reduction of M_w and apparent viscosity. The degradation is attributed to the breakage of glycosidic bonds of KGM, which might lead to formation of carbonyl groups or double bond and cause browning of KGM. The viscosity stability of KGM was improved after irradiation. High irradiation dose caused a small decrease of thermal stability but introduced no significant change on granule structure of KGM. Our results indicated that, in a certain degree, γ -irradiation modification is useful for enlarging application fields of KGM.

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References

- Abu, J. O., Duodu, K. G., & Minnaar, A. (2006). Effect of γ -irradiation on some physicochemical and thermal properties of cowpea (*Vigna unguiculata* L. Walp) starch. *Food Chemistry*, 95, 386–393.
- Abu, J. O., Muller, K., Duodu, K. G., & Minnaar, A. (2005). Functional properties of cowpea (*Vigna unguiculata* L. Walp) flours and pastes as affected by γ -irradiation. *Food Chemistry*, 93, 103–111.
- Bao, J. S., Ao, Z. H., & Jane, J. L. (2005). Characterization of physical properties of flour and starch obtained from gamma-irradiated white rice. *Starch*, 57, 480–487.
- Bhatti, R. S., & Macgregor, A. W. (1988). Gamma irradiation of hullless barley: Effect on grain composition β -glucans and starch. *Cereal Chemistry*, 65, 463–470.
- Cheng, L. H., Karim, A. A., & Seow, C. C. (2007). Effects of acid modification on physical properties of konjac glucomannan (KGM) films. *Food Chemistry*, 103, 994–1002.
- Choi, W. S., Ahn, K. J., Lee, D. W., Byun, M. W., & Park, H. J. (2002). Preparation of chitosan oligomers by irradiation. *Polymer Degradation and Stability*, 78, 533–538.
- Dave, V., Sheth, M., McCarthy, S. P., Ratto, J. A., & Kaplan, D. L. (1998). Liquid crystalline, rheological and thermal properties of konjac glucomannan. *Polymer*, 39, 1139–1148.
- Hai, L., Diep, T. B., Nagasawa, N., Yoshii, F., & Kume, T. (2003). Radiation depolymerization of chitosan to prepare oligomers. *Nuclear Instruments and Methods in Physics Research B*, 208, 466–470.
- Kato, K., & Matsuda, K. (1969). Studies on the chemical structure of konjac mannan. *Agricultural and Biological Chemistry*, 33, 1446–1453.
- Katsuraya, K., Okuyama, K., Hatanaka, K., Oshima, R., Satoh, T., & Matsuzaki, K. (2003). Constitution of konjac glucomannan: Chemical analysis and ^{13}C NMR spectroscopy. *Carbohydrate Polymers*, 53, 183–189.

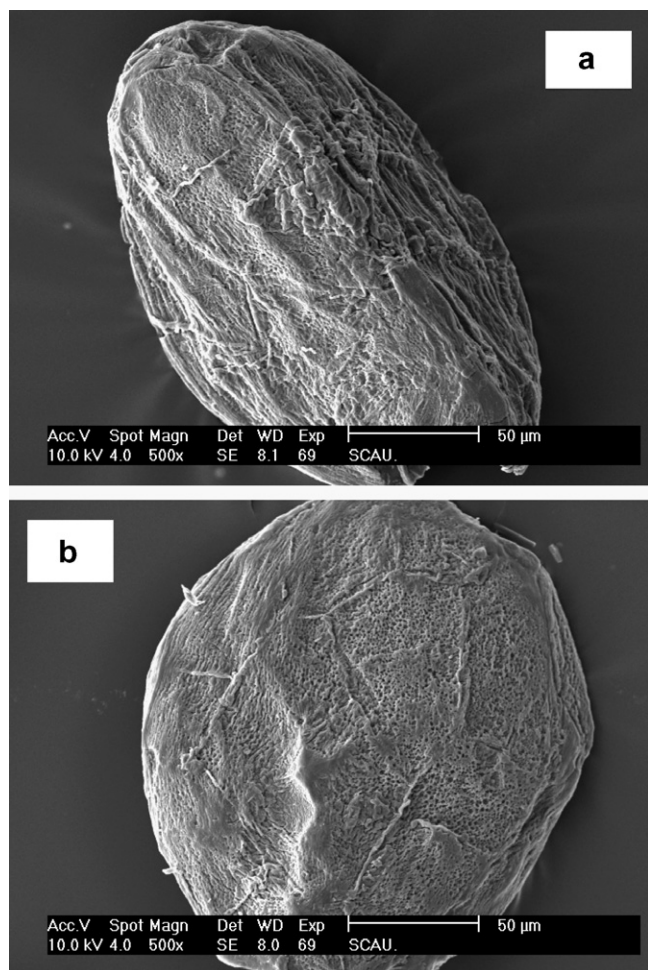


Fig. 7. SEM microphotographs of KGM irradiated at 0 (a) and 100 (b) kGy.

- Kishida, N., Okimasu, S., & Kamata, T. (1978). Molecular weight and intrinsic viscosity of konjac gluco-mannan. *Agricultural and Biological Chemistry*, 42, 1645–1650.
- Kornelia, J., Stephen, E. H., & John, R. M. (1996). Effect of gamma irradiation on the macromolecular integrity of guar gum. *Carbohydrate Research*, 282, 223–236.
- Kuakpetoon, D., & Wang, Y. J. (2006). Structural characteristics and physicochemical properties of oxidized corn starched varying in amylase content. *Carbohydrate Research*, 341, 1896–1915.
- Li, B., Xia, J., Wang, Y., & Xie, B. J. (2005). Grain-size effect on the structure and antiobesity activity of konjac flour. *Journal of Agricultural and Food Chemistry*, 53, 7404–7407.
- Li, B., Xie, B. J., & Kennedy, J. F. (2006). Studies on the molecular chain morphology of konjac glucomannan. *Carbohydrate Polymers*, 64, 510–515.
- Maeda, M., Shimahara, H., & Sugiyama, N. (1980). Detailed examination of the branched structure of konjac glucomannan. *Agricultural and Biological Chemistry*, 44, 245–252.
- Nagasawa, N., Mitomo, H., Yoshii, F., & Kume, T. (2000). Radiation-induced degradation of sodium alginate. *Polymer Degradation and Stability*, 69, 279–285.
- Nnanna, I. A., Phillips, D. R., McWatters, K. H., & Hung, Y. C. (1990). Effect of germination on the physical, chemical, and sensory characteristics of cowpea products; flour, paste, and akara. *Journal of Agricultural and Food Chemistry*, 38, 812–816.
- Prawitwong, P., Takigami, S., & Phillips, G. O. (2007). Effect of γ -irradiation on molar mass and properties of Konjac mannan. *Food hydrocolloids*, 21, 1362–1367.
- Relleve, L., Nagasawa, N., Luan, L. Q., Yagi, T., Aranilla, C., Abad, L., et al. (2005). Degradation of carrageenan by radiation. *Polymer Degradation and Stability*, 87, 403–410.
- Rombo, G. O., Taylor, J. R. N., & Minnaar, A. (2004). Irradiation of maize and bean flours: Effects on starch physicochemical properties. *Journal of the Science of Food and Agriculture*, 84, 350–356.
- Shinsaku, K., Shigetomo, T., Naruhiro, H., & Yoshinory, T. (2002). Preparation and rheological characterization of carboxymethyl konjac glucomannan. *Food Hydrocolloids*, 16, 289–294.
- Sokhey, A. S., & Hanna, M. A. (1993). Properties of irradiated starches. *Food Structure*, 12, 397–410.
- Tian, D. T., Gong, Y., & Xie, H. Q. (2005). Study on aqueous viscosity behavior of konjac glucomannan hydrosol. *Nature Product Research and Development*, 17, 736–739.
- Ulanski, P., & von Sonntag, C. (2000). OH-radical-induced chain scission of chitosan in the absence and presence of dioxygen. *Journal of the Chemistry Society*, 2, 2022–2028.
- Vodenicarova, M., Drimalova, G., Hromadkova, Z., Malovikova, A., & Ebringerova, A. (2006). Xyloglucan degradation using different radiation sources: A comparative study. *Ultrasonics Sonochemistry*, 13, 157–164.
- Wasikiewicz, J. M., Yoshii, F., Nagasawa, N., Wach, R. A., & Mitomo, H. (2005). Degradation of chitosan and sodium alginate by gamma radiation, sonochemical and ultraviolet methods. *Radiation Physics and Chemistry*, 73, 287–295.
- Xiang, J. L., Chen, W. P., & Liu, J. Q. (2004). Development of researches on konjac glucomannan oligosaccharides. *China Food Additive*, 1, 20–23 (in Chinese).
- Xie, C. X., Feng, Y. J., Cao, W. P., Xia, Y., & Lu, Z. Y. (2007). Novel biodegradable flocculating agents prepared by phosphate modification of Konjac. *Carbohydrate Polymers*, 67, 566–571.
- Yamada, K., Tokunaga, Y., Ikeda, A., Ohkura, K., Kaku-Ohkura, S., Mamiya, S., et al. (2003). Effect of dietary fiber on the lipid metabolism and immune function of aged Sprague-Dawley rats. *Bioscience, Biotechnology, and Biochemistry*, 67, 429–433.
- Yu, H. Q., Huang, Y. H., Ying, H., & Xiao, C. B. (2007). Preparation and characterization of a quaternary ammonium derivative of konjac glucomannan. *Carbohydrate Polymers*, 69, 29–40.
- Zhang, H., Yoshimura, M., Nishinari, K., Williams, M. A. K., Foster, T. J., & Norton, I. T. (2001). Gelation behaviour of konjac glucomannan with different molecular weights. *Biopolymers*, 59, 38–50.
- Zhang, X.J., & Jiang, F.T. (2004). Modification and application of konjac glucomannan. *Chemistry and Biological Engineering*, 2, 4–6 (in Chinese).
- Zhang, Y. Q., Xie, B. J., & Gan, X. (2005). Advance in the applications of konjac glucomannan and its derivatives. *Carbohydrate Polymers*, 60, 27–31.