J. Food Sci. Nutr.
Vol. 5, No. 2, p. 93~99 (2000)

Detection of Irradiated Cereals by Viscosity Measurement

Sang-Duk Yi, Kyu-Seob Chang* and Jae-Seung Yang†

Detection Lab. of Irradiated Food, Korea Atomic Energy Research Institute, Taejon 305-600, Korea
**Department of Food Science and Technology, Chungnam National University, Taejon 305-764, Korea*

Abstract

A study was performed to establish the detection method of irradiated cereals. A drastic reduction of the apparent viscosity of suspensions with heat treatment was observed up to 1~2 kGy in brown rice, Job's-tears, polished barley and polished rice. They were gently reduced to samples irradiated at 15 kGy. This trend was similar for all stirring speeds. The viscosity of unirradiated brown rice, Job's-tears, polished barley and polished rice reduced with increasing stirring speeds and this tendency was similar for irradiation doses. Regression expressions and coefficients of brown rice, Job's-tears, polished barley and polished rice on different doses were 0.9399 ($y=3408.0e^{-0.2338x}$), 0.8855 ($y=3597.8e^{-0.6864x}$), 0.9343 ($y=7554.0e^{-0.4998x}$) and 0.9714 ($y=3228.2e^{-0.5312x}$), respectively, at 120 rpm. These results suggest that detection of irradiation for cereals could be possible by viscometric methods.

Key words: cereals, viscosity, gamma irradiation

INTRODUCTION

As seen from a toxicological viewpoint, the irradiation of food with a total radiation dose of up to 10 kGy was declared harmless in 1980 by a committee of experts from FAO/IAEA/WHO in Geneva (1). The radiation treatment of different foods is now legally accepted in at least 35 countries for over 40 different irradiated food items for consumption, although it is still prohibited in others and permitted only for cereals in some 11 countries as of in 1995 (2). Gamma irradiation is a physical technique of cereal preservation against insect infestation and microbial contamination because doses in the range of 0.2~1.0 kGy are effective in controlling insect infestation and increasing the dose to 5 kGy totally kills the spores of many fungi surviving at the lower doses (3). In connection with the ongoing worldwide application of irradiation as a new technology for that reason importance of increasing food preservation, the identification of these food products is becoming more and more important (4). The reliable detection methods are required for consumers and are useful means to check compliance with labeling regulations and supplement labeling (5,6), since it has been widely recognized that consumer confidence can be bolstered when there is clear evidence that the food irradiation process is being effectively controlled by a responsible industry and a governmental regulatory process (7). Previous detection studies for irradiated foods have been widely performed with physical (ESR, TL, PSL, Viscosity, Conudctance/impedance and Gas evolution), chemical (hydrocarbon, Cyclobutanones, Peroxidase, *0*-tyrosine, DNA-comet assay, DNA-changes, and ELISA) and biological (DEFT/APC and Germination) methods (5,8). Among these detection techniques, viscometric detection studies were mainly carried out for dried vegetables and spices using a viscometer and measurement of viscosity has been proposed as a method to detect irradiation treatment of these food products. Additional storage experiments showed that measuring the viscosity may be a simple and inexpensive method for identifying some irradiated spices even after years of storage (9-18). Cereals have a high amount of starch. Starch composed of amylose and amylopectin is a major component related to the viscosity outbreak in cereals and is degraded by gamma irradiation, resulting in a decrease in viscosity (19-26). Therefore, viscosity measurement can be suggested as a detection method for irradiated cereals. The purpose of this paper is to add new data in this field, such as detection of irradiated cereals have not yet been tried in viscometric detection using a viscometer.

MATERIALS AND METHODS

Materials and γ-irradiation

Brown rice (Dongjinbyeo), Job's-tears (Coix lachryma-jobi L. var. Ma-yuen Stapf), polished barley (Sedohadaga) and polished rice (Suweon 232) used in this study were obtained from the Suweon Crop Experiment Station R.B.D. (Rice Breeding Div), Korea, harvested in 1998. The moisture contents of Job's-tears, polished barley, polished rice and brown rice were 12.49±0.2, 11.86±0.5, 14.97±0.7 and 15.30±0.5%. The starch contents of dried Job's-tears, polished barley, polished rice and brown rice were 0.81±0.07, 0.72±0.07, 0.93±0.02 and 0.89±0.03 g/g, respectively. The samples, packed in polyethylene bags, were irradiated at 1, 2, 3, 5, 7, 10 and 15

†Corresponding author. E-mail: jsyang@nanum.kaeri.re.kr
Phone: 82-42-868-8064, Fax: 82-42-868-8064

kGy by gamma rays from a cobalt-60 source (AECL, Canada) with a dose rate of 166.6 Gy/min at the Korea Atomic Energy Research Institute. To measure the exact total absorbed dose of gamma irradiation, the dose rates for cobalt-60 sources were determined by using a ceric-cerous dosimeter. After irradiation, the samples were ground using a Hanil food mixer (FM 680T, Korea) for 4 min and passed through a 20-mesh sieve (Chung Gye Industry Mfg., Co., Korea). The moisture content was measured by the AOAC method (27). Starch content was determined according to Hayashi and Kawashima's method (28) using the enzyme reaction of glucose oxidase and peroxidase.

Measurement of apparent viscosity

Viscosity was measured according to Hayashi et al.'s method (6,12-15) with a slight modification. Job's-tears, polished barley, polished rice and brown rice were placed in a glass bottle to prepare an 8% aqueous solution. After adding 2.14 ml of 33% NaOH, the samples were mixed thoroughly for 30 sec. The glass bottle was autoclaved for about 30 min at 100°C. The glass bottle was left in an incubator for 3 hr at 30°C to allow jellification. Viscosity was determined by using spindle RV 6 (brown rice, Job's-tears and polished rice), RV 7 (polished barley) of Brookfield DV-III rotation viscometer at 30°C and measured at 30, 60, 90, 120, 150, 180 and 210 rpm.

Calculation of the parameters originated from apparent viscosity and statistical analysis

Identification parameters A, B and C were calculated as follows; parameter A=viscosity per irradiation dose/moisture content, parameter B=parameter A per irradiation dose/starch amount in 1 g of sample and parameter C=parameter per irradiation dose/parameter B of control. Significant differences were determined by using Duncan's multiple range test in a one way ANOVA, and regression expressions and coefficients were determined by regression analysis with SPSS (Statistical Package for Social Science) version 7.5. All experiments were repeated three times.

RESULTS AND DISCUSSION

Changes of viscosity for irradiated cereals at various rpm and doses

The viscosities of irradiated brown rice are shown in Table 1. The viscosities of unirradiated brown rice (control) were 7,487.7±1,106.2, 4,885.0±517.5, 3,996.0±278.6, 3,408.7±363.9, 3,065.7±356.0, 2,842.3±277.8 and 2,642.3±357.3 cP, at 30, 60, 90, 120, 150, 180 and 210 rpm, respectively. For irradiated brown rice at 15 kGy the viscosity was measured at 250.0±50.0, 182.2±16.8, 162.3±16.8, 145.1±12.6, 134.3±13.4, 129.6±8.5 and 123.8±8.3 cP and viscosities decreased according to increasing rpm in all irradiation doses. Significant variations in viscosity showed clear differences between irradiation dose and viscosity according to increasing irradiation dose levels ($p<0.05$). Similar results for brown rice have been reported. Sabularse et al. (25) reported that peak viscosity, setback values, final viscosity and viscosity at 50°C, and consistency of all irradiated brown rice decreased with increasing irradiation doses, and the decrease in peak viscosity by irradiation may be attributed to starch depolymerization in rice.

The changes of viscosities in irradiated Job's-tears on 0, 1, 2, 3, 5, 7, 10 and 15 kGy are given in Table 2. The viscosity of Job's-tears measured at 30, 60, 90, 120, 150, 180 and 210 rpm was dropped from 5,000.0±200.0, 4,020.0±192.2, 3,752.0±303.3, 2,886.0±281.0, 2,695.7.3±184.0, 2,500.3±73.0 and 2,256.0±132.9 cP, respectively, in the unirradiated control to 33.3±0.0, 33.3±0.0, 33.6±0.5, 33.9±1.0, 33.3±0.0, 27.7±0.1 and 28.6±0.0 cP in Job's-tears irradiated at 15 kGy, and decreased according to increasing stirring speeds. Significant variations in viscosity showed clear differences between increasing stirring speeds and irradiation dose ($p<0.05$).

Table 3 shows the viscosities of irradiated polished barley with increasing dose levels and various rpms. Viscosities show-

Table 1. Viscosity of irradiated brown rice prepared with an 8% concentration at various rpms

rpm	Irradiation doses (kGy)								
	Control[1)]	1	2	3	5	7	10	15	F value****
30	^{A}7,487.7±1106.2$^{2)a3)}$	$^{A4)}$4,240.3±96.8^{b}	^{A}2,611.7±158.9^{c}	^{A}2,454.3±117.2^{cd}	^{A}2,653.3± 45.1^{d}	^{A}1,014.3±116.6^{e}	^{A}554.4±116.9^{ef}	^{A}250.0±50.0^{f}	102.296
60	^{B}4,885.0± 517.5^{a}	^{B}2,864.7±70.9^{b}	^{B}2,280.0±101.5^{c}	^{B}1,805.3± 25.4^{d}	^{B}1,380.7±103.3^{e}	^{B}720.0± 75.5^{f}	^{B}411.1±101.8^{fg}	^{B}182.2±16.8^{g}	184.994
90	^{BC}3,996.0± 278.6^{a}	^{C}2,340.3±42.4^{b}	^{C}1,655.7±119.8^{c}	^{C}1,489.3± 67.0^{c}	^{C}1,000.3± 91.2^{d}	^{C}585.6± 72.3^{e}	^{BC}349.9± 49.9^{f}	^{BC}162.3±16.8^{f}	333.223
120	^{CD}3,408.7± 363.9^{a}	^{D}2,042.7±32.0^{b}	^{C}1,569.7± 62.0^{c}	^{D}1,314.0± 47.6^{d}	^{C}891.3± 15.7^{e}	^{CD}511.1± 59.1^{f}	^{BCD}300.1± 33.3^{fg}	^{BC}145.1±12.6^{g}	194.099.
150	^{CD}3,065.7± 356.0^{a}	^{E}183.7±10.1^{b}	^{CD}1,482.3±103.6^{c}	^{E}1,182.0± 70.0^{d}	^{D}715.5± 45.6^{e}	^{CD}463.3± 60.3^{f}	^{CD}267.9± 26.7^{fg}	^{CD}134.3±13.4^{g}	154.644
180	^{D}2,842.3± 277.8^{a}	^{F}1,688.7±28.9^{b}	^{DE}1,355.1± 53.9^{c}	^{EF}1,084.7± 76.1^{d}	^{D}680.5± 26.5^{e}	^{D}433.1± 53.0^{f}	^{CD}243.7± 22.3^{g}	^{C}129.6± 8.5^{g}	216.350
210	^{D}2,642.3± 357.3^{a}	^{G}1,561.7±33.5^{b}	^{E}1,215.1± 51.1^{c}	^{F}1,009.5± 67.2^{c}	^{D}609.8± 28.9^{d}	^{D}403.5± 52.3^{de}	^{D}221.7± 16.7^{ef}	^{C}123.8± 8.3^{f}	120.964
F value****	29.845	953.031	83.301	149.162	124.168	26.206	9.736	11.564	

[1)]Control : unirradiated sample
[2)]Mean value±standard deviation for 3 measurements
[3)]Means with the same superscripts in each row are not significantly different among group by Duncan's multiple range test in one way ANOVA ($p<0.05$).
[4)]Means with the same superscripts in each column are not significantly different among group by Duncan's multiple range test in one way ANOVA ($p<0.05$). ****$p<0.000$

Table 2. Viscosity of irradiated Job's-tears prepared with an 8% concentration at various rpms

rpm	Irradiation dose (kGy)								
	Control$^{1)}$	1	2	3	5	7	10	15	F value****
30	^{A}5,000.0±200.0$^{2)a3)}$	$^{A4)}$4,466.7±152.7^{b}	^{A}2,578.0±134.9^{c}	^{A}355.6±19.3^{d}	^{A}222.2±19.2^{de}	^{A}100.0±0.0^{e}	^{A}85.1±16.9^{e}	^{A}33.3±0.0^{eh}	1,294.523
60	^{B}4,020.0±192.2^{a}	^{B}3,625.7± 75.0^{b}	^{B}2,189.0±176.7^{c}	^{B}283.33± 0.0^{d}	^{B}177.7± 9.6^{de}	^{A}94.4±9.6^{e}	^{B}66.7± 0.0^{e}	^{A}33.3±0.0^{e}	948.818
90	^{B}3,752.0±303.3^{a}	^{C}2,989.0±179.0^{b}	^{C}1,593.0± 68.1^{c}	^{C}244.4± 0.0^{d}	^{C}159.3±12.9^{d}	^{B}85.2±6.4^{d}	^{B}66.7± 0.0^{d}	^{A}33.6±0.5^{d}	417.393
120	^{C}2,886.0±281.0^{a}	^{D}2,350.0±180.2^{b}	^{CD}1,496.3± 54.0^{c}	^{D}225.0± 0.0^{d}	^{D}138.9± 4.8^{d}	^{BC}80.5±4.8^{d}	^{B}58.3± 1.3^{d}	^{A}33.9±1.0^{d}	286.675
150	^{CD}2,695.7±184.0^{a}	^{D}2,292.3±202.7^{b}	^{DE}1,418.0± 44.56^{c}	^{DE}213.3± 0.0^{d}	^{D}131.1± 3.8^{d}	^{BC}77.8±3.9^{d}	^{B}60.0± 0.0^{d}	^{A}33.3±0.0^{d}	383.823
180	^{DE}2,500.3± 73.0^{a}	^{DE}2,072.3±170.9^{b}	^{DE}1,338.3± 1.2^{c}	^{EF}203.7± 3.2^{d}	^{D}127.8± 2.7^{de}	^{C}72.21±0.0^{e}	^{B}61.1± 0.0^{e}	^{B}27.7±0.1^{e}	722.469
210	^{E}2,256.0±132.9^{a}	^{E}1,919.3± 38.9^{b}	^{E}1,260.0± 14.7^{c}	^{G}193.6± 2.71^{d}	^{D}122.2± 2.7^{de}	^{C}71.4±0.0^{ef}	^{B}57.1± 0.0^{ef}	^{C}28.6±0.0^{f}	1,070.315
F value****	67.501	111.356	86.738	174.577	40.014	14.435	6.818	110.361	

$^{1)\sim4)}$Refer to the legend in Table 1.
****p<0.000

Table 3. Viscosity of irradiated polished barley prepared with an 8% concentration at various rpms

rpm	Irradiation dose (kGy)								
	Control$^{1)}$	1	2	3	5	7	10	15	F value****
30	^{A}17,577.0±1934.9$^{2)a3)}$	$^{A4)}$7,488.7± 37.5^{b}	^{A}5,116.0±408.9^{c}	^{A}2,922.3±134.9^{d}	^{A}1,576.7±20.8^{e}	^{A}1,077.7±134.7^{ef}	^{A}533.3± 0.0^{ef}	^{A}133.3± 0.0^{f}	206.475
60	^{B}10,942.7± 466.7^{a}	^{B}4,970.0± 34.0^{b}	^{B}3,340.3±308.0^{c}	^{B}1,992.3± 68.3^{d}	^{B}1,055.0±67.7^{e}	^{B}800.0± 57.7^{e}	^{B}400.0± 0.0^{f}	^{B}88.9±38.4^{f}	961.075
90	^{C}8,778.0± 484.6^{a}	^{C}3,944.3± 29.2^{b}	^{C}2,609.0±244.5^{c}	^{C}1,615.3± 67.6^{d}	^{C}896.1±33.8^{e}	^{C}615.4± 46.0^{ef}	^{C}355.6± 0.0^{fg}	^{B}88.9± 0.0	663.213
120	^{CD}7,554.7± 334.1^{a}	^{D}3,518.0± 83.5^{b}	^{CD}2,253.7±217.1^{c}	^{D}1,433.3± 33.5^{d}	^{D}784.9±16.5^{e}	^{CD}550.2± 50.0^{ef}	^{D}311.1±19.2^{fg}	^{BC}77.8±19.2	878.153
150	^{DE}6,910.3± 375.7^{a}	^{E}3,260.3±112.3^{b}	^{D}2,023.3±213.6^{c}	^{E}1,312.3± 18.5^{d}	^{DE}736.3± 8.9^{e}	^{DE}479.2± 26.7^{ef}	^{E}275.6±15.3^{fg}	^{BC}80.0± 0.0	625.726
180	^{DE}6,280.0± 284.5^{a}	^{F}3,103.0±100.1^{b}	^{D}1,937.7±205.3^{c}	^{EF}1224.3± 18.6^{d}	^{E}719.3±12.5^{e}	^{DE}456.1± 33.3^{f}	^{E}266.7± 3.8^{fg}	^{BC}66.7± 0.0	774.524
210	^{E}5,813.0± 271.7^{a}	^{G}2,938.7± 62.3^{b}	^{D}1,802.3±181.0^{c}	^{F}1,131.0± 38.4^{d}	^{F}641.7± 5.2^{e}	^{E}420.1± 19.1^{f}	^{F}234.9±10.9^{fg}	^{C}57.1± 0.0	803.034
F value****	76.998	1479.918	59.306	267.412	323.947	41.189	301.895	6.728**	

$^{1)\sim4)}$Refer to the legend in Table 1.
**p<0.002, ****p<0.000

ed a marked reduction with increasing doses and the complete loss of viscosities was observed at 5 kGy. This trend was similar for all stirring speeds. In all groups, the higher rpm gave rise to the higher reduction in viscosity. Significant difference was clearly shown between increasing irradiation dose and viscosity (p<0.05).

The viscosities of irradiated polished rice with increasing dose levels and various rpms are shown in Table 4. The viscosity of unirradiated polished rice and polished rice irradiated at 1, 2, 3, 5, 7, 10, and 15 kGy was 6559.0±424.6, 3943.0±333.9, 2285.0±31.2, 755.60±19.3. 384.4±16.7, 203.4±28.4, 144.4±19.3, and 66.7±0.0 cP, respectively. Increasing rpm groups showed similar trends with irradiation doses and the viscosity values decreased with increasing stirring speeds. Significant variations in viscosity showed clear differences between increasing stirring speeds and irradiation doses (p<0.05).

Similar results have been reported that the maximum viscosity of both potato and corn starches, with and without oil treatment before irradiation, decreased gradually with increasing doses of irradiation (20). Köksel et al. (3) reported that irradiated durum wheat exhibited significantly lower scores for stickiness, firmness and bulkiness when compared with control samples, probably due to starch deterioration. Other researchers also reported that reduced viscosity in irradiated wheat starch (23) and corn starch (24) was due to the degradation and uncoiling of starch chains, as well as the breaking of hydrogen bonds within the molecule.

Table 4. Viscosity of irradiated polished rice prepared with an 8% concentration at various rpms

rpm	Irradiation dose (kGy)								
	Control$^{1)}$	1	2	3	5	7	10	15	F value****
30	^{A}6,559.0±424.6$^{2)a3)}$	$^{A4)}$3,943.0±333.9^{b}	^{A}2,285.0±31.2^{c}	^{A}755.6±19.3^{d}	^{A}384.4±16.7^{e}	^{A}203.4± 28.4^{e}	^{A}144.4±19.3^{e}	^{A}66.7±0.0^{e}	452.350
60	^{B}4,966.7±176.6^{a}	^{B}2,884.3±200.0^{b}	^{B}1,656.7±11.5^{c}	^{B}600.2±16.7^{d}	^{B}305.5±25.4^{e}	^{AB}173.7± 28.6^{ef}	^{AB}122.2± 9.58^{f}	^{B}55.6±9.6^{f}	1,017.417
90	^{C}3,771.0±194.0^{a}	^{C}2,348.3± 77.7^{b}	^{C}1,396.7±16.9^{c}	^{C}533.3±11.1^{d}	^{B}284.5±16.8^{e}	^{BC}148.5± 17.3^{f}	^{BC}107.4±12.8^{f}	^{B}55.6 ±0.0^{f}	970.150
120	^{D}3,180.3±134.9^{a}	^{D}2,058.6± 38.2^{b}	^{D}1,252.7± 4.6^{c}	^{D}486.7±12.6^{d}	^{C}254.8±12.5^{e}	^{C}133.9±153.9^{f}	^{C}97.2± 9.6^{f}	^{C}44.5±4.8^{f}	1,550.297
150	^{D}2,933.3±300.9^{a}	^{DE}1,850.7± 10.7^{b}	^{E}1,156.7±15.3^{c}	^{E}450.0±10.0^{d}	^{CD}237.9±13.7^{e}	^{C}125.8± 12.5^{e}	^{C}93.3±11.5^{e}	^{C}46.7±0.0^{e}	289.081
180	^{E}2,501.0±137.6^{a}	^{E}1,741.0± 26.7^{b}	^{F}1,056.7±14.2^{c}	^{EF}433.3±11.1^{d}	^{D}224.1±13.9^{e}	^{C}124.7± 8.9^{f}	^{C}90.7±12.9^{f}	^{C}44.4±6.74^{f}	980.775
210	^{E}2,444.7± 97.5^{a}	^{E}1,612.7± 28.7^{b}	^{G}1,007.2±16.7^{c}	^{F}411.3±11.9^{d}	^{D}213.6±12.3^{e}	^{C}116.0± 11.9^{f}	^{C}87.3±10.9^{fg}	^{C}39.7±2.8^{g}	1,665.815
F value****	123.383	88.710	1977.085	235.378	38.776	8.187***	7.866***	14.690	

$^{1)\sim4)}$Refer to the legend in Table 1.
***p<0.001, ****p<0.000

On the basis of the above papers, the reason for the reduction of viscosity in cereals seems to be caused by the free radicals created by gamma irradiation because increasing dosages of gamma irradiation creates increasing intensities of free radicals in carbohydrates (26), which are responsible for molecular changes and fragmentation of the starch molecules, and these changes may affect the physical and rheological properties of starch and decrease viscosity.

Parameter values derived from viscosity of irradiated cereals

To remove the affected variation for viscosity, parameter values derived from the viscosity of brown rice, Job's-tears, polished barley and polished rice are listed in Table 5, 6, 7 and 8, respectively. Hayashi et al. (12) reported that much more consistent viscosity values could be obtained if the viscosity of a sample was normalized for starch content, since macromolecules greatly influence the jellification properties. The parameter values of irradiated cereals showed dose dependent relations between unirradiated and irradiated samples, and indicated that all of the values for unirradiated samples were higher than the irradiated ones. A normalized parameter of samples is a better parameter for detecting irradiation treatment than the viscosity value itself because the moisture and starch content of cereals have an influence on viscosity. Therefore, it is considered that parameters A, B, and C by definition could provide detection values that are not affected by material and measuring conditions.

Regression expressions and coefficients between viscosity and irradiation dose for irradiated cereals

Regression expressions and coefficients of irradiated brown rice, Job's-tears, polished barley and polished rice are listed in Table 9. Regression expressions and coefficients of irradiated brown rice, Job's-tears, polished barley and polished rice were 0.9152 ($y=7487e^{-0.2513x}$), 0.8770 ($y=6510.8e^{-0.7139x}$), 0.9307 ($y=17577e^{-0.5323x}$), and 0.9660 ($y=6581.0e^{-0.598.0x}$), at 30 rpm, respectively and showed very high regression coefficients between irradiation dose and viscosity. This trend was similar for all stirring speeds.

CONCLUSIONS

All samples indicated a decrease in apparent viscosity and standard deviation by increasing rpm. A drastic reduction of the apparent viscosity in the heat-treated suspensions was observed on irradiation doses of 1~2 kGy. The viscosity of brown rice, Job's-tears, polished barley and polished rice was dropped from 3,408.7±363.9, 2,886.0±281.0, 7,554.7±334.1 and 3,180.3±134.9 cP, in the unirradiated control to 145.1±12.6, 33.9±1.0, 77.8±19.2 and 44.5±4.8 cP, respectively, in samples irradiated at 15 kGy and measured at 120 rpm. This trend was similar for all stirring speeds. Regression expressions and coefficients of brown rice, Job's-tears, polished barley and polished rice were 0.9268 ($y=3996.0e^{-0.2374x}$),

Table 5. Parameter values originated from viscosity of irradiated brown rice sample prepared with an 8% concentration at various rpms

rpm	Parameter	Irradiation dose (kGy)							
		Control[1]	1	2	3	5	7	10	15
30	Parameter A[2]	489.39	277.14	173.96	160.41	173.42	66.29	36.23	16.34
	Parameter B[3]	549.87	311.39	195.46	180.23	194.85	74.48	40.71	18.36
	Parameter C[4]	1.0000	0.5663	0.3555	0.3278	0.3543	0.1355	0.0740	0.0333
60	Parameter A	319.28	187.23	149.02	117.99	90.24	47.06	26.87	11.91
	Parameter B	358.74	210.37	167.43	132.57	101.39	52.87	30.19	13.38
	Parameter C	1.0000	0.5864	0.4667	0.3696	0.2826	0.1473	0.0842	0.0373
90	Parameter A	261.18	152.96	108.22	97.33	65.38	38.27	22.87	10.61
	Parameter B	293.46	171.87	121.60	109.36	73.46	43.00	25.70	11.92
	Parameter C	1.0000	0.5856	0.4143	0.3727	0.2503	0.1465	0.0876	0.0406
120	Parameter A	222.79	133.51	102.59	85.88	58.25	33.41	19.61	9.48
	Parameter B	250.33	150.01	115.27	96.49	65.45	37.53	22.03	10.65
	Parameter C	1.0000	0.5993	0.4605	0.3855	0.2615	0.1499	0.0880	0.0426
150	Parameter A	200.37	120.07	96.88	77.26	46.76	30.28	17.51	8.78
	Parameter B	225.13	134.91	108.85	86.81	52.53	34.02	19.67	9.87
	Parameter C	1.0000	0.5992	0.4835	0.3856	0.2333	0.1511	0.0873	0.0438
180	Parameter A	185.77	110.37	88.57	70.89	44.48	28.31	15.93	8.47
	Parameter B	208.73	124.01	99.52	79.65	49.98	31.81	17.90	9.52
	Parameter C	1.0000	0.5941	0.4768	0.3816	0.2394	0.1523	0.0858	0.0456
210	Parameter A	172.70	102.07	79.42	65.98	39.86	26.37	14.49	8.09
	Parameter B	194.04	114.69	89.23	74.13	44.79	29.63	16.28	9.09
	Parameter C	1.0000	0.5910	0.4599	0.3820	0.2308	0.1527	0.0839	0.0468

[1]Control : unirradiated sample
[2]Parameter A : viscosity per irradiation dose/moisture content
[3]Parameter B : parameter A per irradiation dose/starch amount in 1 g of sample
[4]Parameter C : parameter per irradiation dose/parameter B of control

Table 6. Parameter values originated from viscosity of irradiated Job's-tears sample prepared with an 8% concentration at various rpms

rpm	Parameter	Irradiation dose (kGy)							
		Control[1)]	1	2	3	5	7	10	15
30	Parameter A[2)]	400.32	357.62	206.41	28.47	17.79	8.01	6.81	2.67
	Parameter B[3)]	494.22	441.51	254.83	35.15	21.96	9.89	8.41	3.30
	Parameter C[4)]	1.0000	0.8933	0.5156	0.0711	0.0444	0.0200	0.0170	0.0067
60	Parameter A	321.86	290.29	175.26	22.68	14.23	7.56	5.34	2.67
	Parameter B	397.36	358.38	216.37	28.00	17.57	9.33	6.59	3.30
	Parameter C	1.0000	0.9019	0.5445	0.0705	0.0442	0.0235	0.0166	0.0083
90	Parameter A	285.99	239.31	127.54	19.57	12.75	6.82	5.34	2.69
	Parameter B	353.07	295.44	157.46	24.16	15.74	8.42	6.59	3.32
	Parameter C	1.0000	0.8367	0.4459	0.0684	0.0446	0.0238	0.0187	0.0094
120	Parameter A	231.06	188.15	119.80	18.01	11.12	6.45	4.67	2.71
	Parameter B	285.26	232.28	147.90	22.23	13.73	7.96	5.77	3.35
	Parameter C	1.0000	0.8143	0.5185	0.0779	0.0481	0.0279	0.0202	0.0117
150	Parameter A	215.83	183.53	113.53	17.08	10.50	6.23	4.80	2.67
	Parameter B	266.46	226.58	140.16	21.09	12.96	7.69	5.93	3.30
	Parameter C	1.0000	0.8503	0.5260	0.0791	0.0486	0.0287	0.0222	0.0123
180	Parameter A	200.18	165.92	107.15	16.31	10.23	5.78	4.89	2.22
	Parameter B	247.13	204.84	132.28	20.13	12.63	7.13	6.03	2.74
	Parameter C	1.0000	0.8289	0.5353	0.0815	0.0511	0.0289	0.0244	0.0111
210	Parameter A	180.62	153.67	100.88	15.5	9.78	5.71	4.57	2.29
	Parameter B	222.99	189.72	124.54	19.14	12.07	7.05	5.64	2.83
	Parameter C	1.0000	0.8508	0.5585	0.0858	0.0541	0.0316	0.0253	0.0127

[1)-4)]Refer to the legend in Table 5.

Table 7. Parameter values originated from viscosity of irradiated polished barley sample prepared with an 8% concentration at various rpms

rpm	Parameter	Irradiation dose (kGy)							
		Control[1)]	1	2	3	5	7	10	15
30	Parameter A[2)]	1482.04	631.43	431.37	246.40	132.94	90.87	44.97	11.24
	Parameter B[3)]	2058.39	876.99	599.13	342.22	184.63	126.21	62.46	15.61
	Parameter C[4)]	1.0000	0.4261	0.2911	0.1663	0.0897	0.0613	0.0303	0.0076
60	Parameter A	922.66	419.06	281.64	167.98	88.95	67.45	33.73	7.50
	Parameter B	1281.47	582.03	391.17	233.31	123.54	93.68	46.85	10.42
	Parameter C	1.0000	0.4542	0.3052	0.1821	0.0964	0.0731	0.0366	0.0081
90	Parameter A	740.13	332.57	219.98	136.20	75.56	51.89	29.98	7.50
	Parameter B	1027.96	461.90	305.53	189.17	104.94	72.07	41.63	10.42
	Parameter C	1.0000	0.4493	0.2972	0.1840	0.1021	0.0701	0.0405	0.0101
120	Parameter A	636.99	296.63	190.03	120.85	66.18	46.39	26.23	6.56
	Parameter B	884.71	411.99	263.93	167.85	91.92	64.43	36.43	9.11
	Parameter C	1.0000	0.4657	0.2983	0.1897	0.1039	0.0728	0.0412	0.0103
150	Parameter A	582.66	274.90	170.60	110.65	62.08	40.40	23.23	6.75
	Parameter B	809.25	381.81	236.94	153.68	86.22	56.11	32.26	9.38
	Parameter C	1.0000	0.4718	0.2928	0.1899	0.1065	0.6933	0.0399	0.0116
180	Parameter A	529.51	261.63	163.38	103.23	60.65	38.47	22.49	5.62
	Parameter B	735.43	363.38	226.92	143.37	84.23	53.43	31.23	7.81
	Parameter C	1.0000	0.4941	0.3085	0.1950	0.1145	0.0727	0.0425	0.0106
210	Parameter A	490.13	247.78	151.96	95.36	54.11	35.42	19.81	4.81
	Parameter B	680.74	344.14	211.06	132.44	75.15	49.19	27.51	6.68
	Parameter C	1.0000	0.5055	0.3100	0.1946	0.1103	0.0723	0.0404	0.0098

[1)-4)]Refer to the legend in Table 5.

0.8912 ($y=4486.8e^{-0.7154x}$), 0.9273 ($y=8778.0e^{-0.5055x}$) and 0.9695 ($y=3744.0e^{-0.5429x}$), respectively, at 90 rpm. These results suggest that detection of irradiation for cereals could be possible by viscometric methods.

Table 8. Parameter values originated from viscosity of irradiated polished rice sample prepared with an 8% concentration at various rpms

rpm	Parameter	Irradiation dose (kGy)							
		Control[1)]	1	2	3	5	7	10	15
30	Parameter A[2)]	438.14	263.39	152.63	50.47	25.68	13.59	9.65	4.46
	Parameter B[3)]	471.12	283.22	164.12	54.27	27.61	14.61	10.37	4.79
	Parameter C[4)]	1.0000	0.6012	0.3483	0.1152	0.0586	0.0310	0.0220	0.0102
60	Parameter A	331.77	192.67	110.67	40.09	20.41	11.60	8.16	3.71
	Parameter B	356.74	207.17	119.00	43.11	21.95	12.47	8.77	3.98
	Parameter C	1.0000	0.5807	0.3336	0.1208	0.0615	0.0350	0.0246	0.0112
90	Parameter A	251.90	156.87	93.30	35.62	19.00	9.92	7.17	3.71
	Parameter B	270.86	168.67	100.32	38.30	20.43	10.67	7.71	3.99
	Parameter C	1.0000	0.6227	0.3703	0.1414	0.0754	0.0393	0.0285	0.0147
120	Parameter A	212.44	137.52	83.68	32.51	17.02	8.94	6.49	2.97
	Parameter B	228.43	147.87	89.98	34.96	18.30	9.61	6.98	3.19
	Parameter C	1.0000	0.6473	0.3939	0.1530	0.0801	0.0421	0.0305	0.0139
150	Parameter A	195.90	123.63	77.27	30.06	15.89	8.40	6.23	3.12
	Parameter B	210.65	132.93	83.09	32.32	17.09	9.03	6.69	3.35
	Parameter C	1.0000	0.6311	0.3944	0.1534	0.0811	0.0429	0.0318	0.0159
180	Parameter A	167.07	116.30	70.59	28.94	14.97	8.33	6.06	2.97
	Parameter B	179.65	125.05	75.90	31.12	16.09	8.96	6.52	3.19
	Parameter C	1.0000	0.6961	0.4225	0.1732	0.0896	0.0498	0.0363	0.0178
210	Parameter A	163.31	107.73	67.28	27.47	14.27	7.75	5.83	2.65
	Parameter B	175.60	115.83	72.34	29.53	15.34	8.33	6.27	2.85
	Parameter C	1.0000	0.6597	0.4120	0.1682	0.0873	0.0475	0.0357	0.0162

[1)-4)]Refer to the legend in Table 5.

Table 9. Regression expressions and coefficients of brown rice, Job's-tears, polished barley and polished rice between irradiation dose and viscosity at various rpm

rpm	Brown rice	Job's-tears	Polished barley	Polished rice
30	$y=7487e^{-0.2513x}$ $R^2=0.9152$	$y=6510.8e^{-0.7139x}$ $R^2=0.8770$	$y=17577e^{-0.5323x}$ $R^2=0.9307$	$y=6581.0e^{-0.598.0x}$ $R^2=0.9660$
60	$y=4885e^{-0.2393x}$ $R^2=0.9514$	$y=5321.7e^{-0.7168x}$ $R^2=0.8703$	$y=10947e^{-0.5121x}$ $R^2=0.9429$	$y=4837.8e^{-0.5829x}$ $R^2=0.9708$
90	$y=3996.0e^{-0.2374x}$ $R^2=0.9268$	$y=4486.8e^{-0.7154x}$ $R^2=0.8912$	$y=8778.0e^{-0.5055x}$ $R^2=0.9273$	$y=3744.0e^{-0.5429x}$ $R^2=0.9695$
120	$y=3408.0e^{-0.2338x}$ $R^2=0.9399$	$y=3597.8e^{-0.6864x}$ $R^2=0.8855$	$y=7554.0e^{-0.4998x}$ $R^2=0.9343$	$y=3228.2e^{-0.5312x}$ $R^2=0.9714$
150	$y=3065.0e^{-0.2399x}$ $R^2=0.9343$	$y=3423.9e^{-0.6873x}$ $R^2=0.8835$	$y=6910.0e^{-0.4971x}$ $R^2=0.9287$	$y=2942.4e^{-0.5267x}$ $R^2=0.9714$
180	$y=2842.0e^{-0.2327x}$ $R^2=0.9282$	$y=3131.4e^{-0.6745x}$ $R^2=0.8820$	$y=6280.0e^{-0.4819x}$ $R^2=0.9321$	$y=2614.8e^{-0.5102x}$ $R^2=0.9733$
210	$y=2642.0e^{-0.2328x}$ $R^2=0.9176$	$y=2857.5e^{-0.6634x}$ $R^2=0.8781$	$y=5810.0e^{-0.4859x}$ $R^2=0.9443$	$y=2497.5e^{-0.5118x}$ $R^2=0.9745$

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science and Technology (Research of the Long-and-Mid-term Nuclear R & D Program) for financial support during this study.

REFERENCES

1. Anonymous : Wholesomeness of Irradiated Food. Report of a Joint FAO, IAEA, and WHO Expert Committee. *Technical report series 659*. WHO, Geneva (1981)
2. Diehl, J.F. : *Safety of irradiated foods*. Marcel Dekker, Inc., New York, p.347 (1995)
3. Köksel, H., Celik, S. and Tuncer, T. : Effects of gamma irradiation on durum wheats and spaghetti quality. *Cereal Chem.*, **73**, 506 (1996)
4. Heide, L. and Bögl, K.W. : Detection methods for irradiated food-luminescence and viscosity measurements. *Int. J. Radiat. Biol.*, **57**, 201 (1990)
5. Yang, J.S. : General survey of detection methods for irradiation

foods. *J. Korean Nuclear Society*, **29**, 500 (1997)
6. Hayashi, T., Todoriki, S. and Kohyama, K. : Irradiation effects on pepper starch viscosity. *J. Food Sci.*, **59**, 118 (1994)
7. de Alwis, H.M.G. and Grandison, A.S. : Viscometry as a detection method for electron beam irradiation of black pepper. *Food Control*, **3**, 205 (1992)
8. Bögl, K.W. : Identification of irradiated foods-methods, development and concepts. *Appl. Radiat. Isot.*, **40**, 1203 (1989)
9. Barabasy, S., Sharif, M., Farkas, J., Felföldi, J., Koncz, Á., Formanek, Z. and Kaffka, K. : Attempts to elaborate detection methods for some irradiated food an dry ingredients. In "*Detection methods for irradiated foods*" McMurray, C.H., Stewart, E.M., Gray, R. and Pearce, J. (eds.), The Royal Society of Chemistry, Cambridge, p.185 (1996)
10. Farkas, J., Koncz, A. and Sharif, M.M. : Identification of irradiated dry ingredients on the basis of starch damage. *Radiat. Phys. Chem.*, **35**, 324 (1990)
11. Farkas, J., Sharif, M.M. and Koncz, A. : Detection of some irradiated spices on the basis of radiation induced damage of starch. *Radiat. Phys. Chem.*, **36**, 621 (1990)
12. Hayashi, T., Todoriki, S. and Kohyama, K. : Applicability of viscosity measuring method to the detection of irradiated spices. *Nippon Shokuhin Kogyo Gakkaishi*, **40**, 456 (1993)
13. Hayashi, T., Todoriki, S. and Kohyama, K. : Applicability of viscosity measurement to the detection of irradiated peppers. In "*Detection methods for irradiated foods*" McMurray, C.H., Stewart, E.M., Gray, R. and Pearce, J. (eds.), The Royal Society of Chemistry, Cambridge, p.215 (1996)
14. Hayashi, T. and Todoriki, S. : Detection of irradiated peppers by viscosity measurement at extremely high pH. *Radiat. Phys. Chem.*, **48**, 101 (1996)
15. Hayashi, T. : Collaborative study of viscosity measurement of black and white peppers. In "*Detection methods for irradiated foods*" McMurray, C.H., Stewart, E.M., Gray, R. and Pearce, J. (eds.), The Royal Society of Chemistry, Cambridge, p.229 (1996)
16. Heide, L., Nürnberger, E. and Bögl, K.W. : Investigations on the detection of irradiated food measuring the viscosity of suspended spices and dried vegetables. *Radiat. Phys. Chem.*, **36**, 613 (1990)
17. Schreiber, G.A., Leffke, A., Mager, M., Helle, N. and Bögl, K.W. : Viscosity of alkaline suspensions of ground black and white pepper samples : An indication or an identification of high dose radiation treatment?. *Radiat. Phys. Chem.*, **44**, 467 (1994)
18. Sharif, M.M. and Farkas, J. : Analytical studies into radiation-induced starch damage in black and white pepers. *Radiat. Phys. Chem.*, **42**, 383 (1993)
19. Stephen A.M. : *Food polysaccharides and their applications.* Marcel Dekker, Inc., New York, p.67 (1995)
20. Komiya, T., Yamada, T., Kawakishi, S. and Nara, S. : Effect of linseed oil on the physico-chemical properties of potato and corn starches during gamma-irradiation. *J. Jap. Soc. Starch Sci.*, **29**, 1 (1982)
21. Bhatty, R.S. and Macgregor, A.W. : Gamma irradiation of hulless barley: effect on grain composition, β-glucans and starch. *Cereal Chem.*, **68**, 463 (1988)
22. Kang, I.J., Byun, M.W., Yook, H.S., Bae, C.H., Lee, H.S., Kwon, J.H. and Chung, C.K. : Production of modified starches by gamma irradiation. *Radiat. Phys. Chem.*, **54**, 425 (1999)
23. MacArthur, L.A. and DAppolonia, B.L. : Gamma radiation of wheat. II. Effects of low-dosage radiations on starch properties. *Cereal Chem.*, **61**, 321 (1984)
24. Roushdi, M., Harras, A., El-meligi, A. and Bassim, M. : Effect of high doses of gamma rays on corn grains. *Staerke*, **35**, 15 (1983)
25. Sabularse, V.C., Liuzzo, J.A., Rao, R.M. and Grodner, R.M. : Physicochemical characteristics of brown rice as influenced by gamma irradiation. *J. Food Sci.*, **57**, 143 (1992)
26. Sokhey, A.S. and Hanna, M.A. : Properties of irradiated starches. *Food Structure*, **12**, 397 (1993)
27. AOAC : *Official Methods of Analysis.* 16th ed., Association of Official Analytical Chemists, Washington, DC, p.31 (1995)
28. Hayashi, T. and Kawashima, K. : The effect of gamma irradiation on the sucrose content in sweet potato roots and potato tubers. *Agric. Biol. Chem.*, **46**, 1475 (1982)

(Received February 9, 2000)