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5.4 Treatment of Foods with "Soft-electrons" (Low-energy Electrons)

Toru HAYASHI* and Setsuko TODORIKI**

*Japan International Research Center for Agricultural Sciences (JIRCAS)
(Ohwashu, Tsukuba, Ibaraki, 305-8686 Japan)

**National Food Research Institute (NFRI)
(Kannondai, Tsukuba, Ibaraki, 305-8642 Japan)

Abstract

Electrons with energies of 300 keV or lower were defined as "soft-electrons". Soft-electrons can eradicate microorganisms residing on the surface of grains, pulses, spices, dehydrated vegetables, tea leaves and seeds, and reduce their microbial loads to levels lower than 10 CFU/g with little quality deterioration. Soft-electrons can inactivate insect pests infesting grains and pulses and inhibit sprouting of potatoes.

1. Introduction

Since most of the microorganisms contaminating dry food ingredients such as grains, pulses and spices reside on their surfaces, and some insect pests infesting grains and pulses reside on the surface. Therefore, the inner parts do not have to be exposed to heat, gas or radiation for decontamination or disinfestation. The penetration capacity of an electron beam is controlled by the energy; electrons with lower energies display lower penetration capacities[1]. We have defined low-energy electrons at 300 keV or lower as "soft-electrons". Soft-electrons penetrate only the surface of food, while gamma-rays and electron beams at high energies penetrate foods and UV does not penetrate even the surface (Fig.1). Therefore, the quality changes of food caused by soft-electrons are expected to be much more limited than those caused by gamma-rays or high-energy electron beams with much higher penetration capacities. It is expected that soft-electrons can decontaminate/disinfest dry food ingredients such as grains, pulses and spices with little quality deterioration. We carried out studies on the efficacy of soft-electron treatment of foods and agricultural products for decontamination, disinfestation and sprouting inhibition. We will review our studies on soft-electron treatment of foods.

2. Penetration capacity of soft-electrons

Dry ingredient samples were treated with soft-electrons under rotation to expose all the sample surfaces to electrons with low penetration capacities. A grain rotator was developed which enabled samples to rotate by shaking and vibrating them simultaneously at variable speeds. The rotator was placed under the window of a Van de Graaff electron accelerator (Nissin High Voltage Engineering Co., Ltd., Kyoto, Japan), which generated electrons at acceleration voltages of 170-300 kV. The distance between the window of the electron accelerator and the plastic tray of the grain rotator was 17 cm.

Penetration capacities of soft-electrons at different energies were determined based on depth-dose curves. Several pieces of radiochromic film dosimeter (RCF)(5.94 mg/cm^2, FWT-60-00, Far West Technology Inc., Goleta, California, USA) were stacked together in layers at the bottom of the plastic tray of the grain rotator which was placed under the window of the electron accelerator at a distance of 17 cm, and irradiated with electrons for 60 min at different acceleration voltages of 170 kV – 200kV. Absorbance at 510 nm of all RCF films before and 30 min after irradiation were measured and the dose absorbed by each RCF film was determined according to the method of McLaughlin et al.[2]

Energies of electrons at a distance of 17 cm (air) from the window (50 micron thick titanium) of the electron accelerator were lower than those of the electrons at the window (acceleration voltage). The energies of electrons irradiating samples at 17 cm from the window were estimated to be 60, 75, 90, 100, 130, 160 and 210 keV for acceleration voltages of 170, 180, 190, 200, 225, 250 and 300 kV, respectively, based on the mass stopping power of air and titanium[3,4]. Depth-dose curves of electrons at various energies were developed by plotting all the absorbed doses determined with RCF films[5]. The penetration capacity of electrons at 60 keV was about 6 mg/cm^2 and that at 75 keV was about 10 mg/cm^2, while those at 90 and 100 keV were lower than 17.82 mg/cm^2 (5.94 mg/cm^2 x 3 pieces). Doses absorbed by the first RCF film for 1 h were about 30, 58, 70 and 110 kGy at 60, 75, 90 and 100 keV, respectively[5].

3. Decontamination of food ingredients

3.1 Decontamination of grains

3.1.1 Sterility and viscosity of grains exposed to soft-electrons

Energies of electrons necessary to reduce microbial loads to less than 10 CFU/g were 75 keV for brown rice, 160 keV for rough rice, 75 keV for wheat and 130 keV for buckwheat (Table 1) [6]. The results suggested that most of the contaminating microorganisms resided in the region that the electrons with such low energies could reach. Gamma rays at 7.5-12.5 kGy were necessary to achieve the same levels of sterility.

Table 1 Sterility of grains exposed to low-energy electrons or gamma rays (CFU/g of grains)

	brown rice	rough rice	wheat	buckwheat
Control[a]	$4.1x10^6 \pm 4.6x10^5$	$4.7x10^7 \pm 1.5x10^7$	$2.7x10^4 \pm 1.2x10^4$	$1.4x10^6 \pm 6.8x10^5$
75keV, 8 μA, 10min	$5.1x10^2 \pm 2.1x10^2$	-----[b]	$1.2x10^3 \pm 8.3x10^2$	-----
75keV, 8 μA, 40min	<10	-----	<10	-----
100keV, 14 μA, 5min	$1.2x10^3 \pm 5.6x10^2$	$5.8x10^5 \pm 7.0x10^4$	$3.1x10^2 \pm 2.1x10^2$	$1.4x10^3 \pm 9.2x10^2$
100keV, 14 μA, 20min	<10	$6.3x10^3 \pm 1.3x10^3$	<10	$3.3x10^2 \pm 3.6x10^2$
130keV, 22 μA, 1min	$2.5x10^3 \pm 1.6x10^3$	$1.6x10^5 \pm 3.8x10^4$	$2.9x10^3 \pm 1.8x10^3$	$1.8x10^3 \pm 9.0x10^2$
130keV, 22 μA, 6min	<10	<100	<10	<10
160keV, 40 μA, 0.5min	$7.4x10^2 \pm 1.8x10^2$	$1.3x10^5 \pm 4.5x10^4$	$2.0x10^3 \pm 8.9x10^2$	$9.7x10^2 \pm 8.0x10^2$
160keV, 40 μA, 3min	<10	<10	<10	<10
gamma ray, 2.5 kGy	$2.2x10^4 \pm 3.6x10^3$	$3.2x10^5 \pm 4.2x10^4$	$2.5x10^4 4 \pm .7x10^3$	$2.0x10^3 \pm 1.2x10^3$
gamma ray, 5.0 kGy	$3.3x10^3 \pm 1.6x10^3$	$8.4x10^4 \pm 3.8x10^4$	$4.6x10^3 \pm 1.4x10^3$	<100
gamma ray, 7.5 kGy	$5.8x10^2 \pm 1.9x10^2$	$7.4x10^3 \pm 3.2x10^3$	$7.5x10^2 \pm 6.3x10^1$	<10
gamma ray, 10.0 kGy	<10	$6.3x10^2 \pm 3.2x10^2$	<10	<10
gamma ray, 12.5 kGy	<10	<100	<10	<10

a ; untreated sample
b ; data not obtained
(HAYASHI, T. et al., 1997) [6]

Viscosity of heat-gelatinized grain suspensions decreased with the energy of electrons (Table 2) [6]. Viscosity of brown rice and wheat treated with electrons at 75 keV was almost the same as that of untreated samples. Viscosity of rough rice and buckwheat exposed to electrons at 130 keV was slightly lower than that of untreated samples, but much higher than that of the samples irradiated with gamma rays at 10 kGy. The viscosity values of a grain suspension which was heat-gelatinized under an alkaline condition is a parameter for starch degradation[7,8]. The results suggested that electrons with minimum energy for decontamination did not degrade starch molecules inside the grains.

Table 2. Viscosity of 7.5% aqueous suspensions of grains exposed to low-energy electrons or gamma rays (mPa.s)

	Brown rice	Rough rice	Wheat	Buckwheat
Control[d]	211.1 ± 12.5^{c}	149.5 ± 7.7^{c}	287.4 ± 18.2^{bc}	211.3 ± 21.6^{c}
75keV, 8μ_A, 40min	206.0 ± 3.5^{c}	-----[e]	293.6 ± 12.5^{bc}	-----
100keV, 14μA, 20min	185.9 ± 8.6^{ac}	147.3 ± 8.9^{c}	246.6 ± 10.8^{ac}	199.9 ± 25.4^{c}
130keV, 22μA, 6min	146.7 ± 11.9^{ab}	137.3 ± 7.3^{c}	206.4 ± 3.5^{ab}	192.5 ± 6.4^{c}
160keV, 40μA, 3min	136.2 ± 4.6^{abc}	133.4 ± 4.8^{ac}	192.8 ± 8.0^{abc}	165.6 ± 7.5^{abc}
210keV, 40μA, 3min	88.5 ± 3.0^{abc}	105.5 ± 6.8^{ab}	133.6 ± 3.6^{abc}	108.7 ± 0.9^{abc}
Gamma-rays, 0.1kGy	198.4 ± 4.1^{c}	138.3 ± 5.6^{c}	246.5 ± 3.4^{ac}	189.6 ± 12.2^{c}
Gamma-rays, 0.5kGy	160.8 ± 8.3^{ab}	117.9 ± 5.5^{ab}	211.3 ± 4.7^{ab}	143.2 ± 8.3^{ab}
Gamma-rays, 10.0kGy	21.1 ± 1.0^{abc}	31.9 ± 4.9^{abc}	34.6 ± 1.7^{abc}	26.8 ± 4.6^{abc}

a, significantly different from Control ($p<0.05$)
b; significantly different from samples irradiated at 0.1 kGy with gamma-rays ($p<0.05$)
c; significantly different from samples irradiated at 0.5 kGy with gamma-rays ($p<0.05$)
d; untreated sample
e; data not obtained
(HAYASHI et al., 1997) [6)]

The applicability of soft-electrons to wheat depended upon the variety of wheat. Soft-electrons could decontaminate wheat grains of Australian Standard White (ASW), Shirogane and Western White (WW) varieties, but could not decontaminate those of Dark Nórthern Spring (DNS), Norin No. 61 and No. 1 Canadian White (1CW) varieties[9)]. No relationship was observed between the application of soft-electrons and the sensitivity of the contaminating microorganisms to gamma-rays. The difference in the application of soft-electrons was ascribed to the structure of the wheat grain. In varieties such as DNS, Norin No. 61 and 1CW, microorganisms would reside in areas which soft-electrons did not reach.

3.1.2 Quality of milled rice prepared from brown rice treated with soft-electron

Both Koshihikari and Nihonbare could be decontaminated with soft-electrons even at 60 keV[5)]. No significant difference in the viscosity was observed at any milling yield between the control and the rice grains exposed to electrons at 60-90 keV. Milling reduced the effect of electrons on the viscosity; milling of rice grains at a yield of 88% did not result in a significant difference in the viscosity between untreated samples and 100 keV-electron treated samples[5)]. However, milling did not affect the viscosity of rice irradiated with gamma-rays. The results suggested that soft-electrons degraded starch molecules near the surface of rice grains, which could be removed easily by milling. On the contrary, gamma-rays degraded all the starch molecules in rice grains most of which could not be removed by milling[5)].

TABLE 3 TBA values of rice which were exposed to low-energy electrons or gamma rays followed by milling (nmol/g of rice)

treatment	milling yield			
	100%[b]	92%[b]	90%[b]	88%[b]
control [a]	17.69±1.55	4.95±0.38	4.75±0.69	4.23±0.81
60keV, 4μA, 45min	29.68±2.66[c]	7.98±0.20[c]	5.18±0.70	4.75±0.57
75keV, 8μA, 30min	34.21±0.49[c]	9.05±0.83[c]	8.37±0.80[c]	5.43±0.77
90keV, 10μA, 25min	41.45±0.90[c]	15.55±3.96[c]	9.47±0.71[c]	9.43±0.93[c]
100keV, 14μA, 15min	57.66±2.47[c]	19.74±0.67[c]	14.33±0.28[c]	13.70±0.74[c]
gamma-ray, 7.5kGy	60.59±5.64[c]	46.59±3.96[c]	43.83±3.08[c]	43.23±4.70[c]

[a] untreated sample
[b] n=3 ; mean standard deviation
[c] significantly different from control ($p<0.05$)
(HAYASHI et al., 1998) [5]

Thiobarbituric acid (TBA) value is a parameter of lipid oxidation. TBA value of brown rice increased with the energy of electrons. TBA values of brown rice samples exposed to electrons at 60-100 keV were significantly higher than that of untreated control (Table 3) [5]. The use of gamma rays at 7.5 kGy resulted in a higher TBA value than that of electrons with energies of 60-100 keV. Milling decreased the TBA values of all the samples, especially those of electron-treated samples. Accordingly, the differences in the TBA values between the control and the electron-treated rice grains decreased markedly after milling. The difference in the TBA values between the control and the rice samples exposed to electrons at 60 keV was not significant at a milling yield of 90% or lower, and the difference between the values of the control and the rice samples exposed to electrons at 75 keV was not significant at a milling yield of 88%. The results suggested that most of the lipids oxidized by electrons at 60 and 75 keV were removed by milling at yields of 90 and 88%, respectively.

Hardness and stickiness under low and high compressions of cooked rice grains (90% milling yield) exposed to electrons at 60-75keV were almost the same as those of the control[5]. Hardness and stickiness under low and high compressions of gamma-irradiated samples were lower than those of the control. Hardness and stickiness under low compression are parameters for rheological properties of the surface of cooked rice grains, and those under high compression are parameters for the properties of overall cooked rice grains[10]. The results showed that rice grains which were exposed to electrons at 60-75 keV and milled at a yield of 90% displayed the same rheological properties as the control. The results indicate that milling at yields of 88-90% removed the portion of rice exposed to electrons at 60 keV which could eradicate most of the microorganisms contaminating brown rice.

3.2 Decontamination of other ingredients

Green tea leaves were exposed to electrons at 100keV reduced the microbial load to undetectable levels without affecting the color and aroma to an extent to reduce the commercial value[11].

Soft-electrons at 100 keV reduced the microbial loads of shredded dehydrated vegetables to levels lower than 10 CFU/g, although the time necessary for electron treatment was different[9]. Longer duration of electron treatment was necessary for dehydrated vegetable samples which required a higher dose of gamma-rays for disinfection. The microorganisms contaminating dehydrated vegetables showed the same resistance to soft-electrons as to gamma-rays. Black pepper could be decontaminated with electrons at 210 keV, while white pepper, basil and coriander could be decontaminated at 100 keV. Pulses such as soybean, adzuki bean and black soybean could be decontaminated with electrons at 60 keV[12].

4. Decontamination of Seeds

Electrons at 60-75keV reduced microbial counts of seeds of radish (Kaiware-daikon) and alfalfa to undetectable levels without any detrimental effects on the germination ability[13]. However, electrons at 90keV or higher lowered the germination percentage of radish sprout seeds and electrons at 100keV lowered that of alfalfa seeds. Soft-electrons could decontaminate seeds of mungbean without detrimental effect on germination[14].

5. Inhibition of Sprouting

Initiation of sprouting of potatoes was retarded by the treatment with electrons at 160keV, and the sprouting was inhibited by electrons at 250 keV or higher[14]. However, the tubers treated with electrons at 100 keV started to sprout at the same time as the untreated samples.

6. Control of insect pests

Soft-electrons with doses of 65 keV or higher at low doses inactivated eggs, pupae, larvae of red flour beetle and Indian meal moth, and adults of these insects could be inactivated by the treatment at higher doses[15].

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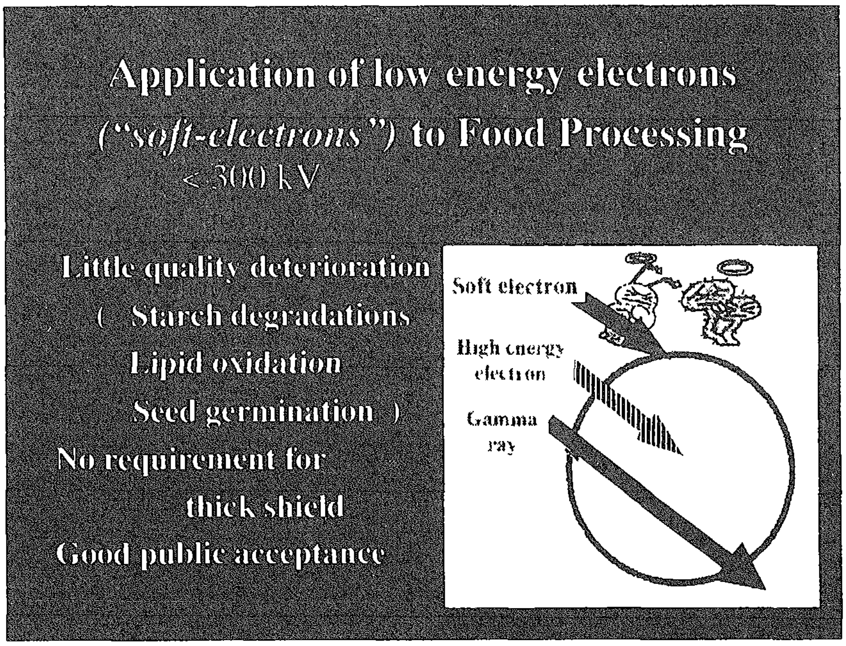

Fig.1 Penetration and advantage of soft-electron