Effect of High Electric Fields on Some Fruits and Vegetables

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To investigate the effect of electric fields on the postharvest life of some fruits and vegetables, they were exposed to an alternating current high electric field (HEF) for short periods. The high electric field (430 kV/m) treatment on pears, plums and bananas in the preclimacteric period suppressed the respiration rate during the climacteric period. Similarly, a little effect on the respiration rate was also observed in the apples treated by HEF in a postclimacteric period. Physico-chemical properties (i.e., °Brix, pH, hardness and Hunter 'Lab' values) of the bananas 17 days after the HEF treatment indicated that HEF treatment retarded ripening (1.5~2 days) as compared to the control. It was found that the exposure of HEF (0.5~3.0 hr) on green sweet peppers elongated its freshness/greenness Respiration and also reduced the percentage of fresh weight loss as compared to the control.

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Introduction

The effect of high electric field (HEF) on post-harvest physiology of fruits and vegetables is a new area of investigation. Asakawa¹⁾ performed pioneering work on the evaporation of water under the influence of alternating electric fields. Respiration rates in lettuce and spinach were reduced by the treatment with electric fields and its effect is directly proportional to the voltage and the time of exposure²⁾. Some researchers have demonstrated the effect of electric fields on microorganisms^{4), 5), 7)}, germination of rice plant seeds⁸⁾ and disinfection of plant seeds⁹⁾. Electric current applied to bottle gourd seeds prior to sowing affected plant growth, sex expression and yields¹¹⁾. It has been shown previously that a plant grown in an electrostatic field of sufficient magnitude has a reduced ability to grow as compared with the control¹²⁾. Further, Sidaway¹³⁾ showed the differences of plant response towards the negative and positive signs of electrostatic fields.

Animals and plants have electric fields, which seem to be a vital part of their physiology¹⁴⁾. The internal electric fields of plants and animals may be affected by externally applied electric fields. The effect of HEF to preserve fruits and vegetables in a fresh state due to the activation of water has been described¹⁵⁾. A few reports are available about the effect of HEF on the preservation of fruits and vegetables, but reproducibility of results has not yet been ascertained. Keeping this in mind, the present experiment was conducted to learn the effect of external electric fields on some fruits and vegetables.

Materials and Methods

Materials

'Fuji' apple (*Malus domestica* Borkh.), 'Nijisseiki' Japanese pear (*Pyrus pyrifolia* Nakai var. *culta* Nakai), 'Karari' plum (*Prunus salicina* Lidl.), banana (*Musa* AAA cv. Cavendish sub-group) and sweet pepper (*Capsicum annuum* L.) were procured from the farmers and the local market. Experi-

ments on apples and plums were performed in July whereas the experiments on pear, sweet peppers and bananas were performed in August, October and November, respectively. Apples were treated by HEF in a post-climacteric period. Plums, pears and bananas were treated in a pre-climacteric period. Green bananas (Without ethylene treatment) were used for the experiment. The weights of apples, pears, plums and bananas (from single hand) for each sample group were approx. 650 g ($n=3$), 700 g ($n=3$), 380 g ($n=25$) and 650 g ($n=5$), respectively. Three hundred grams ($n=8$) of mature green sweet pepper was sorted for each sample group.

The samples were treated by the alternating HEF as shown below :

Fig. 1 Schematic diagram of the alternating current electric field generator.

The components of the electric field generating device were provided from the electric parts manufacturers and was set up in the laboratory. The voltage input into a step-up transformer (3) (Taiyo Electric Co. Ltd., Osaka ; output : 15 kV, 20 mA) was regulated by a voltage regulator (2) via a safety fuse (1) (15 A, 250 V). The output terminals from the transformer were connected to the Cu wire (4) ($\phi 1 \text{ mm} \times 20 \text{ mm}$) and the Cu plate (6) ($300 \text{ mm} \times 200 \text{ mm}$). For HEF treatment, samples (except green sweet peppers) were kept on Cu plate (6) and alternating HEF was applied for 5 or 20 min. The voltage was slowly increased (to eliminate sparking) by a voltage input regulator (2) until a voltmeter (8) showed 8.6 kV at the fixed head distance (5) of 20 mm (430 KV/m).

In the case of green sweet pepper, the HEF was applied, as in the previous case, in a sealed polyethylene (PE) bag ($200 \times 220 \text{ mm}$, 0.05 mm thickness). The sealed bag was pierced by Cu wire (4) and made it airtight to reduce moisture loss during the treatment. After the HEF was applied for 0.5 to

3.0 hr the electric source was cut off and the hole made by the Cu wire was immediately sealed. The whole experiment was conducted at 25°C and 35% relative humidity.

Respiration rate

The sample was kept in a desiccator (glass) fitted with a rubber stopper on the lid for sampling. A magnetic stirrer was placed in the desiccator to enable perfect sampling of the gases produced by fruits after an interval of two hours. A gaseous sample (1.0 mL) was drawn and directly injected into a gas chromatograph (Shimadzu, GC-8A) containing a $\phi 3 \text{ mm} \times 5 \text{ m}$ stainless steel column packed with silica gel 60/80. A flow rate of carrier gas (N_2) flow was maintained at 45 mL/min and injection/detection and column temperatures were fixed at 150°C and 80°C , respectively. Carbon dioxide gas was detected by using a thermal conductivity detector attached with the gas chromatograph. Head space volume of the sample in a desiccator was calculated as a total inside volume of desiccator minus the volume of the sample.

pH, °Brix, surface color and hardness

The middle portion of each banana was taken, pulped, and a 25 g sample of the pulp was dissolved in water to make 100 mL of solution. The pH and °Brix of the solution was measured, and the °Brix was multiplied by four to find the actual values. Surface color was recorded at different sites of each fruit using a Color and Color Difference meter (Tokyo Denshoku Co., Ltd. TC 3600 U). Hardness was determined by a Universal Hardness meter (cone type).

Results and Discussion

The high electric field was applied to the sample as shown in Fig. 1. External electric fields induced the electric fields inside the fruits and vegetables (unpublished). Before HEF treatment, the initial respiration rate of the apples, pears, and plums was measured. Then, the samples were exposed to the HEF for either 5 or 20 min. The HEF caused a decrease in the respiration rate of the pears, plums and bananas (Fig. 2). Since apples in a post-climacteric period were used for the experiment, there

was a little difference in respiration rates between the control and the treated samples. The climacteric peaks of the treated and non-treated samples were determined at the same time, irrespective of the treatment periods of the plums, pears and bananas. However, the time to reach the climacteric peak differed among the various fruits after the HEF treatment. In addition to the respiration rate, the ethylene production rate was also measured in the apples and bananas. No difference in the ethylene production rate was observed between the treated and control samples (data not shown). The respiration rate in lettuce and spinach is depressed by the exposure of the HEF (3~20 min at 15kV, 30~50mm head)³⁾. A plant grown in an electrostatic field of sufficient magnitude has a reduced ability to grow as compared with the control¹⁰⁾. It is well known that a lower respiration rate indicates lower overall metabolic processes occurring in the plant or its parts.

No visible differences were observed in the apples, pears and plums during postclimacteric storage. However, in the case of bananas 17 days after the HEF treatment, the degree of ripeness of the control was more advanced than the treated samples (Table 1). The °Brix, pH, hardness and Hunter 'Lab' values of the treated samples were compared with those of the controls. The higher the level of total soluble solid (°Brix), the hardness and lower Hunter L, a, b values indicate a comparatively less degree of ripening. The control had 20 °Brix in contrast to 18.8~19.2° Brix in the 5 or 20 min HEF treated samples. The pH value did not change very much during the ripening of the bananas, however, a little difference was observed between the treated and non-treated samples. The texture of the treated samples was firmer than the control. The Hunter L, a, b values of treated samples were lower than the control. Overall physico-chemical analyses indicated that the HEF treatment delayed the nor-

Fig. 2 Effect of the alternating current high electric field (430kV/m) treatment on respiration rate of some fruits at 25°C.

—○— : Control, —▲— : 5 min, —■— : 20 min.

Table 1 Effect of the alternathing current high electric fields (430kV/m) treatment on physico-chemical properties of bananas.

	°Brix	pH	Hardness* (kg/cm ²)	Hunter color values*		
				L	a	b
Initial	4.0	5.47	2.6±0.3	48.8±0.7	-12.9±0.4	21.1±0.3
Control (17 days)	20.0	5.90	0.7±0.1	58.7±1.5	1.2±1.0	28.1±0.6
5 min (17 days)	18.8	5.78	0.8±0.1	56.0±0.9	0.3±1.0	26.7±0.5
20min (17 days)	19.2	5.61	1.0±0.1	55.8±1.1	0.1±0.7	27.5±0.7

* Mean±SE of 5 samples

mal ripening of bananas by 1.5~2 days. The respiration rate is reduced in lettuce and spinach³⁾ which may be due to the activation of water by the HEF¹⁵⁾.

Weight loss of the apples, pears, plums, bananas and sweet peppers were measured after HEF treatment, but no difference was found between the control and the treated samples (data not shown). However, it is reported that an altern-ating HEF caused a depression in evaporation of water¹⁵⁾ and reduced the weight loss from the leafy vegetables³⁾.

Because the evaporation rate was very high under the alternating HEF treatment^{1), 6)} the green sweet peppers were sealed in polyethylene (PE) bag to control excessive weight loss. A preliminary experiment showed that a 20min electric field treatment of green sweet pepper caused an insignificant effect. Therefore, in this experiment the treatment time was increased. Fresh weight losses of samples before and after opening the PE package were measured (Fig. 3). There was no difference in weight loss in green sweet peppers before opening the PE package, but after opening the PE package weight losses from the treated samples were lower than that of the control. No significant difference was found in 0.5, 1.5 and 3.0 hr treated samples. However, the longer the treatment time, the smaller was the weight loss. Tanaka¹⁵⁾ reported that HEF form a cluster of water molecules as a result of which the weight loss of the samples may be reduced.

By visual observation, it was noted that on the 28th day after treatment the surface color of the treated samples remained greenish while the control samples turned yellowish. Then, PE package

Fig. 3 Effect of the alternating current electric field (430kV/m) treatment on the weight loss of sweet pepper. Arrow indicates the day of PE package opening.

□ : Control (unpacked), ▤ : Control (PE packed),
 ▨ : 0.5 hr (PE packed), ▩ : 1.5 hr (PE packed),
 ▦ : 3.0 hr (PE packed).

was opened and surface color was measured by Hunter 'a' value(+ red, - green) (Fig. 4). Toda³⁾ reported that HEF influenced the shelf life freshness of some fruits and vegetables. On day 28, there was quite a difference in color between the control (both packed and unpacked), and the treated samples, but no significant difference was found among the treated (0.5~3.0 hr) samples. The green coloration was also observed by Blackman²⁾ during a short period exposure to an electric field. Lemberg¹⁰⁾ has shown that a typical porphyrin ring

Fig. 4 Effect of the alternating current electric field (430kV/m) treatment on the average Hunter 'a' value of sweet pepper. Arrow indicates the day of PE package opening.

--○--: Control (unpacked). —○—: Control (PE packed),
 —▲—: 0.5 hr (PE packed), —■—: 1.5 hr (PE packed),
 —▼—: 3.0 hr (PE packed).

can be opened (by oxidation) in the α -position resulting in the formation of a deep-green pigmented porphyrin. Both the weight loss and the red color development (Fig. 3 and Fig. 4) of the unpacked samples were considerably faster than the PE packed samples.

Based on the above results, it can be concluded that alternating current HEF treatment during preclimacteric period suppresses the respiration rate of some fruits, e. g. , pears, plums and bananas. The HEF treatment on apples after the climacteric period also showed a small effect on the respiration rate. However, the ethylene production rate in apples and bananas was not affected by the HEF. Ripening of the mature green bananas and sweet peppers was delayed by the exposure of HEF. No difference in fresh weight loss was found except in sweet peppers. The weight loss of the control was higher than the treated samples after opening the PE packages 28 days after HEF exposure. It shows that alternating HEF treatment for short periods

on some fruits and vegetables suppresses, at least to the lesser extent, physiological changes occurring during maturation and ripening. Therefore, the exposure of the alternating HEF on some fruits and vegetables may be beneficial to elongate their shelf life. Although the effects of HEF on plants and microorganisms have been studied by various authors^{4), 5), 7)~15)}, the detailed mechanism of how this process actually works is still unknown. Before applying the alternating HEF on fruits and vegetables for practical purposes, it is necessary to further study the extent of the effect it has at the various stages of maturity of those fruits and vegetables.

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収穫後の果実、野菜に対する高圧電場の影響

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収穫後の果実、野菜の貯蔵に対する電場処理の影響を検討するために、60Hzの交流高圧電場(HEF)で、数種の青果物を短時間処理した。HEF処理はクライマクテリック前のナシ、スモモ、バナナに対してクライマクテリックピーク時の呼吸量を減少させた。またクライマクテリック後のリンゴ果実に対しても呼吸の抑制効果が認められた。バナナの物理化学的性質(ブリックス、pH、硬度、ハンターLab値)の大部分はHEF処理区の方が対照区と比べて追熟を遅らせ、外観から判断すると約2日間黄化を抑制することを示した。さらにピーマンを密封し、HEF処理後、25℃で28日間貯蔵すると無処理区は赤色が出てきたのに対して処理区はいずれも緑色のままであった。またハンターa値も両者で明らかに有意差があり、測定後さらに開封のまま赤色になるまでおくと新鮮物重の減少割合を抑えることから、ピーマンの鮮度を長く維持できることが見出された。

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