Effects of ultraviolet C, controlled atmosphere, and ultrasound pretreatment on free ferulic acid in canned sweet corn kernels

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Abstract Because canned sweet corn kernel (CSCK) products are subject to high market competitiveness, producing them with a higher content of free ferulic acid (FFA), a functional ingredient, using non-thermal and green technologies may be an alternative solution for Thai exporters. This study aimed to investigate the effects of pre-canning ultraviolet C (UVC), controlled atmosphere (CA), and ultrasound treatments on the FFA content, texture, and colour of CSCKs. UVC irradiation (0, 1.94 and 4.01 kJ/m²) was tested in combination with storing corn under CA at %O₂:%CO₂:%N₂ ratios of 21:0.03:78, 3:10:87, and 3:15:82 before canning. Based on the FFA content, two UVC–CA pretreatments were selected for the ensuing experiment. The effects of the selected UVC–CAs in combination with 0, 10, or 20 min of 35 kHz ultrasound before canning were measured. The FFA content, moisture, texture, and colour of the CSCKs treated with the nine UVC–CA combinations were not significantly different. Corn irradiated with 1.94 kJ/m² UVC and stored under 3:15:82 %O₂:%CO₂:%N₂ before canning exhibited the highest FFA content, followed by corn treated with no UVC and stored at 3:15:82 %O₂:%CO₂:%N₂. Corn treated with ultrasound combined with the two selected UVC–CA treatments showed no differences in FFA content, moisture, texture, or colour. Corn kernels treated with UVC–

CA–ultrasound had a higher FFA content than untreated kernels. UVC–CA–ultrasound pretreatment showed a trend of increasing CSCK FFA content with no change in physical properties. Thus, UVC–CA–ultrasound pretreatment appears to be an alternative process that might add value to CSCKs by increasing FFA content.

Keywords Ferulic acid · Sweet corn · Ultraviolet C · Controlled atmosphere · Ultrasound

Introduction

Ferulic acid, or 4-hydroxy-3-methoxycinnamic acid, exerts an antioxidant effect in diseases such as cancer, diabetes, cardiovascular disease, and degenerative neurological conditions. (Zhao and Moghadasian 2008). Srinivasan et al. (2007) reported that ferulic acid has anti-inflammatory, anti-diabetic, anti-aging, anticancer, antiapoptotic, hepatoprotective, neuroprotective, pulmonary protective, hypotensive, anti-atherogenic, and radioprotective effects. Ferulic acid is a phenolic acid that is commonly found in cell walls of Gramineae plants in an ester form (Lozovaya et al. 2000) and is cross-linked with polysaccharides or proteins (Ou and Kwok 2004). Through analyses of corn, wheat, oat, and rice, Adom and Liu (2002) found that corn contained the greatest amount of ferulic acid and that more than 98% was in a bound form. Moreover, thermal processing and enzyme and alkaline digestion assisted in releasing free ferulic acid (FFA) from plant cell walls. FFA is a good antioxidant scavenger of nitrogen dioxide, superoxide, hydroxyl radicals and free radicals of nitrogen dioxide (Ou and Kwok 2004). Saulnier et al. (2001) reported that maize bran heated at 160 °C did not contain FFA, whereas FFA was detected upon heating above

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180 °C. This finding is similar to results reported by Dewanto et al. (2002), who found that thermally processed corn had an increased FFA content and decreased bound ferulic acid content compared to raw corn. In Parmar et al. (2016), reported a reduction in ferulic acid contents in canned kidney beans, filed peas and chickpeas. Parmar et al. (2017) found that 11 varieties of freeze-dried kidney beans showed non-significant differences in ferulic acid. The use of feruloyl esterase to release ferulic acid from cell walls of plants is not practical due to the high cost of enzyme production and the time-consuming nature of bacterial digestion of bound ferulic acid. Mild alkaline digestion with sodium hydroxide at 50–70 °C is a more rapid alternative (Ghatak and Panchal 2010).

However, emerging techniques for preserving and increasing active substances in food without heating (non-thermal processes), including high-pressure processing, pulsed electric field treatment, ultrasound/sonication, ozone utilization, and ultraviolet radiation of fruits and vegetables, have been increasingly studied. Recently, there have been some reports on the positive and negative effects on the functional ingredients of fruits and vegetables after treatment with ultraviolet C (UVC) at 100–280 nm. UV significantly increases the total phenolic contents and flavonoid content of broccoli (Costa et al. 2006), free phenolic contents of banana (Pongprasert et al. 2009), and ferulic acid contents of roasted peanuts (Sales and Resurreccion 2010). The contents of phenolic compounds in tomato fruits show no difference between samples irradiated without UVC or with 2 kJ/m² UVC or between samples irradiated with 4 or 8 kJ/m². However, the contents of the phenolic compounds, such as gallic acid, chlorogenic acid, syringic acid, *p*-coumaric acid, and quercetin, in samples receiving no UVC irradiation are significantly different than those in samples irradiated with 4 kJ/m² (Liu et al. 2012). By contrast, UVC decreases phenolic contents in strawberry (Pan et al. 2004). Lemoine et al. (2010) found that hot air with UV reduced yellow colour formation and decreased the loss of chlorophyll in fresh-cut broccoli but increased phenolic contents and antioxidant activity during storage. In the same year, Rodov et al. (2010) reported that flavonol levels increased in peeled onion irradiated with low-intensity (1.2 kJ/m²) and medium-intensity UV (6.0 kJ/m²) but that decreases were observed upon exposure to high intensity UV (12 kJ/m²). Additionally, there are many reports of storage conditions affecting the functional contents of fruits and vegetables. Decreases in polyphenolic content are inhibited in mango stored under 3%O₂ + 10%CO₂ + 87%N₂ compared to that in mango stored in normal air (Kim et al. 2007). Jaramillo et al. (2007) found that the derivatives of ferulic acid increased in white asparagus stored under aerobic rather than anaerobic conditions. Fresh asparagus stored at 25 °C for

2 days exhibits a phenolic content two times greater than that of asparagus stored at 4 °C. Total flavonols were found to increase by 58%, and anthocyanin increased by 39% in sheet-sliced onions kept in the dark at 1–2 °C for 16 days (Pérez-Gregorio et al. 2010). Htwe et al. (2010) found that storing Homnil rice and Red Hommali rice under atmospheres with 0, 5, and 10% oxygen maintained the anthocyanin content. By using a combination of UVC and controlled atmosphere (CA) storage, the firmness of shiitake mushrooms irradiated with UVC, stored in a modified atmosphere package for 15 days at 1 °C with 95% relative humidity, and then stored at 20 °C for 3 days was maintained. Increases in flavonoid, ascorbic acid, H₂O₂ and superoxide anion contents were observed by Jiang et al. (2010). Ultrasound is a new commercially effective extraction process used in the food industry to increase the yield of extracted components, increase extraction rates, and reduce extraction time (Vilkhu et al. 2008; Chemat and Zill-e-Huma 2011). This technique is defined as a “green and innovative” technology.

Sweet corn is an economic crop of Thailand. Seventy-five percent of the total sweet corn output is processed into canned sweet corn. In 2014, the export volume increased 19% compared with that in 2013, and the export value increased by 15% in US dollars (Thai Processors' Association 2015). The corn industry is likely to expand further, as The Office of Industrial Economics (2016) reported that the export value of canned sweet corn in 2016 had increased by 20.1% from that in 2015. Demand for canned sweet corn remains high in the EU market, and the production and export demand of sweet corn from Thailand is increasing every year, especially to Asian countries, including Japan, Taiwan, and Korea. However, competitiveness in the global market tends to increase. Thai exporters have faced problems such as anti-dumping measures, increased tax rates, and baht appreciation. To enhance the market competitiveness of canned sweet corn kernel products, producing these products with greater contents of health-beneficial ingredients, such as FFA, may be an alternative strategy. Because there is no research on the use of UVC irradiation, CA conditions, and ultrasound waves for pretreatment in sweet corn kernel canning, this study aimed to investigate their effects on the FFA content, texture, and colour of canned sweet corn kernels. The results provide new knowledge that may help the sweet corn industry to add value to their products via these non-thermal and green technologies.

Materials and methods

Fresh sweet corn

The fresh sweet corn (*Zea mays* var. *saccharata*) cultivar Insee 2, harvested at 68–70 days after planting, was purchased from the National Corn and Sorghum Research Center, Pak Chong District, Nakhon Ratchasima Province and transported in a foam box to the Institute of Food Research and Product Development, Kasetsart University, Bangkok within 24 h. The fresh sweet corn was stored in a refrigerator at 6 °C for 4 h upon arrival.

Effects of ultraviolet C and controlled atmospheric conditions

Sweet corn preparation and treatment

After removing the peel and silk, the sweet corn was irradiated with a UVC lamp (Sylvania G 40 W, Japan) at intensities of 0, 1.94 and 4.01 kJ/m² (coded V1, V2, and V3) for 6 min and was then stored under CA conditions with %oxygen:%carbon dioxide:%nitrogen ratios of 21:0.03:78 (normal air), 3:10:87, and 3:15:82 (coded C1, C2, and C3, respectively) at 6 °C for 20 h before canning. The nine pretreatments were as follows: 0 kJ/m² UVC + normal air (V1C1), 0 kJ/m² UVC + 3%O₂:10%-CO₂:87%N₂ (V1C2), 0 kJ/m² UVC + 3%O₂:15%-CO₂:82%N₂ (V1C3), 1.94 kJ/m² UVC + normal air (V2C1), 1.94 kJ/m² UVC + 3%O₂:10%CO₂:87%N₂ (V2C2), 1.94 kJ/m² UVC + 3%O₂:15%CO₂:82%N₂ (V2C3), 4.01 kJ/m² UVC + normal air (V3C1), 4.01 kJ/m² UVC + 3%O₂:10%CO₂:87%N₂ (V3C2), and 4.01 kJ/m² UVC + 3%O₂:15%CO₂:82%N₂ (V3C3).

Canning

After separating the sweet corn kernels from the cob, 110 g of sweet corn kernels was added to 307 × 111 cans, followed by the addition of 60 g of drinking water, and the cans were then sterilized at 121 °C for 12 min. This sterilization time was selected based on a preliminary test to check that no *Clostridium botulinum* was found in the cans of sweet corn kernels.

Analysis of canned sweet corn qualities

1 month after canning, three cans of sweet corn kernels from each treatment were mixed together and analysed as follows.

Ferulic acid analysis (modified from Buranov and Mazza 2009) A 5 g of canned sweet corn kernels was blended with 30 ml of 0.5 M sodium hydroxide using an Ultra-Turrax® T25 basic homogenizer with a S25 N probe (IKA®-Werke, Germany) at a speed of 6500 rpm for 1 min. The mixture was then heated in a 50 °C water bath (Heto SBD 50, Denmark) with shaking stroke of 170 for 4 h. After the mixture cooled, it was neutralized with concentrated hydrochloric acid (Merck, Germany), and had 90 ml of 95% ethanol was added to precipitate hemicelluloses and glucomannan. The mixture was next centrifuged at 4500 rpm for 5 min with a 1617 rotor (Universal 32, Hettich, Germany). The supernatant was evaporated in a Büchi Syncore® Analyst (Switzerland) at 45 °C until approximately 1 ml of liquid remained, following by adjustment with AR-grade pure ethanol (Merck, Germany) in a 10 ml volumetric flask. The sample solution was subsequently filtered through a nylon membrane filter, 0.45 µm pore size. FFA content was analyzed by HPLC (Agilent 1100, USA) with a UV detector at 254 nm and an ACE®5 C18 column (Scotland; 5 µm and 150 × 4.6 mm) at room temperature using HPLC-grade acetonitrile (J.T. Baker, USA) and 0.1% formic acid (Merck, Germany) at 20:80 (v/v), filtered through a 0.2 µm nylon membrane filter as a mobile phase in an isocratic system with a 1 ml/min flow rate. One-microliter samples were injected. FFA was calculated from a standard curve of 99% standard ferulic acid (Sigma-Aldrich, USA).

Moisture (AOAC 2005) Two-gram canned sweet corn kernels were determined for moisture content using hot air oven at 105°C according to AOAC method **Hardness** (modified from Fan and Sokorai 2007) Five-gram samples of canned sweet corn kernels were measured for hardness using a Model TA.XT2i Texture Analyzer (Stable Micro System, UK) with a mini Kramer shear 5-blade probe at an operating speed of 2 mm/sec and an operating distance of 20 mm.

Colour A windowed grain holder was filled with canned sweet corn kernels. Their colour was measured using a Spectraflash® SF600® Plus instrument (Data Color International, USA) with a 30-mm aperture and Commission Internationale de l'Éclairage (CIE) standard illuminant D65/10.

Two pretreatments yielding large amounts of FFA were selected for the next experiment.

Effects of the selected ultraviolet C–CA conditions and ultrasound

Preparation of sweet corn kernels

After the sweet corn was treated under the selected UVC–CA conditions, corn kernels were separated, and glass beakers were filled with the kernels. Drinking water was then added to cover the kernels. Next, the beakers were placed in a Transsonic 570/H system (Elma®, Germany) generating low-frequency ultrasound waves (35 kHz) for 0, 10, or 20 min (code S1, S2, and S3). The six pretreatments were designated VxCxS1, VxCxS2, VxCxS3, VyCyS1, VyCyS2, and VyCyS3.

Canning

Samples of 110 g of sweet corn kernels with 60 g of water from the treated beakers were added to 307 × 111 cans. The canned sweet corn was then sterilized at 121 °C for 12 min.

Analysis of canned sweet corn qualities

The same methods described in “Effects of the selected ultraviolet C–CA conditions and ultrasound” section were used.

Statistical analysis

The experimental design for the UVC–CA experiment was a 3×3 in completely randomized design (CRD), while that for the UVC–CA ultrasound experiment was a 2×3 in CRD. Both experiments were conducted with two replications. ANOVA and least significant difference (LSD) tests were used to evaluate the differences between mean values, with significance set at the 5% level ($p < 0.05$) using SPSS 16 software (SPSS Inc., USA).

Results and discussion

Effects of UVC–CA conditions

Before canning, sweet corn was treated with UVC at intensities of 0, 1.94, and 4.01 kJ/m² (coded V1, V2, and V3) and stored under CA conditions with %oxygen:%carbon dioxide:%nitrogen ratios of 21:0.03:78 (normal air), 3:10:87, and 3:15:82 (coded C1, C2, and C3, respectively) at 6 °C for 20 h. The FFA contents of all canned sweet corn kernel samples were not significantly different ($p > 0.05$). Corn kernel samples could be separated into three groups according to the atmospheric conditions:

group 1 (V1C1, V2C1, V3C1), group 2 (V1C2, V2C2, V3C2), and group 3 (V1C3, V2C3, V3C3). Among the samples from each group, FFA contents tended to be stable when the UVC intensity increased (Fig. 1). The three levels of UVC (0, 1.94, and 4.01 kJ/m²) did not influence FFA levels of sweet corn kernels. This finding was similar to those of Liu et al. (2012), who found that the levels of the phenolic compounds catechin and caffeic acid were not significantly different in tomatoes treated with UVC at 0, 2, 4, 8, or 16 kJ/m². Zainol et al. (2016) also reported that UV light did not affect on ferulic acid extraction from banana stem waste when UV was used for pretreatment. By contrast, strawberries showed decreased anthocyanin and phenolic contents after being exposed to UVC at 1–4.1 kJ/m² (Pan et al. 2004). FFA levels were obviously higher in the group 3 samples than in the groups 1 and 2 samples. V2C3 showed the highest FFA content of 217.22 ± 1.26 mg/100 g (dry basis), followed by 205.95 ± 24.13 and 191.28 ± 44.36 mg FFA/100 g (dry basis) in V1C3 and V3C3, respectively. The kernels treated with all UVC intensities in combination with a normal air or 3:10:87 %O₂:%CO₂:%N₂ atmosphere (groups 1 and 2) exhibited low FFA contents ranging from 158.08 to 169.98 mg/100 g (dry basis). This finding was similar to a study in which total polyphenolics increased in cherimoya fruit exposed to a 20:20:60 %O₂:%CO₂:%N₂ atmosphere but remained unchanged under normal air (Asiss et al. 2001). No difference was observed between the total phenolic contents of sweet corn kernels stored under a normal air or 5%O₂ + 10%CO₂ atmosphere (Riad et al. 2003).

The canned sweet corn kernels from all treatments exhibited 80.02–80.28% moisture content (data not shown), 12.94–15.20 kg hardness, 62.45–64.78 lightness (L* value), 5.16–7.39 redness (a* value), and 36.51–47.98

Fig. 1 FFA content of canned sweet corn kernels pretreated with UVC–CA before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; V3, 4.01 kJ/m² UVC; C1, normal air; C2, 3%O₂:10%CO₂:87%N₂; and C3, 3%O₂:15%CO₂:82%N₂)

yellowness (b^* value), none of which were significantly different between treatment ($p > 0.05$) (Figs. 2, 3). Hardness tended to be stable, ranging from 12.94 to 15.20 kg, which is similar to the unchanged firmness observed in shiitake mushrooms irradiated with 4 kJ/m² UVC and then stored in a modified atmosphere-package for 15 days at 1 °C (Jiang et al. 2010). Corn kernel colour also did not significantly differ. This agreed with results of Raid et al. (2003), who reported that CA could prevent browning in cooked sweet corn kernels. By contrast, calyx browning has been observed in strawberries irradiated with UVC at 1–4.1 kJ/m² (Pan et al. 2004), and button mushrooms exposed to UVC show immediately darkening compared to non-irradiated samples (Lu et al. 2016).

Due to resulting in the highest FFA contents, the treatments of no UVC in combination with 3:15:82 %O₂:%CO₂:%N₂ atmosphere storage (V1C3) and 1.94 kJ/m² UVC in combination with 3:15:82 (V2C3) were selected as the two pretreatments for the next experiment.

Effects of selected UVC–CA conditions and ultrasound

Post-treatment V1C3 and V2C3 corn kernels were sonicated with low-frequency ultrasound waves (35 kHz) for 0, 10, or 20 min (coded S1, S2, and S3) before canning, yielding six pretreatments: V1C3S1, V1C3S2, V1C3S3, V2C3S1, V2C3S2, and V2C3S3. The FFA contents of all canned sweet corn kernels did not differ significantly ($p > 0.05$) (Fig. 4). However, the V1C3S3 sample showed the highest FFA content of 287.99 ± 48.66 mg/100 g (dry basis), followed by V1C3S2, V2C3S3, and V2C3S2, which contained 277.07 ± 23.86 , 249.06 ± 62.91 , and 244.87 ± 10.91 mg FFA/100 g (dry basis), respectively.

Fig. 2 Hardness of canned sweet corn kernels pretreated with UVC–CA before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; V3, 4.01 kJ/m² UVC; C1, normal air; C2, 3%O₂:10%CO₂:87%N₂; and C3, 3%O₂:15%CO₂:82%N₂)

Fig. 3 Colour value of canned sweet corn kernels pretreated with UVC–CA before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; V3, 4.01 kJ/m² UVC; C1, normal air; C2, 3%O₂:10%CO₂:87%N₂; and C3, 3%O₂:15%CO₂:82%N₂)

Fig. 4 FFA content of canned sweet corn kernels pretreated with UVC–CA–ultrasound before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; C3, 3%O₂:15%CO₂:82%N₂; S1, no ultrasound; S2, 10 min ultrasound; S3, 20 min ultrasound)

The FFA contents of the canned sweet corn kernels were positively correlated with the ultrasound pretreatment time. This finding agreed with those of Tao and Sun (2015), who reported that ultrasound extraction efficiency is time-dependent; longer extraction times were correlated with higher extraction yields. Ultrasound caused an increase in FFA due to surface deterioration of the corn kernels. Awad et al. (2012) reported that surface erosion and mass transfer increased by ultrasound at frequencies above 20 kHz, resulting in shorter extraction times and higher yields. In addition, cell structure damaged possibly by solvent streams from collapsing bubbles combined with mechanical vibration, has been found in cabbage leaves treated with ultrasound at 37 kHz (Pongmalai et al. 2013).

The moisture contents and hardness of all treated kernels were not significantly different ($p > 0.05$), ranging from

Fig. 5 Hardness of canned sweet corn kernels pretreated with UVC–CA–ultrasound before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; C3, 3%O₂:15%CO₂:82%N₂; S1, no ultrasound; S2, 10 min ultrasound; S3, 20 min ultrasound)

Fig. 6 Colour value of canned sweet corn kernels pretreated with UVC–CA–ultrasound before canning (V1, no UVC; V2, 1.94 kJ/m² UVC; C3, 3%O₂:15%CO₂:82%N₂; S1, no ultrasound; S2, 10 min ultrasound; S3, 20 min ultrasound)

80.04 to 81.96% (data not shown) and 13.76–15.20 kg, respectively (Fig. 5). The colour of all treated corn kernels was not significantly different ($p > 0.05$), with L*, a, and b* ranging from 61.69–65.16, 5.62–7.99, and 38.21–53.94, respectively (Fig. 6). 10 min of ultrasound seemed to decrease b* in V1C3S1 and V2C3S1, while 20 min of ultrasound seemed to maintain b* in V1C3S2 and increase b* in V2C3S2. An ultrasound frequency of 35 kHz may have affected the colour of the canned sweet corn kernels. Awad et al. (2012) reported that ultrasound from 20 to 500 kHz alters the properties of food.

Conclusion

The combination of UVC irradiation and CA storage prior to sweet corn kernel canning did not significantly increase FFA. A CA with 3:15:82 %O₂:%CO₂:%N₂ tended to affect

the FFA content, whereas the three tested levels of UVC had no effect. Treating sweet corn with 35 kHz ultrasound before canning tended to increase the FFA content of canned sweet corn kernels compared to that in untreated samples. The texture and colour of the canned sweet corn kernels showed no clear effects of any pretreatment. Therefore, a UVC–CA ultrasound pretreatment could be a potential strategy for adding value to canned sweet corn kernels in terms of FFA content. More experiments are needed to confirm the potential of these pretreatments to increase FFA levels. By evaluating the effect of each pretreatment separately and strictly controlling the maturity and harvesting season of sweet corn, significant results may be determined. Ultrasound pretreatment may be a potentially non-thermal, green technology for increasing the FFA contents of other thermally processed corn kernel products.

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Compliance with ethical standards

Conflict of interest None.

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