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The effects of infrared treatment on physicochemical characteristics of vegetable soybean

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Abstract

Vegetable soybean (Edamame) blanching with hot water/steam is an energy- and water- intensive process that may also result in compromised product quality. The effectiveness of infrared (IR) heating to dry and simultaneously blanch Edamame was investigated at heating intensities of 11.06, 8.43 and 6.99 kW/m^2. Temperature, weight, texture, and green intensity of heated samples for various durations were determined. In general, product weight decreased during IR heating. The largest weight reduction (9.5 %) was achieved after 100 s of heating at the highest IR heating intensity. Hardness was reduced alongside treatment duration, reaching the lowest values (11172.9−10847 N) at 100 or 120 s despite heating intensity. The highest green intensity was recorded (0.33) for treatments at 100 or 120 s. The new process combined drying and blanching into one step which potentially improves processing efficiency and product quality.

Keywords: Food science, Food analysis, Food safety, Food technology, Nutrition

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1. Introduction

Vegetable soybean (also referred to as "Edamame), a popular vegetable in East Asia has started to gain popularity among western countries. For instance, Montri et al. (2006) reported that in Philadelphia, PA consumers are interested in purchasing fresh, in-shell edamame, and edamame-based patties from supermarkets. This vegetable soybean is usually served as part of a dish or in salads, though it is also consumed as a snack. Simonne et al. (2001), suggested that American consumers are likely to accept edamame as a snack after being freeze dried. Kelley and Sánchez (2005) reported that U.S. consumers prefer a buttery flavor and texture, in contrast to Japanese consumers who prefer a flower-like and beany flavor. Currently most edamame consumed in the U.S. is imported from China, usually marketed frozen, thereby indicating the need of diverse edamame-based products.

Increase in popularity of edamame is probably due to its nutritional value. Edamame does not only supply the essential amino acids but is a complete protein source (Mebrahtu, 2008). On average the nutritional contents of edamame, based on a serving size of 155 g (one cup) are 189 calories, 8 g of fat, 16 g of carbohydrates, 3 g of sugar, and 17 g of protein (Song et al., 2003; Hu et al., 2007; Carson, 2010; Xu et al., 2012; Suwan, 2015).

Traditionally, edamame undergoes blanching before freezing and storage. Typically, hot water (70−100 °C) is used for 2−5 min to blanch edamame. However, Song et al. (2003) suggest blanching for 10−30 min. Blanching not only deactivates enzymes, thus prolonging shelf life, but also improves flavor and texture. Song et al. (2003) describe the effect of blanching at various times on nutrients, proteins, and vitamins in edamame. Overall, amino acids, vitamins, and soluble sugars tend to decrease with water blanching; less reduction occurs if treated for short periods of time. Edamame blanched with hot water absorbs water, which increases product weight and could be a negative aspect in the development of dry snack products.

Development of new products utilizing edamame has been limited due to lack of information on characteristics of vegetable soybeans under diverse processing conditions. Texture of edamame is complex and due to lack of a standard protocol for measuring texture in edamame there is inconsistency on the methodology and units reported (Xu et al., 2012; Suwan, 2015). Besides blanching, Mozzoni et al. (2009) also evaluated the feasibility of canning edamame. Qing-Guo et al. (2006) describe the kinetics of various characteristics of edamame during vacuum drying, hot air drying, and freeze drying. These have been the few resources focused on understanding the impact of diverse processing methodologies on edamame.

Infrared (IR) heating presents an alternative procedure to heat foods and to broaden the categories of products that could be made from edamame. IR wavelength ranges

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from 76 − 1000 μm. When IR radiation impinges the food surface, IR energy is absorbed at discrete frequencies thereby heating the food product. IR heating process is reported to have higher energy efficiency and shorter drying duration when compared to other drying methods (Kocabiyik, 2010). For instance, IR has been studied for apples, bananas, and other vegetables to achieve the same results as with blanching; it has also been reported for use on rice and corn drying (Pan and Atungulu, 2011; Wilson et al., 2015; Wilson, 2016). IR has also been used in combination with hot air drying to improve product quality, increase energy efficiency and reduce the duration of the treatment (Kocabiyik, 2010).

The aim of this research is to provide the kinetics of physicochemical characteristics of edamame during IR heating and evaluate the impact of heating intensity on edamame beans. The findings could benefit attempts to develop new edamame-based products.

2. Materials and methods

The commercial edamame processing company AVS (American Vegetable Soybean & Edamame, Inc.) supplied fresh vegetable soybeans. The variety used for the experiment was 8080. Edamame was shelled and stored at 4 °C until processing (less than a week). Samples were standardized based on size, using two oblong meshes of 30.48 × 1.91 cm and 40.64 × 1.91 cm (12 × ¾ '' and 16 × ¾ '') to use a more homogeneous sample for treatment.

2.1. Infrared equipment and treatments

A laboratory-scale IR equipment with two catalytic IR emitters provided by Catalytic Industrial Group (Independence, KS, USA) was used to conduct this research. This equipment generates IR radiation energy by catalyzing natural gas to produce heat along with small amounts of water vapor and carbon dioxide as by-products. A radiometer (Ophir-Spiricon, LLC, North Logan, UT) was used to determine energy transfer (IR intensity) from IR energy source to the product. The radiometer measures power emitted in kW; the IR intensity was calculated by dividing the supplied power by area of heated black body (Equation (2)).

$$Energy\ transfer\ (IR\ heating\ intensity) = \frac{Measured\ power\ (kW)}{Heated\ black\ body\ area\ (m2)} \tag{2}$$

Once samples were screened and standardized by size, they were divided into subgroups (40 g) and randomly assigned to one of the following treatments:

High IR heating intensity (11.06 kW/m^2): Sample placed at 6 cm from the IR emitter.

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Medium IR heating intensity (8.43 kW/m^2): Sample placed at 8 cm from the IR emitter.

Low IR heating intensity (6.99 kW/m^2): Sample placed at 11 cm from the IR emitter.

To determine the temperature profile of edamame, two T-type- thermocouples (time constant of 0.15 s) were embedded in the surface of the beans to record internal temperature of edamame. Samples were placed under the IR emitter for various durations (20, 40, 60, 80, 90,100, and 120 s). Once samples were removed from the IR equipment they were placed in a re-sealable zipper storage bag and cooled immediately in iced water. Furthermore, all the samples remained for the same period under ice, before storing them at 4 °C.

Green intensity, texture, and weight were measured from each subsample within a day of treatment. The design of experiment was a two-factor factorial, with IR heating intensity and heating duration as fixed factors (Table 1). The experiment was conducted four times (blocks). There were five missing treatment combinations: High - 90 s, High - 120 s, Medium - 100 s, Medium -120 s, and Low - 90 s, due to the negative impact these treatments had on edamame. For instance, at high heating-intensity samples tend to burn after 100 s, but at medium heating-intensity burning of the skin occurred at 90 s.

2.2. Color determination

Color was measured using Hunter's scale. 'L', 'a', and 'b' values were determined with a HunterLab ColorFlex EZ Spectrophotometer (Hunter Associates Laboratory, Inc. Virginia, USA). 'L' is the degree of lightness/darkness, 'a' the degree of redness (+) and greenness (−); and 'b' the degree of yellowness (+) and blueness (−). The instrument was calibrated on a white card with values $L = 93.6$, $a = 0.6$, and $b = -2.3$. Each sample was measured two times and results were averaged. Green intensity was calculated as $y = -a/b$.

Table 1. Two-factor factorial design of experiment with IR heating intensity and heating duration as fixed factors.

Infrared (IR) Heating intensity	Infrared heating duration (s)
Low	20
Medium	40
High	60
	80
	90
	100
	120

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2.3. Texture analysis

Texture was assessed based on the protocol reported by Suwan (2015), where texture is measured as hardness, using a Texture Analyzer TA.XT Plus (Texture Technologies by Stable Micro Systems LTD, Hamilton, MA) and a compression test utilizing two compression platens of 7.6 cm diameter. A loading weight of 5000 g and a distance of 5 cm were selected as parameters for the test. For each run, four beans were selected and the average force of four runs was the hardness value expressed in Newton (N).

2.4. Weight reduction

To account for weight reduction, weight was measured for each sample. Weight was recorded before treatment and once the sample had cooled to room temperature (25 °C) after the treatment. Percentage of weight reduction was calculated from:

Weight reduction (%) = [Initial weight (g) - final weight (g)/Initial weight (g) $\times$100]

2.5. Statistical analysis

Analysis of variance, and Student's t test (least significant difference test) was performed with a statistical software (JMP version 13.0., SAS Institute) to determine significant differences within and among samples. Level of significance (α) was set at 5% for comparing means. Tukey's HSD analysis was conducted to determine differences among LS means.

3. Results and discussion

3.1. Temperature profile at three different heating intensities

The internal surface temperature of edamame beans was recorded and temperature profile for each heating intensity is illustrated in Fig. 1. As expected, the lower the heating intensity, the slower the temperature rise. Duration of IR treatment was constrained by two main factors, damage on the quality of edamame (roasting/burning) and on the temperature profile the inner temperature of the beans of at least 75 °C. The three intensity levels were based on the equipment configuration. Traditionally, edamame has been blanched using hot water or water steam for 120−180 s (Mozzoni et al., 2009; Xu et al., 2012; Suwan, 2015) hence treatment duration in this study did not exceed 120 s, mainly due to skin damage on edamame.

Temperature presented a similar trend between the three levels, yet less differences were observed among high and medium heating intensities when compared to low heating intensity. Samples treated under medium heating intensity had a different behavior than samples from other intensities, for instance at 100 s samples tend to

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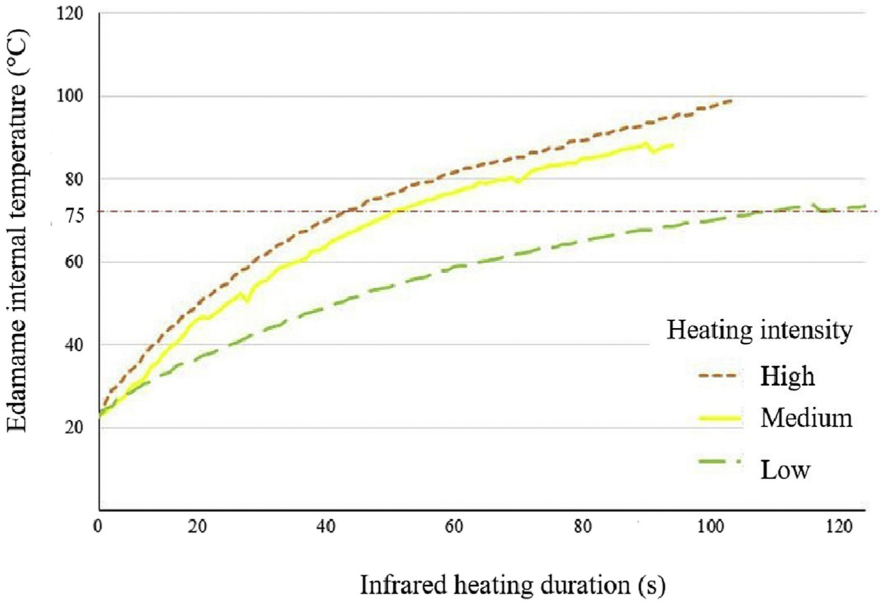

Fig. 1. Temperature profile of edamame beans during infrared heating under three heating intensities. Horizontal red dashed line represents targeted temperature (75 °C). Heating intensity is based on product-to-emitter gap (PEG). High heating intensity represents samples with PEG size of 6 cm, similarly medium is 8 cm, and low is 11 cm.

burn, consequently 90 s was selected as the longest duration for medium intensity. Wilson (2016), reported a similar temperature rise on corn kernels treated under IR with a PEG of 11 cm, yet for the authors' experiment temperature was measured at the external surface of corn resulting on higher temperatures.

3.2. Weight reduction

The interaction between heating intensity and IR heating duration was significant for weight reduction with a p-value of <0.0001 (Tables 2 and 3). The largest weight reduction (9.5 %) was achieved when edamame was treated under high heating intensity for 100 s. Percentage of weight reduction increased as duration under

Table 2. Analysis of variance, P- values of weight reduction, texture, and green intensity of edamame under infrared (IR) heating.

Source	Degrees of freedom	Weight reduction	Texture	Green intensity
IR heating intensity	2	<0.0001	0.2311	0.0204
IR heating duration	6	<0.0001	<0.0001	<0.0001
Heating intensity × IR heating duration	7	<0.0001	0.0845	0.9179
Blocks	3	0.2079	0.8802	0.4121
Error	45			

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Table 3. Percentage of weight reduction on edamame under different infrared (IR) heating durations and intensities.

IR heating duration (s)	Weight reduction (%) under three IR heating intensities[a]		
	High[b]	Medium[b]	Low[b]
20	0.99 ± 0.29[I]	1.29 ± 0.29[HI]	1.29 ± 0.29[HI]
40	2.10 ± 0.29[GHI]	2.59 ± 0.29[FGH]	2.23 ± 0.29[GHI]
60	4.03 ± 0.29[DEF]	3.38 ± 0.29[EFG]	3.76 ± 0.29[EF]
80	6.79 ± 0.29[BC]	5.46 ± 0.29[CD]	4.77 ± 0.29[DE]
90		6.42 ± 0.29[BC]	
100	9.56 ± 0.29[A]		6.38 ± 0.29[BC]
120			7.85 ± 0.29[B]

[a] LS Means followed by the same letter are not significantly different at the 0.05 level by the Tukey's HSD test.

[b] High, medium, and low represent heating intensity (based on product-to-emitter gap sizes of 6, 8, and 11 cm 11.06, 8.43 and 6.99 kW/m^2, respectively).

treatment increased, achieving 9.5 % when heated for 100 s under a high heating intensity (PEG size of 6 cm). The observed weight reduction is probably associated with a decrease on moisture content, due to membrane disruption caused by high temperatures. These results support the concept of utilizing IR heat to dry or as a pre-drying step to produce freeze dried products. Pan et al. (2008) and Zhu et al. (2010) already used IR radiation as a drying technology for bananas and apples. IR has also resulted on a rapid drying method for corn kernels with potential benefits of microbial decontamination (Wilson, 2016).

Moisture content was not measured in this study, but it normally ranges around 60–72 % (Qing-guo et al., 2006), assuming weight reduction was caused by moisture losses. Theoretically moisture content was reduced from 66 to 56 % in 100 s under a high IR heating intensity. IR could be used as part of the drying methodology, combining IR with conventional hot air. Hebbar et al. (2004) reported increased energy efficiency when combining IR and hot air, compared with either process alone, on potatoes and carrots.

3.3. Texture

The statistical model for texture was significant with R^2 value of 0.88, suggesting a good fit of the general model for this study. IR heating duration was the only effect that presented significant differences (Tables 2 and 4). Texture decreased as IR heating duration increased despite heating intensity.

Hardness values decreased as treatment duration increased. The softest texture was obtained when edamame was treated for 100 s under both high and low IR heating intensity treatment. Results indicated a major effect of IR treatment duration over

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Table 4. Comparison of edamame texture and green intensity means under seven infrared heating durations.

Infrared heating duration (s)	Sample size	Mean Texture (N)[a]	Mean Green Intensity[a]
20	12	20372.89[A] ± 1904.85	0.20 ± 0.021[C]
40	12	18904.33[A] ± 1832.44	0.22 ± 0.017[C]
60	12	14911.68[B] ± 1785.79	0.23 ± 0.020[C]
80	12	12783.33[BC] ± 1603.79	0.30 ± 0.020[AB]
90	4	12517.35[BC] ± 903.50	0.29 ± 0.034[B]
100	8	10847.03[C] ± 1254.05	0.31 ± 0.023[AB]
120	4	11172.90[C] ± 590.87	0.33 ± 0.019[A]

[a] Means followed by the same letter are not significantly different at the 0.05 level by the Tukey's HSD test.

heating intensity. Pohl et al. (1988), reported hardness is due to starch and pectin, which under heat are gelatinized and some pectin substances become soluble hence softening the product. Additionally, disruption of the middle lamella and softening of the protein matrix of the beans contributed to reduced hardness (Whistler and BeMiller, 1997). Low and medium heating intensities demonstrate similar patterns on hardness reduction (Fig. 2). Under high heating intensity edamame showed a different behavior. Probably due to the sudden increase of internal temperature at a high heating intensity.

Reduced hardness has also been reported for products after blanching and canning (Mozzoni et al., 2009; Suwan, 2015). Yet hardness achieved in this study is higher than previous reports (Qing-Guo et al., 2006; Mozzoni et al., 2009; Xu et al., 2012); the difference is likely due to the use of fresh samples rather than frozen-thawed

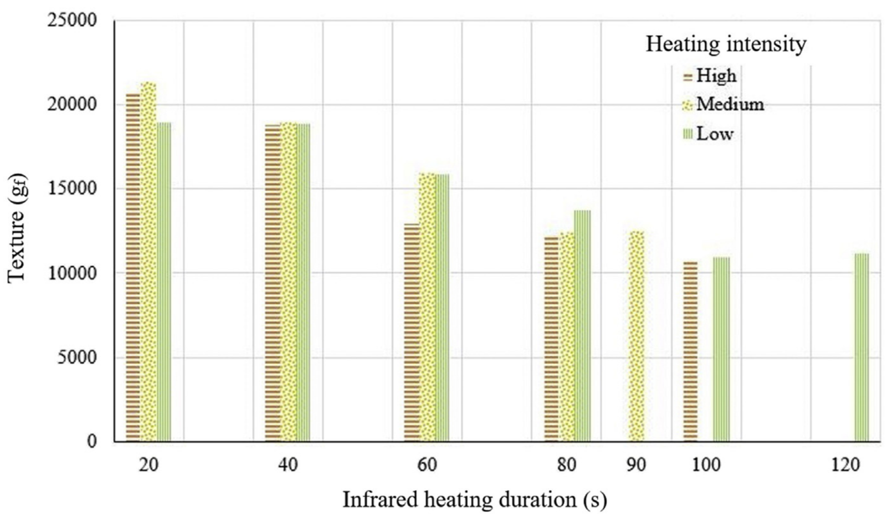

Fig. 2. Texture of edamame under different infrared heating intensities and duration. High, medium, and low represent different product-to-emitter gap sizes of 6, 8, and 11 cm respectively.

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(used in previous studies). Hardening of edamame is not desired by consumers. Suwan (2015) reported a negative correlation (-0.482) between hardness and acceptability by a sensory panel, which indicates a soft texture might increase consumer preference.

3.4. Green intensity

The general statistical model for green intensity presented R^2 value of 0.87. IR heating intensity and heating duration were both significant main effects at a p-value of 0.0204 and <0.0001, respectively. Conversely, the interaction between main effects was not significant (Table 2). Hence, mean comparison was performed independently for IR heating duration and heating intensity (Table 4). The highest green intensity (0.38) was achieved by treating edamame for 120 s.

Green intensity followed the same pattern among heating intensities across treatment duration. Thus, reinforcing the null interaction between main effects (IR heating duration and intensity). The highest values for green intensity were recorded when edamame was exposed to IR heating for 100 and 120 s at low and high intensities. Results are in agreement with Xu et al. (2012) who used hot water with calcium chloride for blanching treatment which increased green intensity of edamame. Conversely, Mozzoni et al. (2009) reported that green intensity decreased as duration of blanching increased. Differences are caused by the addition of CaCl (Xu et al., 2012). Industry samples sourced from the commercial edamame processing facility (water blanched) had a green intensity that ranged from 0.32 − 0.38; similar values were achieved when edamame was treated under IR for 100 or 120 s.

4. Conclusion

Infrared heating is a technology with potential of dehydrating and blanching edamame. IR heating edamame for 100 or 120 s, resulted in weight reduction, texture and color improvement. Weight decreased consistently across treatments indicating moisture loses. Under high heating intensity (11.06 kW/m^2) the highest weight reduction was achieved (9.5 %) when samples had been treated for 100 s. Texture, measured as hardness, decreased consistently among IR heating intensities. Despite of the heating intensity, treating edamame for 100 or 120 s resulted on the lowest hardness (11172.9−10847 N). Green intensity increased alongside treatment duration. The largest green intensity was achieved after treating edamame for 100 or 120 s.

Overall, treating edamame under IR heat for 100 or 120 s resulted in the highest percentage of weight reduction, lowest hardness, and highest green intensity. Further research is recommended to develop a blanching protocol using IR heat for peroxidase inactivation. Overall, the study demonstrated the potential of IR heating as processing methodology to dry and blanch edamame.

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Declarations

Author contribution statement

Laura M. Lara, Shantae A. Wilson, Pengyin Chen, G.G. Atungulu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Carson, L.C., 2010. Cultivation and Nutritional Constituents of Virginia Grown Edamame. MSc thesis. Virginia Tech Univ. https://vtechworks.lib.vt.edu/bitstream/handle/10919/32241/Carson_LC_T_2010.pdf.

Hebbar, U., Vishwanathan, K.H., Ramesh, M.N., 2004. Development of combined infrared and hot air dryer. J. Food Eng. 65, 557−563.

Hu, Q., Zhang, M., Mujumdar, A.S., Xiao, G., Sun, J., 2007. Performance evaluation of vacuum microwave drying of edamame in deep-bed drying. Dry. Technol. 25 (4), 731−736.

Kelley, K.M., Sánchez, E.S., 2005. Accessing and understanding consumer awareness of and potential demand for edamame. HortScience Publ. Am. Soc. Horticult. Sci. 40. http://hortsci.ashspublications.org/content/40/5/1347.full.pdf.

Kocabiyik, H., 2010. In: Pan, Z., Atungulu, G.G. (Eds.), Infrared Heating for Food and Agricultural Processing. CRC Press, pp. 101−116. In: https://www.crcpress.com/Infrared-Heating-for-Food-and-Agricultural-Processing/Pan-Atungulu/p/book/9781420090970.

Mebrahtu, T., 2008. Analysis of nutritional contents in vegetable soybeans. J. Crop Improv. 21 (2), 157−170.

https://doi.org/10.1016/j.heliyon.2019.e01148

Montri, D.N., Kelley, K.M., Sánchez, E.S., 2006. Consumer interest in fresh, in-shell edamame and acceptance of edamame-based patties. HortScience 41 (7), 1616–1622. http://hortsci.ashspublications.org/content/41/7/1616.full.pdf.

Mozzoni, L.A., Chen, P., Morawicki, R.O., Hettiarachchy, N.S., Brye, K.R., Mauromoustakos, A., 2009. Quality attributes of vegetable soybean as a function of boiling time and condition. Int. J. Food Sci. Technol. 44 (11), 2089–2099.

Pan, Z., Atungulu, G.G., 2011. Infrared Heating for Food and Agricultural Processing. CRC Press. https://trove.nla.gov.au/work/37049285?q&versionId=4812129.

Pan, Z., Shih, C., McHugh, T.H., Hirschberg, E., 2008. Study of banana dehydration using sequential infrared radiation heating and freeze-drying. LWT Food Sci. Technol. 41 (10), 1944–1951.

Pohl, J., Snyder, H.E., Kwon, T.W., 1988. Soybean utilization. AVI book, published by van Nostrand Reinhold company, New York.1987. Food/Nahrung. 32 (4), 408–408.

Qing-Guo, H., Min, Z., Mujumdar, A.S., Wei-hua, D., Jin-cai, S., 2006. Effects of different drying methods on the quality changes of granular edamame. Dry. Technol. 24 (8), 1025–1032.

Simonne, A.H., Weaver, D.B., Wei, C., 2001. Immature soybean seeds as a vegetable or snack food: acceptability by American consumers. Innovat. Food Sci. Emerg. Technol. 1, 289–296.

Song, J.-Y., An, G.-H., Kim, C.J., 2003. Color, texture, nutrient contents, and sensory values of vegetable soybeans [Glycine max (L.) Merrill] as affected by blanching. Food Chem. 83 (1), 69–74.

Suwan, P., 2015. Effects of Blanching on Color, Texture and Sodium Chloride Content during Storage Time of Frozen Vegetable Soybean Modeling for Commercial Scale. PhD diss. University of Nebraska. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1054&context=foodscidiss.

Whistler, R.L., BeMiller, J.N., 1997. Carbohydrate Chemistry for Food Scientists. Eagan press.

Wilson, S.A., 2016. Development of Infrared Heating Technology for Corn Drying and Decontamination to Maintain Quality and Prevent Mycotoxins. MS thesis. University of Arkansas. https://scholarworks.uark.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=3081&context=etd.

Wilson, S.A., Atungulu, G.G., Couch, A., Sadaka, S., 2015. Radiant heating and tempering treatments for improving rate of moisture removal during drying of shelled corn. Appl. Eng. Agric. 31 (5), 799–808.

 https://doi.org/10.1016/j.heliyon.2019.e01148

Xu, Y., Sismour, E., Pao, S., Rutto, L., Grizzard, C., Ren, S., 2012. Textural and microbiological qualities of vegetable soybean (edamame) affected by blanching and storage conditions. J. Food Process. Technol. 3 (7), 165.

Zhu, Y., Pan, Z., McHugh, T.H., Barrett, D.M., 2010. Processing and quality characteristics of apple slices processed under simultaneous infrared dry-blanching and dehydration with intermittent heating. J. Food Eng. 97 (1), 8−16.

 https://doi.org/10.1016/j.heliyon.2019.e01148