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Effect of infrared heating on degradation kinetics of key lime juice physicochemical properties

Sara Aghajanzadeh *, Mahdi Kashaninejad, Aman Mohammad Ziaiifar

Department of Food Process Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Basij Square, Gorgan, Iran

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ABSTRACT

The effect of IR heating on retention and kinetics of some physicochemical properties of key lime juice were investigated. The juice was thermally treated at 60, 70, 80 and 90 °C in 15, 10, 5, 2.5 min using IR and conventional thermal treatment in water bath. The effect of heating on ascorbic acid (AA), pectin methylesterase (PME), cloud stability and color of the juice were studied. The higher Z-value of AA during IR heating (25.12 °C) indicated the higher thermal resistance of this vitamin compared to conventional method (24.15 °C)). Higher PME inactivation and cloud stability were observed during conventional treatment. IR heating was effective in color preservation of the juice because of lower changes in browning index and $L^* \times a^* \times b^*$ combination. All these obtained results were related to shorter come up time during IR heating. Finally, correlation matrix was used to evaluate the linear relation between the juice properties.

Industrial relevance: In this study, infrared (IR) heating was used as an alternative method for key lime juice thermal processing. Come up time decreased due to quick rising in initial temperature of the juice to the target temperature during IR heating. Hence, the juice was heated less during this method compared to the conventional thermal treatment in water bath. Totally, IR heating could be introduced as a new and effective method for the preservation of nutritional values and color of juice such as key lime juice.

1. Introduction

Citrus are known as the important fruits in tropical and sub-tropical regions due to their quality and nutritional values. Key lime (*Citrus aurantiifolia*) is a citrus which is used as food seasoning and also in preparation of drinks like lemonade and carbonated beverages. The color of immature key lime is green and it turns to yellow when it becomes mature. Antioxidants especially ascorbic acid (AA) is high in key lime like other citrus. This vitamin is not synthesized in the human body and >90% is supplied via fruits and vegetables consumption (Lee & Kader, 2000). Studies show that consumption of fruit with high antioxidant content could be effective to reduce the risk of chronic diseases such as cardiovascular diseases and different types of cancer. Preservation of AA in citrus products during food processing procedures is considered as a major challenge, because it is highly sensitive to processing conditions such as high temperatures, low relative humidity, physical damages and chilling injuries (Lee & Kader, 2000). Non enzymatic browning occurs due to reactions between sugars, amino acids and AA. Via the degradation of AA, several decomposition reactive products occur that these compounds may combine with amino acids and result in formation of brown pigments (Burdurlu, Koca, & Karadeniz, 2006). This phenomenon is considered as one of the major factors, which impacts off-taste, off-color and citrus juice acceptance. As, the first quality affects on the consumers to buy a product is its visual appearance. Color is one of the important visual properties of food products that could be changed during thermal processing (Ahmed, Kaur, & Shivhare, 2002; Ahmed & Shivhare, 2001a, 2001b). Several researchers have studied the effect of thermal treatments methods on the color of various juices (Rattanathanalerk, Chiewchan, & Srichumpoung, 2005; Rhim, Nunes, Jones, & Swartzel, 1989; Vikram, Ramesh, & Prapulla, 2005; Wibowo et al., 2015).

Turbidity or cloudy appearance in citrus juice is a desirable property that influences color and organoleptic quality of the product (Tiwari, Muthukumarappan, O'donnell, & Cullen, 2009). Pectin has the key role on turbidity, viscosity and also stability of the citrus juice. Pectin Methylesterase (PME), also known as pectinase, pectin esterase and pectin methoxylase, is responsible for the de-esterification of methoxylated pectin and formation of insoluble calcium pectate. During these phenomena, precipitation of the cloud particles occurs. Thermal treatment is a most common method for PME inactivation to prevent from unwanted juice clarification and control the microbial and enzymatic activities in high acid products such as citrus juice. But conventional thermal processing method using water bath needs long heating time that leads to quality detritions in vitamin content, color and rheological characteristics (Ling, Tang, Kong, Mitcham, & Wang,

* Corresponding author.
E-mail address: saraaghajanzadeh@yahoo.com (S. Aghajanzadeh).

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2015). Over the years, new food processing technologies have developed to reduce or eliminate these undesirable effects during conventional thermal treatments.

Infrared (IR) irradiation is generally applied for heating treatments of foods including dehydration, baking, cooking, roasting, thawing, blanching and inactivation of microorganisms (Cullen, Tiwari, & Valdramidis, 2011). IR radiation is part of the electromagnetic spectrum in wavelength range between 0.5 and 100 μm range (Cullen et al., 2011). It has some advantages compared to conventional thermal treatments such as direct heat penetration, high energy efficiency, faster and uniform heating, equipment compactness and lower degradation of nutritional components (Rastogi, 2012).

The penetration depth of IR depends on the wavelength of IR radiation and also the composition and structure of the sample. Based on wavelength, IR is commonly categorized into three regions: near-IR (0.78–1.4 μm), mid-IR (1.4–3.0 μm) and far-IR (3.0–1000 μm) (Rastogi, 2012). Far-IR radiation is usually applied in food processing as the most food components absorb irradiative energy in this region (Cullen et al., 2011). In this method a thin surface layer of food material will be heated due to the shallow penetration of IR irradiation. The absorbed energy is then transferred by conduction or convection method within the food. Using near-IR for drying apple slices was faster than the conventional convective method and reduced the process time by 50% (Nowak & Lewicki, 2004). It was reported that using continuous convective air drying with IR treatment could be effective in reduction of the overall color change while maintaining high drying rates (Tan, Chua, Mujumdar, & Chou, 2001). Boudhrioua, Bahloul, Slimen, and Kechaou (2009) mentioned that the application of IR radiation for blanching and/or IR drying increased the total phenols content of the olive leaves compared to fresh ones. Also, using IR drying was effective in preservation of the greenness color of fresh leaves and enhancement their luminosity (Boudhrioua et al., 2009). Convective and combined convective-infrared were used to drying Murta berries. Application of combined convective-infrared resulted in better color preservation that the other method at 50 and 60 °C) (Puente-Díaz, Ah-Hen, Vega-Gálvez, Lemus-Mondaca, & Scala, 2013).

In spite of the advantages of IR heating, no study has been reported on the effects of IR heating on quality aspects of lime juice. So the aim of this study was to investigate the effect of this novel food processing method on retention and kinetics of AA degradation, PME inactivation, cloud stability and also color deterioration of key lime juice. Conventional thermal processing was also used to compare the efficiency of IR heating method.

2. Materials and methods

2.1. Sample preparation

Fresh Key limes (*Citrus aurantiifolia*) were purchased from a local market (Gorgan, Iran) and kept at 4 °C) until the experiments were carried out. The washed and clean limes were cut into halves and squeezed using a juice extractor (Khorshid lemon juicer, Iran). It was then filtered using a sieve with mesh 170 to remove large particles. The prepared juice was immediately processed using conventional and IR heating methods.

2.2. Conventional heating

30 ml of lime juice with initial moisture content of 88.07 ± 0.05% (w.b.) was transferred into a clean 100 ml beaker and heated in water bath (WNB-22, Memmert, Germany, 1800 W) at 60, 70, 80 and 90 °C) for 15, 10, 5, 2.5 min, respectively. Initial time was set when the juice reached to the desired temperature. The data were recorded using 1 mm diameter copper–constant thermocouple (T-type) connected to a data logger (TC-08, Pichotechnology Co, UK). Finally, the sample was cooled in ice-water bath to minimize the effect of cooling time on physicochemical properties.

2.3. Infrared heating

An infrared heating system was developed at the Department of Food Process Engineering of Gorgan University of Agricultural Sciences and Natural Resources (Fig. 1) to study the effect of IR radiation on quality of lime juice. This system consisted of a radiant heating chamber with infrared module (1500 W). The distance between the surface of the juice and infrared source was adjusted to minimum (8.5 cm). A temperature controller was used to set the temperature during process to ± 1 °C. The juice was mixed every 15 s for uniform heating. Sample volume, container and thermal conditions (temperature and time) were exactly similar to the conventional heating as described before.

2.4. Physicochemical analysis

2.4.1. Ascorbic acid measurement

AA content of samples was determined using iodine titration method by taking 0.88 mg AA equivalent to 1 ml of iodine solution (Kashyap & Gautam, 2012). 20 ml of the lime juice was mixed with 150 ml of distilled water and titrated with idiom solution using starch solution (1%) as indicator. For preparation of iodine solution, 5 g potassium iodide (KI) and 0.268 g potassium iodate (KIO_3) were dissolved in 200 ml of distilled water. Then, 30 ml of 3 M sulfuric acid (H_2SO_4) was added into the beaker and diluted with distilled water until 500 ml solution. Titration continued up to the solution reached a fixed dark-blue color and AA content was estimated using Eq. (1):

$$\text{mg Ascorbic acid per 100 mg of the sample} = 0.88 \times \text{ml iodine solution} \quad (1)$$

2.4.2. Measurement of pectin methylesterase activity

To measure the PME activity, 5 ml of lime juice was mixed with 20 ml of 1% pectin-salt solution (10 g pectin and 15.3 g NaCl diluted in 1 L distilled water) and incubated at 30 °C. The pH of the solution was adjusted to 7 using NaOH (2 N). Then, the pH of the solution was readjusted to 7.7 using NaOH (0.05 N). Finally, 0.1 ml of NaOH (0.05 N) was added and the time was recorded to reach pH = 7.7 (Kimball, 1999). The enzyme activity unit (PEU) was calculated according to Eq. (2):

$$\text{PEU(unit/mL)} = \frac{(0.05\ \text{N NaOH})\ (0.1\ \text{ml of NaOH})}{(5\ \text{ml sample})(\text{time (minute)})} \quad (2)$$

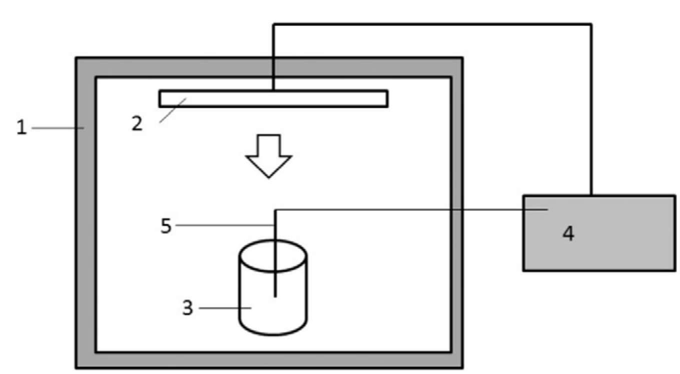

Fig. 1. Schematic diagram of infrared heater used for processing of key lime juice: 1) chamber; 2) infrared lamp; 3) sample; 4) thermocontroller; 5) thermocouple.