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Effect of repetitive ultraviolet irradiation on the physico-chemical properties and microbial stability of pineapple juice

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ABSTRACT

The study aims to investigate the effect of repetitive ultraviolet irradiation (UV–UV) and the combination effect with dimethyl dicarbonate (UV–DMDC–UV) on the physico-chemical properties and microbiological stability of pineapple juice. UV dosages of 10.76 mJ/cm^2 percycle and 250 ppm of DMDC were used. There was a significant decrease in turbidity, total phenolic and vitamin C in the treated juices. The UV–UV reported a significant reduction of 1.91 log CFU/ml in total plate count and 1.4 log CFU/ml in yeast and mould. Post addition of DMDC into the UV irradiated juice (UV–UV–DMDC) showed reductions of 2.61 log CFU/ml for TPC and 4.87 log CFU/ml for YM. This study demonstrated the effectiveness of UV irradiation in preserving the nutritional quality and the addition of DMDC can have a combination effect with the UV irradiation of juice in terms of microbial reduction. However, the treatments were not sufficient to achieve adequate microbial reduction as required by the FDA.

Industrial relevance: Dimethyl dicarbonate (DMDC) is one of the effective anti-microbial agents that can control a wide range of microorganisms which includes *Escherichia coli* 0157:H7 and yeast. The effect of dimethyl dicarbonate (DMDC) in reducing microbial counts was significant in this study. According to Threlfall and Morris (2002), DMDC is used to prevent fermentation in excessive yeast contamination in wine production. Moreover, Halim et al. (2012) stated that DMDC has shown promising results for microbial inactivation of fruit juices in a preliminary study in lab. Therefore, combination effect with additives (DMDC) may be able to increase the efficiency of the UV irradiation for microbial reduction in juice and longer the shelf life of juice.

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1. Introduction

Fruit juices are defined as unfermented but yet can be fermentable products collected from fresh, mature and healthy fruits (Anon, 2006). Such juices can be formed using a single strength of fruit or a number of fruits. Fruit juices are famous for their good food value and high mineral and vitamin content (Bates et al., 2001; Kabasakalis, Siopidou, & Moshatou, 2000). Recently, the trend of fruit juice consumption has been on the rise over the last few decades due to their diverse health benefits (Bates, Morris, & Crandall, 2001; Borenstein, Dai, Wu, Jackson, & Larson, 2005; Liu, 2003). Pineapple juice is famous for its very pleasing aroma and flavour (Rattanathanalerk, Chiewchan, & Srichumpoung, 2005). It is generally drinkable in single-strength, reconstituted or concentrated forms, and can be mixed with other juices to develop new flavours for beverages and other products due to its strong acid flavour (Carvalho, Castro, & Silva, 2008). The Morris pineapple variety has the advantages of producing fruits that are high in sugar (11–18 °Brix) and are attractive for their golden yellow flesh colour (De Silva, Kadir, Aziz, & Kadzimin, 2008). According to the Malaysia Pineapple Industry Board (MPIB) (2011), the estimated production cost for the Morris variety is cheaper than other varieties such as Josephine. Hence, the Morris pineapple could have the potential to attract consumers and increase their preference for pineapple juice in the industry.

Fruit juice, especially fresh or unpasteurized juice, has a high tendency for spoilage due to being unprotected by skin or a cell wall and by exposure to the air and microorganisms from the environment. According to Wood and Moellering (2003), microorganisms can adapt themselves to adverse environments which were previously harmful to them. Hence, due to microbial resistance, the juice industry has to constantly face this problem. From estimation by the United States Food and Drug Administration (FDA), there are 140 juice related illnesses that can be prevented yearly. Hence, the labelling rules for juice products have increased the awareness of consumers of the dangers of drinking untreated juice (FDA, 2001a). Further, Foley et al. (2002) explained that there are nearly 16,000 to 48,000 illness issues annually that arise due to unpasteurized juice consumption.

Pasteurization is an effective technology used to satisfy safety requirements in the fruit juice industry. Thermal treatment can

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achieve a 5-log reduction in the number of most resistant pathogens as required by the FDA. Currently, pasteurization is the most widely used process in the Malaysian juice industry for effective microbial eradication. However, the application of thermal energy may cause undesirable effects on the flavour and nutritional content of the juice as well as the physicochemical properties (Mosqueda-Melgar, Raybaudi-Massilia, & Martín-Belloso, 2008). Nevertheless, the cost of the equipment can be too expensive especially for small operations.

Ultraviolet irradiation is a non-thermal disinfection technology that is applied at a low temperature (Tran & Farid, 2004). It can potentially be used as an alternative to thermal pasteurization in the juice industry. Based on the work of Canitez (2002), this process does not create chemical residues. Moreover, it is a low-cost operation and is effective against many microorganisms (Bintsis, Tzanetaki, & Robinson, 2000). Ultraviolet-C is considered to be germicidal against microorganisms such as bacteria, viruses, protozoa, yeasts, moulds, and algae (Bintsis et al., 2000), where the highest effect is achieved between 250 and 270 nm. Koutchma, Froney, and Moraru (2009) stated that the most efficient inactivation can be obtained at 253.7 nm due to the maximum absorption of UV photons by the genetic materials of microorganisms at this specific wavelength. The efficiency of ultraviolet irradiation relies on the absorbance of the medium, flow rate of the fluid, moisture content, amount of solid particles and suspended materials, fluid thickness, reactor design, ultraviolet intensity which is interconnected to the exposure time, age of lamps used, type of microorganisms and growth phase of the organism, and initial microbial density (Begum, Hocking-Ailsa, & Miskelly, 2009; Bintsis et al., 2000; Caron, Chevrefils, Barbeau, Payment, & Pre'vost, 2007; Guerrero-Betran & Barbosa-Canovas, 2005; Hansen, 1976; Koutchma et al., 2009). However, the poor penetration property of ultraviolet light is the main limitation.

Although research has proven that UV irradiation is able to provide a 5-log reduction of *Escherichia coli* O157:H7 in apple cider, very few studies have been carried out to determine the effect of UV when used in combination with preservatives that are commonly applied in juices. According to Tandon, Worobo, Churey, and Padilla-Zakour (2003), ultraviolet irradiation alone might not be effective enough against spoilage microorganisms such as yeast and moulds in apple cider. Dimethyl dicarbonate (DMDC) is one of the effective anti-microbial agents that can control a wide range of microorganisms which includes *E. coli* 0157:H7 and yeast. The effect of dimethyl dicarbonate (DMDC) in reducing microbial counts was significant in this study, although small. Based on Threlfall and Morris (2002), DMDC is used to prevent fermentation in excessive yeast contamination in wine production. DMDC is also permitted for use in single strength juices given that it also has an inhibitory action in moulds and bacteria (Fisher & Golden, 1998). DMDC has shown promising results for microbial inactivation of fruit juices in a preliminary study in lab, as well as in the published work of others (Halim et al., 2012). The legal limit for the usage of DMDC in non-alcoholic beverages and juice is 250 mg/L or 250 ppm. The usage of DMDC in 100% juice is approved by the FDA as of June 2000 (FDA, 2001b). Thus it is interesting to observe the effect of combination with UV.

Previous studies have proven that one cycle of ultraviolet irradiation on pineapple juice is not sufficient to achieve a 5 log reduction of microorganisms as required by the Food and Drug Administration (FDA) (Chia, 2011a,b; Hamzah, 2009). For this reason, a repeat using two cycles of ultraviolet irradiation is suggested in this study. Moreover, a combination effect with additives (DMDC) may be able to increase the efficiency of the UV irradiation for microbial reduction in juice. Hence, the objective of this study is to determine the effect of two cycles of ultraviolet irradiation (UV–UV) and the combination effect of dimethyl dicarbonate with ultraviolet irradiation (UV–DMDC–UV) on the physico-chemical properties and microbiological stability of pineapple juice.

2. Materials and methods

2.1. Preparation of pineapple juice

Pineapple fruits (*Ananas comosus* L.) of the Morris variety at commercial maturity were purchased from a commercial farm in Selangor, Malaysia. After the fruits were washed, the skins were removed using a meat slicer (300SL, DEUGI, Italy). Then, the flesh of the fruits was cut into smaller pieces using a food slicer (ECA-201, EMURA, Japan). The juice was then produced using a supermasscolloider (ZA10-20J, MASAKO, Japan), an ultra-fine friction grinder. It was followed by filtering the juice through a bean grinder (MH-280, Taiwan). The juice was filtered again using a 500 micron aperture stainless steel screen (BS 410-1, ALPHA, England) prior to treatment.

2.2. Ultraviolet pasteurizer

The filtered pineapple juice was treated using a CiderSure 3500-B laboratory unit (Macedon, New York). This equipment was already commercialized to treat juice or cider using ultraviolet irradiation (Koutchma, Keller, Chirtel, & Parisi, 2004; Matak et al., 2007; Shamsudin, Chai, Mohd Adzahan, & Wan Daud, 2013). This laboratory unit consists of electronic controls and a process tube, through which the fluid flows. The UV irradiation consists of eight low-pressure lamps that emit UV light at 254 nm. The sensors provide information for UV dosage calculations. The ultraviolet dosage applied in study was 10.76 mJ/cm^2 per cycle which is the highest dose that can kill microbes. The thickness of the thin film was in the range 0.21 to 0.48 mm.

The flow rate of the fruit juice was set to run automatically in the ultraviolet pasteurizer. The machine will auto select a flow rate that should give a higher microbial count reduction. For the repetitive ultraviolet irradiation, the ultraviolet irradiated juice was allowed to run through another cycle. The flow rate was shown on the touch screen panel of the machine. The irradiated juice that had gone through two cycles was used for the analyses.

For the study of the effect of DMDC addition on the UV treatment, dimethyl dicarbonate (DMDC) from Velcorin with a maximum limit of 250 ppm was added into the juice immediately after the first cycle of UV irradiation (FDA, 2001b). Then, the juice was allowed to stand for 90 min at room temperature ($\pm$27 °C) to allow full hydrolysis in the juice before entering for the second cycle.

From the flow rate display on the screen of the UV pasteuriser, the exposure time of the juice in the UV pasteurizer was calculated. The calculation for the ultraviolet dosage followed the method reported by Chia (2011a). With the consideration of the energy lost by heat and when the ultraviolet light passed through the quartz tube, the power density was calculated. By using the calculated power density, the sensor placement factor was determined. Lastly, the ultraviolet dosage was calculated by multiplying the irradiance of the juice by the exposure and sensor placement factor.

2.3. Physico-chemical analyses

2.3.1. Total soluble solids (TSS)

The total soluble solid (TSS) level of the juice was determined using a digital refractometer (AR-2008, Kruss, Germany). The measured value was expressed as °Brix. A substantial amount of extracted juice was dropped onto the refractometer. The reading shown was the reading of the total soluble solids for the juice. Two replications of the treatment were conducted. For each replication, duplicate measurements were conducted and the results averaged.

2.3.2. Total phenolic

The total phenolic content of the juice was measured using the Folin–Ciocalteau method as reported by Lukanin, Gunkp, Bryk, and

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