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Effects of UV-irradiation detoxification in a photodegradation reactor on quality of peanut oil

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Abstract

A new experimental laboratory-scale photodegradation reactor has been developed to study the effects of UV-irradiation detoxification on physicochemical properties of peanut oil based on the photogradation efficiency of aflatoxin B1. The color, acid value, peroxide value, and unsaturated fatty acids were determined at different irradiation times (0, 5, 10, 20, and 40 min). The results showed that UV irradiation increased significantly the lightness of peanut oil in 40 min of exposure time, and it was strongly exponential correlated with the treatment time (R = 0.9947). However, the acid value and peroxide value were increased slightly at 10 min of irradiation time, and reached to 3.62 ± 0.07 mmol/kg and 1.38 ± 0.02 mg/g at 40 min of irradiation time with acceptable levels, respectively. In addition, UV irradiation obviously destroyed the unsaturated fatty acids in peanut oil in various degrees, and their decreases were time dependent.

Introduction

Peanut oil is the main edible vegetable oil for consumers in China and other Asian countries owning to its high nutrient content, pleasant flavor, palatability, and cooking results. However, newly pressed peanut oil is often contaminated by aflatoxin B1 (AFB1) came from AFB1-contaminated peanut. AFB1 belongs to a group of fungal toxins known as mycotoxins, and it is associated with both acute and chronic toxicity in animals and humans including acute liver damage, liver cirrhosis, and liver cancers (Wagacha and Muthomi, 2008; Zain, 2011). Chronic toxicity associated with ingestion of low doses of AFB1 in peanut oil is of greater concern.

Since aflatoxins are known to be genotoxic and carcinogenic, people have been looking for the effective methods for detoxification. Presently, various physical, chemical, and biological methods have been used to decomposed aflatoxins in foods (Netke *et al*., 1997; Das and Mishra, 2000; Haskard *et al*., 2000). UV irradiation as an effective physical method has been used to destroy aflatoxins for many years in food industry (Yousef and Marth, 1986; Samarajeewa and Gamage, 1988). Specifically, Liu *et al.* (2011a) have also obtained three photogradation products of aflatoxin B1 in a model system.

However, most of UV-irradiation detoxification studies were done in a mode system (Liu *et al*., 2011a), and only in a static state for the products being irradiated (Liu *et al.*, 2011b), so its practical application in food industry still needs a systematic study. In this study, a laboratory photodegradation reactor designed in the lab was used to decompose AFB1 in peanut oil. For the reactor, the choice of UV wavelength and irradiation intensity, the thickness of peanut oil, irradiation time, and cooling of oil after being irradiated are all concerned. The reactor can be operated continuously and applied in large-scale production, which makes it suitable for the detoxification of peanut oil in the oil industry.

Reported literatures have found that different processing methods affect the physicochemical properties of vegetable oils (Hassanein *et al*., 2003; Chemat *et al.*, 2004; Zeng *et al.*, 2010). Hassanein *et al*. (2003) reported that the peroxide value, free acidity and color absorbance of vegetable oils were proportionally increased with the increase of microwave heating time, while the total tocopherol contents and polyunsaturated fatty acids were decreased. Chemat *et al*. (2004) reported that the peroxide value of sunflower oil was increased when it was treated by ultrasound wave, and its flavor and composition were deteriorated. Zeng *et al.* (2010) reported that little change of the composition of peanut oil was observed after pulsed electric field treatment, while the peroxide value was increased significantly. Kolakowaka (2003) reported that there were obvious changes in the chemical composition of lipids and other quality deterioration when exposed to high doses of UV light.

UV irradiation results in the formation of free radicals, such as lipid radicals, superoxide radicals and H_2O_2, and catalyzes other oxidation process

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(Kolakowska, 2003). However, up to now, few researches focusing on the effects of UV-irradiation on quality of peanut oil have been reported. The objective of this study was to investigate the effects of UV-irradiation on physicochemical properties of peanut oil during the UV-detoxification process using a laboratory-scale reactor.

Materials and Methods

Materials and reagents

The peanut oil was prepared by extruding aflatoxin-contaminated peanut with a screw-press machine (TGF-1, Tiangongfang Co., Ltd., China) in the lipid laboratory, Shandong Agricultural University. The extracted peanut oil was filtered to remove the impurities. The standard unsaturated fatty acids (oleic acid, linolic acid, linolenic acid, and eicosenoic acid) were purchased from Sangon Biotech (Shanghai, China). All other reagents in this experiment were of analytical grade, purchased from Keshang Biochemical Reagents Co., Ltd. (Taian, China).

Laboratory photodegradation reactor and treatment

A laboratory-scale reactor (Figure 1) was constructed and the reaction conditions were optimized for the removal of AFB1 in peanut oil. The reactor includes fluid conveying system (pump, valve, flowmeter and pipe), UV irradiation system (six UV lamps, fluid distributing pipe, and fluid guiding plate), water-cooling system, and oil sump. The reactor was operated in a closed irradiation chamber for preventing operators from being injured. The detoxification was done in a recirculation mode by the continuous pumping of peanut oil to the UV irradiation system. UV irradiation can raise the temperature of oil, deteriorate its quality, so it is necessary to cool it immediately with a water-cooling system after being irradiated. System parameters, such as UV wavelength, irradiation intensity, irradiation time, and flow rate of oil, are all shown to influence the photodegradation rate of AFB1 to varying degrees. The optimal experimental design and response surface methodology were employed in this regard.

Throughout the study, the UV lamps (power 36 W) with a wavelength of 365 nm and irradiation intensity of 6.4 mW/cm^2 were used to treat peanut oil. The thickness of oil was less than 3 mm by controlling its flow rate at 0.55 L/min with a flowmeter (LZM-15GF, Jintai Ltd., China). The peanut oil samples were pumped (MP-20R, Xinxishan, Shanghai) to the irradiation chamber to receive the UV irradiation for

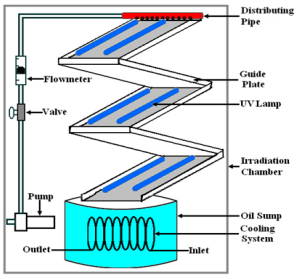

Figure 1. Diagram of experimental photo-degradation reactor

0, 5, 10, 20, and 40 min, respectively. The treated samples were cooled immediately to the room temperature with a water-cooling system after being irradiated. The untreated sample was used as the control.

Measurement of color

The color of peanut oil was determined by a Minolta chroma meter (Model CR-400, Konica Minolta Sensing, Japan) using the Hunter scale for L, a, and b. L represents lightness with a range from 0 (black) to 100 (white); a represents red (+a) or green (-a), and b represents yellow (+b) or blue (-b). Oil sample was placed in a 9-cm diameter plate, and a chromametric calibration plate was used as background. In this study, only L value was used as the color change. The higher the value, the lighter the oil.

Determination of acid value and peroxide value

The acid value of peanut oil was determined according to the number of milligrams of potassium hydroxide necessary to neutralize the free acids in 1 g of sample (GB/T 5530-2005, China). The peroxide value was determined with the method GB/T 5538-2005, China, and expressed as mmol active oxygen/kg of oil.

Determination of unsaturated fatty acids

Oil sample was converted to its methyl ester prior to analysis by gas chromatography (GC). Oil sample (100 mg) was resolved with 4 mL of n-hexane in a centrifuge tube, and then 2 mL of 1 mol/L methanolic KOH was added in the tube to methylate at 40^{o}C for 30 min. 2 mL of saturated NaCl solution was added to the reaction mixture with strenuous vibration, and allowed to cool after thorough mixture. The lower aqueous methanol layer was allowed to separate and discard while 2 mL of the upper hexane layer was separated and transferred to a dry centrifuge tube. 1 g of Na_2SO_4 without water was added to the centrifuge tube to remove the moisture in methyl ester. GC analyses were conducted under the following conditions: a fused-silica capillary

column (Rtx-Wax, 0.25 μm film thickness, 30 m × 0.25 mm i.d.) and a flame-ionization detector (FID) were used; nitrogen was used as the carrier gas; flow rate was 0.8 mL/min; split ratio was 1:10. The initial column temperature was 180°C for 1 min, raised to 230°C at 10°C/min, and maintained for 6 min. The injector and FID temperatures were 230°C and 280°C, respectively. 1 μL of sample was injected by autosampler. Unsaturated fatty acids were identified by comparing the retention time of the chromatograph peak with that of authentic standard.

All experiments were carried out at least three times, and all values were expressed as means ± standard deviation (SD). The differences between the control and treated samples were compared by t-test using SPSS 18.0 software. The results were considered significant if the P values were less than 0.05.

Results and Discussion

Measurement of color

The color changes of peanut oil before and after UV irradiation are shown in Figure 2. Seen from the Figure 2, the L value increased with the increase of UV exposure time, i.e. the color of peanut oil changed lighter than that of the control without UV treatment. In addition, the increase of L value was significant in 40 min ($P < 0.05$), and strongly exponential correlated with the treatment time ($R = 0.9947$). The increase of L value may be due to the destruction of natural pigments (such as anthocyanins and anthocyanidins) in peanut oil induced by UV irradiation (Bakhshayeshi *et al*., 2006), or due to the oxygenolysis induced by the free radicals produced from UV irradiation (Wang *et al*., 2009). So UV irradiation can improve the organoleptic quality of peanut oil.

Determination of acid value and peroxide value

The peroxide value (POV) and acid value (AV) of untreated and UV-treated peanut oils at different irradiation times are shown in Figure 3. In 10 min of UV exposure, the POV of peanut oil was insignificantly increased ($P > 0.05$), while after 10 min, it was significantly increased from 3.11 ± 0.04 mmol/kg (untreated) to 3.60 ± 0.18 mmol/kg ($P < 0.05$) in 20 min, and then slowly reached to 3.62 ± 0.07 mmol/kg in 40 min ($P > 0.05$). For the AV of peanut oil, no significant increase was observed in 20 min of UV exposure ($P > 0.05$), while it was increased from 1.33 ± 0.02 mg/g (untreated) to 1.38 ± 0.02 mg/g after being irradiated for 40 min. According to the requirements of the Chinese standard (GB 1534-2003), the POV and AV of the crude peanut oil are less than 7.5 mmol/kg^{-1} and 4.0 mg/g, so it can be concluded that the quality of peanut oil was acceptable after being irradiated for 40 min.

Table 1. Changes of unsaturated fatty acids in peanut oil during the UV treatment (mg/100 mg)

Unsaturated fatty acid	UV irradiation time (min)				
	0	5	10	20	40
Oleic acid (C18:1)	34.18±0.34^{a}	34.02±2.66^{a}	32.21±1.23^{ab}	31.56±0.69^{b,**}	30.69±1.16^{b,**}
Linolic acid (C18:2)	27.28±0.30^{a}	26.39±0.60^{a}	24.90±0.12^{b,**}	24.52±0.49^{b,**}	23.16±0.55^{c,**}
Linolenic acid (C18:3)	0.11±0.00^{a}	0.10±0.02^{a}	0.09±0.00^{b,**}	0.09±0.01^{b,**}	0.08±0.01^{b,**}
Eicosenoic acid (C20:1)	0.68±0.01^{a}	0.67±0.03^{a}	0.64±0.01^{b,**}	0.63±0.02^{b,**}	0.54±0.01^{c,**}

All values represent the means ± standard deviation; n=3

^{a,b,c}statistically significant differences in the same row are indicated by different superscripts ($P<0.05$)

**statistically significant differences in the fatty acid contents between treated and untreated samples ($P<0.01$).

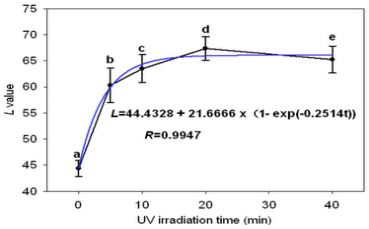

Figure 2. L value of peanut oil at different UV irradiation times. (a, b, c, d, and e represent statistically significant differences in L value compared with that of the control).

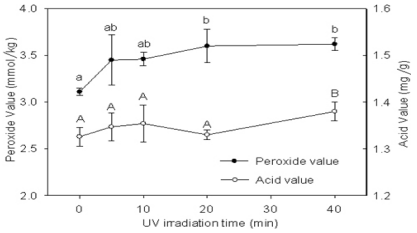

Figure 3. Changes of peroxide value and acid value of peanut oil at different UV irradiation times. (a, b or A, B represent statistically significant differences in peroxide value and acid value compared with those of the control, respectively).

Determination of unsaturated fatty acids

The saturated acids are relatively stable in food processing, and many published studies have indicated that different processing methods rarely affected them, while unsaturated fatty acids were affected obviously (Xu *et al*., 1999; Saffan, 2008; Zeng *et al*., 2010). In this study, so the composition and contents of the unsaturated fatty acids in UV-treated peanut oil are mainly concerned, and the results are presented in Table 1. It was demonstrated that various unsaturated fatty acid contents significant decreased in 40 min of UV exposure ($P < 0.01$). The oleic acid content decreased from 34.18 ± 0.34 mg/100 mg for the untreated oil to 32.21 ± 1.23 mg/100 mg for the treated one in 10 min of irradiation ($P > 0.05$), meanwhile, the linolic acid, linolenic acid, and eicosenoic acid were significantly decreased by 8.72%, 18.18%, and 5.88%, respectively, compared with those of the control ($P < 0.01$). The results revealed that UV

irradiation obviously affected the unsaturated fatty acids of peanut oil, and their decreases were time dependent. Therefore, the irradiation time should be as short as possible to reduce the nutrition loss of oil during the detoxification process.

Conclusions

Our study shows that UV irradiation improved the light, increased the peroxide value and acid value of peanut oil, but decreased the contents of unsaturated fatty acids using a laboratory-scale reactor. In 10 min of exposure time, the peroxide value and acid value have not significantly increased, and the losses of unsaturated fatty acids are at acceptable levels. In addition, UV irradiation produced some free radicals in peanut oil, which further accelerated the oxidation of unsaturated fatty acids, and then raised its peroxide value, so the storage stability of peanut oil after irradiation needs to be further researched.

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