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ARTICLE

Comparison of the retention rates of thiamin, riboflavin, and niacin between normal and high-oleic peanuts after roasting

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Abstract This study investigated the amounts of thiamin, riboflavin, and niacin in normal and high-oleic peanuts and compared the retention rates after roasting via HPLC analysis. Method validation showed a high linearity ($r^2 > 0.99$), and the limits of detection and quantification were 0.001–0.038 and 0.002–0.115 μg/mL, respectively. Accuracy and precision were confirmed using standard reference materials. Thiamin content was not significantly different between the normal and high-oleic cultivars; however, it significantly decreased in the roasted peanut cultivars. Although there were no significant differences in riboflavin between the cultivars, a significantly increased amount of riboflavin was observed in the roasted peanuts, which confirms that riboflavin is highly stable to thermal treatment such as roasting. With only a small difference between the cultivars, niacin showed a decreased retention rate with roasting in normal cultivars, but a significantly increased retention rate with roasting in high-oleic cultivars. The amount of thiamin, riboflavin, and niacin present in peanuts and their retention rates after roasting showed variations among the cultivars. This study provides basic data on the water-soluble vitamins in raw and roasted peanuts.

Keywords High-oleic peanuts · Niacin · Retention rate · Riboflavin · Thiamin

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Introduction

The peanut, a nutritionally high-value legume, has been widely utilized as a food material since 950 B.C. in South America [1]. The cultivation and research of peanuts has continuously advanced, and a myriad of studies have focused on increasing its production, product quality, and developing cultivars that are highly resistant to insects [2]. Consumption of peanuts leads to reduced body weight, attenuated blood pressure, and decreased serum cholesterol [3]. In general, normal peanuts are composed of 50% fat-soluble components, 25% proteins, and various water-soluble vitamins. Peanuts include a variety of fat-soluble fatty acids, primarily oleic acid (55%) and linoleic acid (25%). High-oleic cultivars, containing more than 80% oleic acid and less than 5% linoleic acid, have been developed through breeding improvements since the 1980s [4–6]. According to the literature, two genes, *ahFAD2A* and *ahFAD2B*, were identified that are relevant to the proportion of oleic acid in peanuts. High activation of these two genes increased the fatty acid composition of normal cultivars, while low activation resulted in cultivars with a high proportion of oleic acid (> 80%) [7–9]. In South Korea, our research team investigated the fat-soluble nutrients and oxidative stability of high-oleic peanuts as compared with normal cultivars [10]. Another study compared the antioxidant activities based on the amount of polyphenol compounds and sensory characteristics between high-oleic peanuts and normal cultivars [11].

Vitamins, the trace nutrients present in foods and food materials, are essential for higher animals to survive, and need to be ingested through food, as only minimal-to-no vitamins are synthesized in the body [12]. Vitamins are categorized into fat- and water-soluble vitamins. Among

the water-soluble vitamins, thiamin (vitamin B_1) was discovered first. Thiamin regulates in vivo enzyme activities and plays paramount roles in carbohydrate metabolism. It is also known to stimulate appetite and digestion and is involved in neuromodulatory functions [13]. Riboflavin (vitamin B_2) is involved in growth promotion, oral mucosal protection, and in vivo oxidation and reduction. Riboflavin deficiency can cause stunted growth in children, stomatitis, glossitis, and angular stomatitis [14]. Niacin (vitamin B_3) governs the oxidation and reduction of nutrients, dilates peripheral blood vessels to promote blood circulation, and reduces cholesterol levels in the body. When scarce, however, it can cause pellagra, black tongue disease, and dermal and mucosal damage [15]. Although studies have reported on the functional properties of the vitamins, only a few of them have investigated the stability of the vitamins in a variety of complex food matrices. The prediction of changes in stability induced by different chemical forms is known to be difficult [12]. Thiamin is not thermally stable, having a low retention rate at 100 °C and higher temperatures. Riboflavin is oxidatively and thermally stable but can easily be devitaminized under alkali conditions and UV exposure. Niacin exhibits relatively superior thermal stability compared with vitamins thiamin and riboflavin, but shows a high affinity for hydrolysis in acid and alkali solutions [16]. To this end, the processing methods to maintain the stability of water-soluble vitamins in foods and food materials need investigation, and studies have investigated methods to increase the retention rate of water-soluble vitamins by applying a minimal amount of cooking water and reduced heating time [17]. Additionally, studies comparing nutrient compositions in peanuts between normal cultivars and high-oleic cultivars have mainly focused on fat-soluble components and the related aroma and flavor components, but only a handful of studies have compared the amounts of water-soluble vitamins [18–20]. A previous study by our research team [21] also compared the amount of a fat-soluble vitamin of peanuts, tocopherol, in normal and high-oleic cultivars, and the result showed that normal cultivars contained higher tocopherol levels than high-oleic cultivars.

Therefore, the objective of this study was to investigate the amounts of thiamin, riboflavin, and niacin in normal and high-oleic peanut cultivars, and examine the retention rates of the vitamins after roasting, a conventional peanut processing method.

Materials and methods

Materials

The normal cultivars used in this study, *Daekwang* and *Poongan*, and high-oleic cultivars, *K-Ol* and *Milyang#14*, were provided by the National Institute of Crop Science at the Rural Development Administration (Milyang, Gyeongnam, Republic of Korea). All peanut samples were cultivated from 2016 to 2017 and were provided fresh. The samples were vacuum-packaged upon arrival to prevent acidification and stored at − 20 °C until analysis. Thiamine hydrochloride; riboflavin-5′-adenosine diphosphate (FAD), riboflavin-5′-phosphate (FMN), and riboflavin; and nicotinic acid and nicotinamide, were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA) and used as standards for vitamin B_1, B_2, and B_3 analysis, respectively. All other chemicals used in the study were analytical grade and purchased from Sigma-Aldrich Co.

Extraction and pretreatment

To extract vitamins thiamin and niacin from peanuts, a method outlined by Kim et al. [22] was used. Briefly, 25 mL of a 5 mM sodium 1-hexanesulfonate solution was added to 5 g of homogenized sample and extracted by a sonicator (8510E-DTH, Branson, Danbury, CT, USA) at 40 °C for 30 min, followed by centrifugation of the extracts at 15,000 rpm for 10 min (Smart 15, Hanil, Seoul, Republic of Korea). The supernatant was then passed through a 0.45-μm syringe filter for water-soluble solvents (Whatman Inc., Maidstone, UK). To extract vitamin B_2 from peanuts, a method by Kim et al. [22] and a vitamin analysis method by Food Codex 1.2.2.3 [23] were utilized. That is, 5 g of a homogenized sample was dissolved in 50 mL distilled water and a reflux extraction method was then applied in an 80 °C water bath (SH-502, Seyoung Co., Incheon, Republic of Korea) for 30 min. The extracts underwent a first filtration through a Whatman No. 1 filter paper (Whatman, Amersham, UK) and then a second filtration with a 0.45-μm syringe filter for water-soluble solvents.

HPLC analysis

To determine the amounts of thiamin and niacin in raw and roasted peanuts, an Agilent 1100 infinity HPLC with a diode array detector (Agilent Co., Wilmington, DE, USA) was used. The column used for separation was a YMC-Pack ODS AM (250 × 4.6 mm, 5 μm) and used at 40 °C. The wavelength of the detector was set to 270 nm. The mobile phase for solvent A was a mixture of 7.5 mL acetic

acid, 0.2 mL triethylamine, and 5 mM sodium 1-hexanesulfonate and solvent B was methanol (solvent B), and the analysis was carried out under a linear gradient elution. The flow rate of the mobile phase was set to 0.8 mL/min, and the mobile phase was varied as follows: 0 min: 100% solvent A, 8 min: 100% solvent A, 20 min: 75% solvent A, 30 min: 55% solvent A, 31 min: 100% solvent A, 45 min: 100% solvent A (Table 1). An Agilent 1100 HPLC system (Agilent Co.) with a fluorometric detector was utilized to determine the amount of vitamin B_2. The analytical column used for separation was a YMC-Pack Pro RS C_{18} (250 × 4.6 mm, 5 μm, YMC, Seongnam, Republic of Korea) and used at 40 °C. The wavelengths of the detector were set to 445 nm for excitation and 530 nm for emission. The mobile phase was prepared with 10 mM NaH_2PO_4 (pH 5.5) and methanol (75:25, v/v), and the analysis was conducted at a flow rate of 0.8 mL/min under isocratic elution conditions (Table 1) [23].

Calculation of vitamin amount

Utilizing the standards, the vitamin amounts were calculated using the formula below.

$$\text{Vitamin amount (mg/100 g)} = \frac{S \times a \times b}{\text{sample weight (g)}} \times \frac{100}{1000} \quad (1)$$

where S concentration of the extracted solution standards (μg/mL), a total volume of the extracted solution (mL), and b dilution factor of the extracted solution.

Limit of detection (LOD) and limit of quantification (LOQ)

Using the calibration curves of the standard reference materials for thiamin, riboflavin, and niacin, the LOD and LOQ were calculated using the equations below [24]:

$$\text{LOD} = 3.3 \times \delta/S \quad (2)$$

$$\text{LOQ} = 10 \times \delta/S \quad (3)$$

where δ is the standard deviation of the Y-intercept of the standard curve and S is the mean of the slope.

Method validation of thiamin, riboflavin, and niacin using the standard reference materials

To validate the methods for thiamin, riboflavin, and niacin analysis, the standard reference materials (SRM) 1849a (Infant/adult nutritional formula) and SRM 2387 (peanut butter) were purchased from NIST (National Institute of Standards and Technology, Gaithersburg, MD, USA).

Statistical analysis

The amounts of the water-soluble vitamins thiamin, riboflavin, and niacin were analyzed using an SAS 9.1 (Statistical Analysis System, SAS Institute Inc., Cary, NC, USA). A paired t test ($P < 0.05$) was used to determine significance.

Table 1 HPLC operating condition for vitamin thiamin, riboflavin, and niacin analyses

	Thiamin and Niacin	Riboflavin
Instrument	Agilent 1100 series	Agilent 1100 series
Column	YMC-Pack ODS AM (250 mm × 4.6 mm, 5 μm)	YMC PRO RS C18 (250 mm × 4.6 mm, 5 μm)
Column temp.	40 °C	40 °C
Detector	Diode array detector (270 nm)	FLD (Ex = 445 nm, Em = 530 nm)
Flow rate	0.8 mL/min	0.8 mL/min
Mobile phase	A: 5 mM sodium 1-hexanesulfonate (acetic acid 7.5 mL + triethylamine 0.2 mL/1 L)	10 mM NaH_2PO_4 (pH 5.5): MeOH = 75:25 (v/v)
	B: 100% MeOH	
Gradient profile	0 min: A 100%	Isocratic
	8 min: A 100%	
	20 min: A 75% + B 25%	
	30 min: A 55% + B 45%	
	31 min: A 100%	
	45 min: A 100%	
Injection volume	20 μL	20 μL

Results and discussion

Method validation

The analysis of thiamin, riboflavin, and niacin in peanut cultivars was validated via linearity, LOD, and LOQ using SRM. The results are shown in Table 2. Thiamin, riboflavin, and niacin all exhibited r^2 values of 0.991–0.999, indicating high linearity. The LOD showed the highest value for vitamin thiamin with 0.038 μg/mL, followed by 0.019 and 0.008 μg/mL for the nicotinic acid and nicotinamide forms of niacin, respectively. Riboflavin as analyzed by the fluorometric detector demonstrated a lower LOD value (FAD, 0.004 μg/mL; FMN, 0.001 μg/mL; riboflavin, 0.001 μg/mL) than thiamin and niacin as analyzed by the UV detector. Like the LOD, the LOQ exhibited the highest value for thiamin with 0.115 μg/mL, followed by 0.056 and 0.025 μg/mL for the nicotinic acid and nicotinamide forms of niacin, respectively. Riboflavin analyzed by FLD showed lower LOQ values (FAD, 0.013 μg/mL; FMN, 0.002 μg/mL; riboflavin, 0.002 μg/mL) than vitamins thiamin and niacin analyzed by the UV detector. A previous study analyzing the LOD of water-soluble vitamins in baby milk using HPLC reported less than 0.1 μg/mL for thiamin and less than 0.05 μg/mL for riboflavin and niacin [25]. Kim et al. [26] also found a LOD of 0.011 μg/mL for thiamin, 0.014 μg/mL for riboflavin, 0.044 μg/mL for nicotinic acid, and 0.024 μg/mL for nicotinamide. Based on the results from the previous studies, the LOD ranges of the present study are reasonable, confirming the validity of our analysis of thiamin, riboflavin, and niacin in peanut cultivars.

Accuracy and repeatability of the analysis were examined using SRM, and the results are described in Table 3. The ranges of analytical values were within with the ranges certified by NIST. Bias values, the difference between the certified values and analytical values, were very small (0.07 for thiamin, 0.09 for riboflavin, and 1.20 for niacin). The relative standard deviation (%RSDr) was below 10%, and the Z value, which indicates significance when absolute values are within ± 2, was − 1.4, 1.8, and 1.2 in vitamins thiamin, riboflavin, and niacin, respectively, confirming the reliability of the analysis.

Thiamin

The amounts of thiamin in normal peanuts and high-oleic peanuts, as well as changes in retention rates after roasting, were investigated. The results are shown in Fig. 1 and Table 4. In Fig. 1, thiamin showed a retention time of 21 min. Raw peanuts contained 0.77 ± 0.11 and 0.81 ± 0.01 mg/100 g of thiamin in the normal cultivars,

Table 2 Linearity, limit of detection (LOD), and limit of quantification (LOQ) of vitamin thiamin, riboflavin, and niacin by HPLC analyses

Vitamins	Compounds	Calibration curve	r^2	Linear range (μg/mL)	LOD (μg/mL)	LOQ (μg/mL)
Thiamin	Thiamin	$Y = 41.81x + 0.87$	0.999	0.078–0.625	0.038	0.115
Riboflavin	FAD	$Y = 47.01x + 0.08$	0.991	0.0178–0.1425	0.004	0.013
	FMN	$Y = 413.53x - 5.24$	0.991	0.0166–0.1331	0.001	0.002
	Riboflavin	$Y = 964.71x - 35.54$	0.996	0.1419–1.1350	0.001	0.002
Niacin	Nicotinic acid	$Y = 40.36x - 0.14$	0.991	0.020–0.156	0.019	0.056
	Nicotinamide	$Y = 32.95x - 0.46$	0.999	0.625–5.000	0.008	0.025

FAD flavin adenine dinucleotide, *FMN* flavin mononucleotide

Table 3 Accuracy and repeatability precision (%RSDr) for the analysis of thiamin, riboflavin, and niacin in standard reference materials (SRM 1849a and SRM 2387)

Vitamins	Contents (mg/100 g)			% of certified value	%RSDr	Z value
	Certified value[a]	Analytical value[b]	Bias			
Thiamin (SRM 1849a)	1.25 ± 0.09	1.32 ± 0.12	0.07	105.60	9.09	− 1.4
Riboflavin (SRM 1849a)	2.03 ± 0.05	1.94 ± 0.07	0.09	95.57	3.61	1.80
Niacin (SRM 2387)	10.80 ± 1.00	9.60 ± 0.08	1.20	88.89	0.83	1.2

[a]The certified reference values for the vitamin thiamin, riboflavin, and niacin in SRM 1849a and SRM 2387 were derived from the combination of results provided by NIST and collaborating laboratories

[b]Values (mean ± SD) are based on five replicate analyses

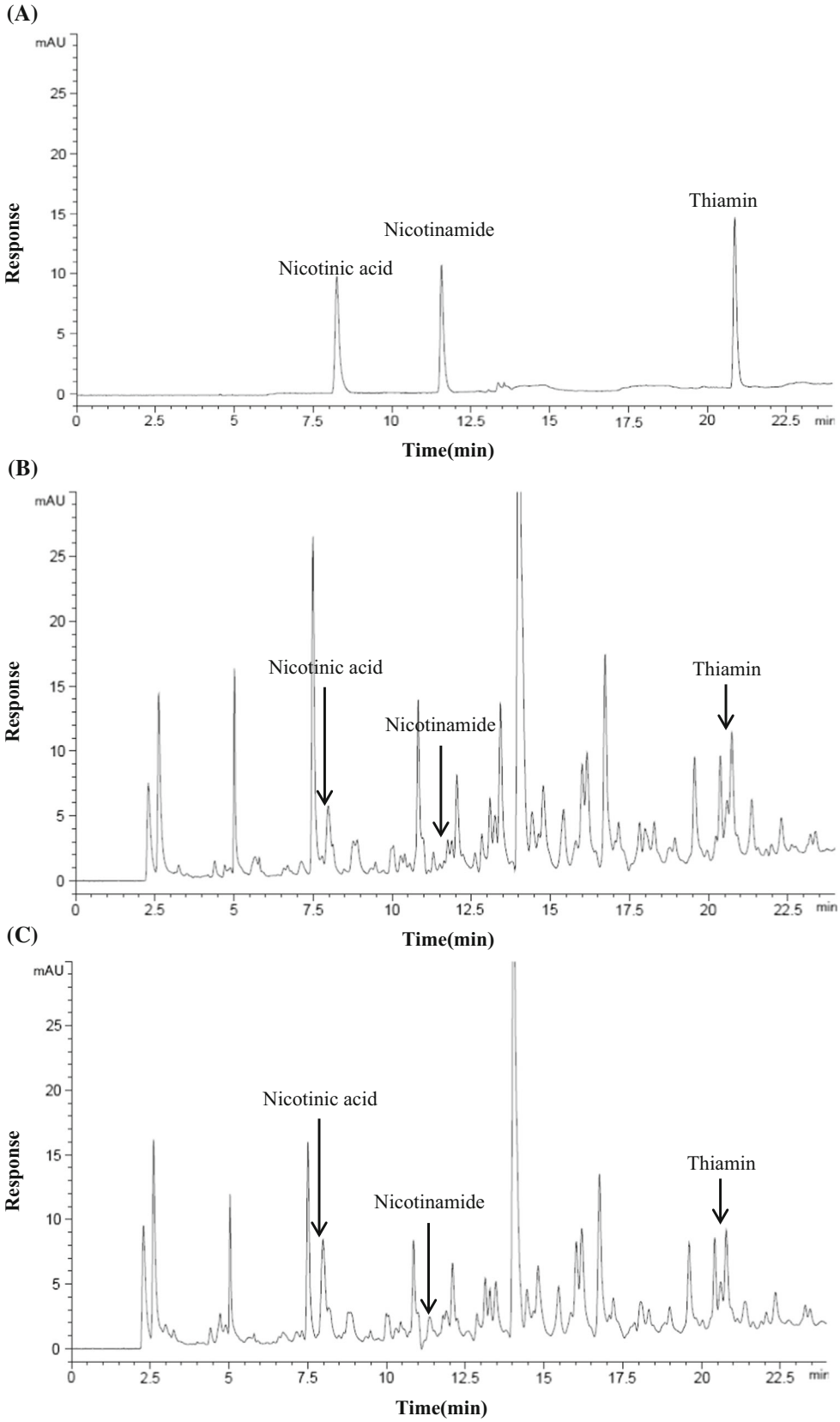

Fig. 1 Typical chromatograms of thiamin and niacin in standards (**A**), raw peanuts (**B**) and roasted peanuts (**C**)

Table 4 Contents of thiamin in raw and roasted peanuts

Type	Contents (mg/100 g) Thiamin
Normal	
Daekwang	
Raw	0.81 ± 0.01[a]
Roasted	0.22 ± 0.11[b]
Poongan	
Raw	0.77 ± 0.11[a]
Roasted	0.55 ± 0.08[b]
High-oleic	
K-Ol	
Raw	0.99 ± 0.02[a]
Roasted	0.74 ± 0.05[b]
Milyang#14	
Raw	0.60 ± 0.02[b]
Roasted	0.88 ± 0.13[a]

Data were expressed as mean ± standard deviation

Different letters (a, b) correspond a significant difference between raw and roasted peanuts within same cultivar ($P < 0.05$)

whereas the high-oleic cultivars contained 0.60 ± 0.02 and 0.99 ± 0.02 mg/100 g of thiamin, indicating no statistically significant difference in thiamin amounts between normal and high-oleic cultivars ($P > 0.05$). Comparing only two types of peanuts is, however, somewhat limited for elucidating significant differences between normal and high-oleic cultivars; therefore, studies need to consistently perform comparisons among the cultivars. Based on the USDA Nutrient Database Report [27] that reported 0.64 mg/100 g of thiamin in normal peanut cultivars, the cultivars analyzed in this study were confirmed to have higher amounts of thiamin than the reported value. Previous studies found that the amount of nutrients contained in peanuts can differ greatly due to extrinsic factors including cultivation period, location, and weather, as well as the type of cultivar [28–30]. After roasting, thiamin exhibited 27 and 71% retention rates in normal cultivars, while high-oleic cultivars showed 74 and 146% retention rates, indicating a decrease in the amount of thiamin in 3 out of 4 samples. The USDA Nutrient Database Report [27] reported 0.15 mg/100 g of thiamin in roasted peanuts, which is calculated to be a 23% retention rate when compared with 0.64 mg/100 g of thiamin in raw peanuts. Thiamin is highly vulnerable to thermal treatment and is therefore known to have a low retention rate in general [16]. High temperature and prolonged duration of thermal treatment easily break molecular ring structures and methylene group chemical bonds in thiamin, leading to devitaminization [31]. Although thiamin is relatively stable at 100 °C, its loss rate increases to 35% at the pasteurization temperature of 121 °C. The loss rate induced by high temperature can be retained to a certain extent by structures in the food, such as stabilization through bonds with proteins [32]. Thiamin possesses a paramount acid resistance at pH 2.0–4.0, with decreased stability in alkali conditions [31]. Additionally, thiamin loss in food not only occurs during cooking processes, but due to hot water during washing, and therefore, reduced hot water and cooking time will help increase the retention rates of thiamin [17].

Riboflavin

The amount of riboflavin in normal and high-oleic peanuts and changes in retention rate after roasting were examined. The results are shown in Fig. 2 and Table 5. In Fig. 2, FAD, FMN, and riboflavin were separated with retention times of 5.2, 8.1, and 15.2 min, respectively. FAD was not detected in normal peanuts, and after roasting, 0.01, 0.02, and 0.02 mg/100 g of FAD were identified in *Daekwang*, *K-Ol*, and *Milyang#14* cultivars, respectively. All normal and high-oleic peanut samples contained 0.01 mg/100 g of FMN, and *Daekwang*, *Poongan*, *K-Ol*, and *Milyang#14* cultivars exhibited 0.05, 0.06, 0.12, and 0.12 mg/100 g of FMN, respectively, after roasting. Riboflavin, on the other hand, was found in amounts of 0.02, 0.02, 0.05, and 0.02 mg/100 g in *Daekwang*, *Poongan*, *K-Ol*, and *Milyang#14* cultivars, respectively, but was reduced to 0.01, 0.01, 0.01, and 0.00 mg/100 g, respectively, after roasting. Thus, when considering all three forms together, roasting causes a two–sevenfold increase in the amount of riboflavin. Statistically significant differences were not observed in the amount of riboflavin between normal and high-oleic peanuts ($P > 0.05$), but significant differences were found between raw and roasted peanuts ($P < 0.05$). This increase in riboflavin after roasting was also seen in the USDA Nutrient Database Report [27], which reported 0.14 and 0.20 mg/100 g of riboflavin in raw peanuts and roasted peanuts, respectively. Riboflavin is stable to oxidation and thermal treatment; however, it is susceptible to destruction under alkaline conditions and exposure to visible and UV light [17]. Although riboflavin, as a strong oxidizing agent, easily reacts with radicals such as hydrogen ions, it is stable to external chemical energy and is reversibly reduced to dihydroriboflavin by a reducing agent [33]. Riboflavin also binds to proteins within foods, enabling the protection of prosthetic groups. Therefore, the relatively lower loss of riboflavin compared with thiamin in the results of this study can be explained by vitamin precursors that are converting into activated vitamins, thus increasing the measured amounts of riboflavin. In addition, increased amounts of riboflavin released from foods will

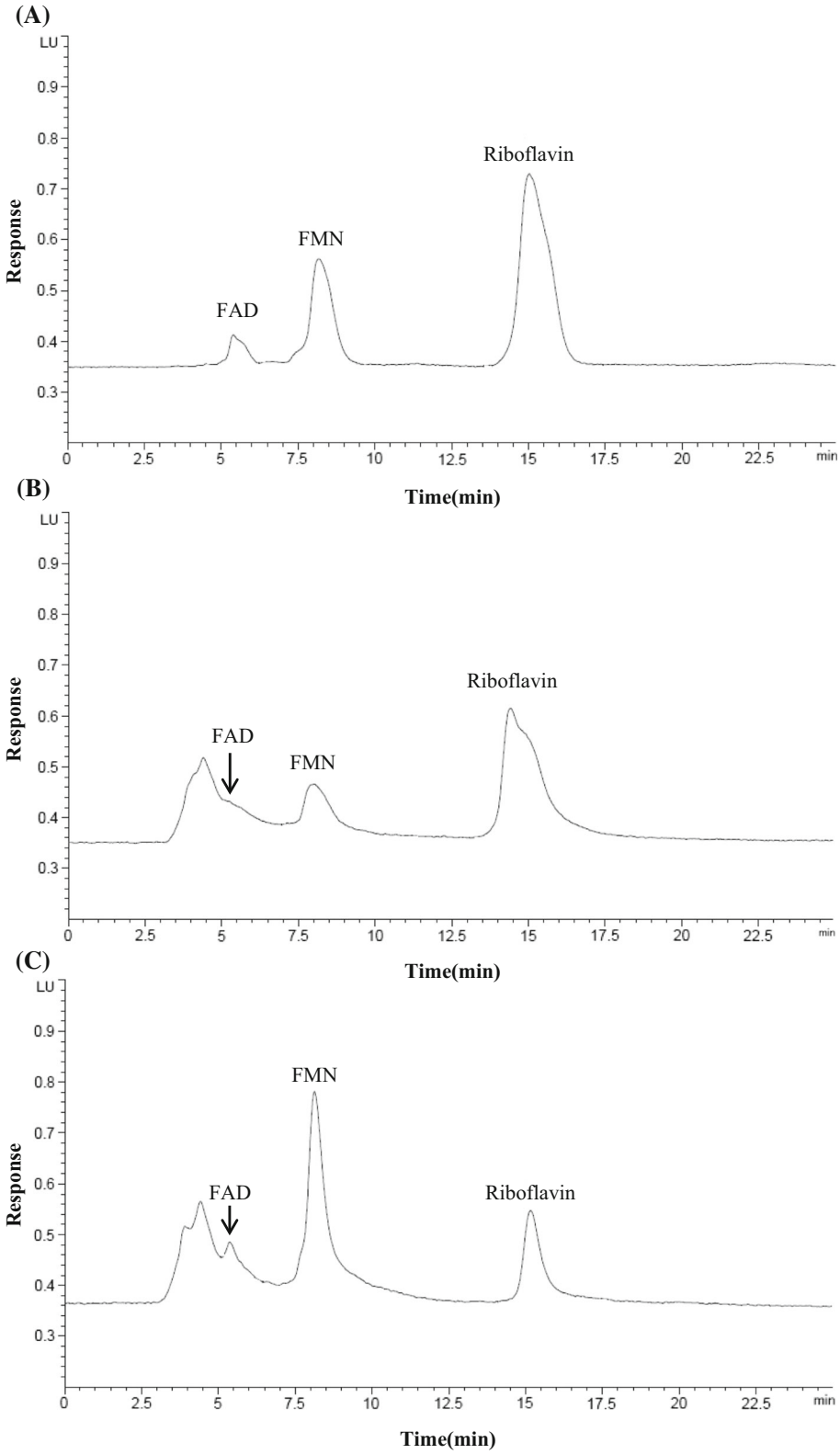

Fig. 2 Typical chromatograms of riboflavin in standards (**A**), raw peanuts (**B**) and roasted peanuts (**C**)

induce an increase in extraction efficiency and therefore may heighten the measured amount of riboflavin [34]. Lee et al. [12] found that riboflavin exerted superior heat-induced dissolution rates and sensitivity against humidity compared with other water-soluble vitamins. FMN and FAD are reported to be readily converted into riboflavin at

Table 5 Contents of riboflavin in raw and roasted peanuts

Type	Contents (mg/100 g)				
	FAD	FMN	Riboflavin	Total riboflavin Eq.	Total riboflavin
Normal					
Daekwang					
Raw	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	0.02 ± 0.00^{a}	0.03 ± 0.00^{b}	0.03 ± 0.00^{b}
Roasted	0.01 ± 0.00^{a}	0.05 ± 0.01^{a}	0.01 ± 0.00^{b}	0.06 ± 0.01^{a}	0.07 ± 0.01^{a}
Poongan					
Raw	0.00 ± 0.00	0.01 ± 0.00^{b}	0.02 ± 0.00^{a}	0.03 ± 0.00^{b}	0.03 ± 0.00^{b}
Roasted	0.00 ± 0.00	0.06 ± 0.01^{a}	0.01 ± 0.00^{b}	0.06 ± 0.01^{a}	0.07 ± 0.01^{a}
High-oleic					
K-Ol					
Raw	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	0.05 ± 0.01^{a}	0.06 ± 0.00^{b}	0.06 ± 0.00^{b}
Roasted	0.02 ± 0.01^{a}	0.12 ± 0.01^{a}	0.01 ± 0.00^{b}	0.11 ± 0.01^{a}	0.15 ± 0.01^{a}
Milyang#14					
Raw	0.00 ± 0.00^{b}	0.01 ± 0.00^{b}	0.02 ± 0.00^{a}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}
Roasted	0.02 ± 0.01^{a}	0.12 ± 0.01^{a}	0.01 ± 0.00^{b}	0.10 ± 0.01^{a}	0.14 ± 0.01^{a}

Data were expressed as mean ± standard deviation. Different letters (a, b) correspond a significant difference between raw and roasted peanuts within same cultivar ($P < 0.05$)

FAD flavin adenine dinucleotide, *FMN* flavin mononucleotide, *Total riboflavin eq.* Total riboflavin equivalent = (FAD × 0.4537 + FMN × 0.7869 + riboflavin)

Table 6 Contents of vitamin niacin in raw and roasted peanuts

Type	Contents (mg/100 g)		
	Nicotinic acid	Nicotinamide	Total niacin
Normal			
Daekwang			
Raw	0.33 ± 0.02^{a1}	0.28 ± 0.02^{a}	0.61 ± 0.04^{b}
Roasted	0.32 ± 0.01^{a}	0.05 ± 0.00^{b}	0.37 ± 0.02^{a}
Poongan			
Raw	0.38 ± 0.01^{b}	0.46 ± 0.08^{a}	0.84 ± 0.09^{a}
Roasted	0.47 ± 0.01^{a}	0.40 ± 0.06^{a}	0.87 ± 0.07^{a}
High-oleic			
K-Ol			
Raw	0.78 ± 0.02^{b}	0.44 ± 0.02^{b}	1.22 ± 0.04^{b}
Roasted	1.22 ± 0.02^{a}	0.73 ± 0.02^{a}	1.95 ± 0.05^{a}
Milyang#14			
Raw	0.38 ± 0.02^{b}	0.36 ± 0.03^{b}	0.75 ± 0.05^{b}
Roasted	0.77 ± 0.03^{a}	0.69 ± 0.09^{a}	1.46 ± 0.12^{a}

Data were expressed as mean ± standard deviation

Different letters (a, b) correspond a significant difference between raw and roasted peanuts within same cultivar ($P < 0.05$)

acidic conditions, i.e., pH < 5.0 [35]. Although individuals often pay little attention to their intake of riboflavin owing to the mildness of the diseases caused by its deficiency compared with other vitamins, the deficiency of FMN and FAD, functional vitamins essential for lipid metabolism, lowers the oxidation of fatty acids, accumulates triacylglycerols in the liver, and decreases linoleic acid, linolenic acid, and arachidonic acid levels in serum and the liver, leading to similar side effects as those associated with the deficiency of essential fatty acids [36]. Another study found degenerated myelin of the central and peripheral nervous systems in riboflavin-deprived mice because of abnormal lipid metabolism that resulted from riboflavin deficiency. Hence, as riboflavin is involved in the metabolism of neurotransmitters, a fair amount of riboflavin needs to be ingested [37].

Niacin

The amount of niacin in normal and high-oleic peanuts and changes in the retention rate after roasting were examined. The results are shown in Fig. 1 and Table 6. In Fig. 1, nicotinic acid and nicotinamide were separated at retention times of 7.9 and 11.6 min, respectively. Nicotinic acid amounts were not significantly different between normal and high-oleic peanuts ($P > 0.05$), while, except for the *Daekwang* cultivar, there were significant differences between the raw and roasted peanuts ($P < 0.05$). The increase was particularly higher in high-oleic peanuts than normal peanuts (from 0.78 to 1.22 mg/100 g for *K-Ol* and from 0.38 to 0.77 mg/100 g for *Milyang#14*). Nicotinamide amounts decreased in normal peanuts after roasting (from 0.28 to 0.05 mg/100 g for *Daekwang* and from 0.46 to 0.40 mg/100 g for *Poongan*), and a significant increase

in nicotinamide was observed after roasting high-oleic peanuts (from 0.44 to 0.73 mg/100 g for *K-Ol* and from 0.36 to 0.69 mg/100 g for *Milyang#14*) ($P < 0.05$). The total amount of vitamin B significantly increased in all samples after roasting ($P < 0.05$), with the exception of *Daekwang*. The USDA Nutrient Database Report [27] noted 12.07 mg/100 g and 13.36 mg/100 g of niacin in raw peanuts and roasted peanuts, respectively. Niacin, a heterocyclic pyrimidine ring, has a highly stable structure and a high retention rate even when external energy is applied. Intermediate substances that release free radicals such as hydroxy radicals and hydrated electrons in foods are first oxidized with strong oxidizing agents such as riboflavin or other food components before reacting with niacin, resulting in extremely small niacin loss compared with other vitamins [38]. Niacinamide exists in free- or nucleotide-bound forms and is characterized as highly resistant to heat, light, acid, alkali, and oxidation. The studies on niacinamide therefore mainly utilized hydrolysis methods with acids and bases [39]. A study by Ahn [16] also reported that niacin had a high retention rate during cooking processes due to relatively low influences from thermal treatment, bleaching, and boiling in comparison with other water-soluble vitamins.

Discussion

This study investigated the amounts of thiamin, riboflavin, and niacin present in normal and high-oleic peanuts, and compared the retention rates of the vitamins after roasting. Method validation to analyze thiamin, riboflavin, and niacin using HPLC resulted in high linearity and superior LOD and LOQ compared with the literature. Accuracy and precision were confirmed by their conformation to the expected ranges of SRM. Riboflavin and niacin contents tend to increase with the roasting of raw peanuts, which is consistent with previous studies. Such an increase may be caused by heightened extraction efficiency from the thermal treatment of protein- or carbohydrate-bound vitamins in foods, rather than an increase in the amount of vitamin itself. This study is of significance in providing information on the amounts of water-soluble vitamins in varied peanut cultivars and basic data regarding changes in the amount of water-soluble vitamins after roasting processes.

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