

Effect of Drying Temperatures on the Peanut Quality during Hot Air Drying

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Abstract: Peanuts are usually with high moisture after harvest and must be dried to prevent mildew. Hot air drying is the most commonly used method for peanut drying. The purpose of this study was to evaluate the drying temperatures on the peanut qualities. In this paper, fresh peanuts were dried with solar radiation (control group) and hot air at 35-60\(\degree\)C until the moisture content of peanut reduced below 10%. The physical (texture, damaged percentage of red testa and breakage percentage of peanut kernel), physiological (germination) and biochemical (the contents of vitamin E and aflatoxin B\(_2\); acidity values, iodine values, peroxide values and fatty acid composition of peanut oil; solubility, emulsifying, foaming, water-holding capacity and oil-binding capacity of peanut protein) properties of peanut kernel were determined under different drying conditions (solar radiation, 35\(\degree\)C, 40\(\degree\)C, 45\(\degree\)C, 50\(\degree\)C, 55\(\degree\)C, 60\(\degree\)C). The results showed that hot air temperatures had obvious influences on peanut qualities. The damaged percentage of red testa and breakage percentage of peanut kernel increased remarkably when the drying temperatures were above 45\(\degree\)C. Meanwhile, when drying temperatures were more than 45\(\degree\)C, the acid value and peroxide value of the extracted oil increased significantly. Furthermore, some properties exhibited prominent changes when the temperatures were higher than 50\(\degree\)C, such as hardness, brittleness, germination percentage, and the Vitamin E content of peanut kernel. In addition, the research results revealed that hot air can increase hydrophobicity of peanut protein and affect the functional properties of peanut protein. Therefore, it could be concluded that peanut should be dried by hot air below 45\(\degree\)C for quality maintenance. It also provided reference to choose suitable drying temperatures based on the final use of peanut.

Key words: peanut, hot air drying, drying temperatures, qualities

1 Introduction

Peanut is a widespread industrial oil crop, mainly cultivated in tropical and subtropical regions. Peanut food, such as peanut oil, peanut protein products, roasted peanut, fried peanut, peanut butter, and peanut confections, is widely used due to its high nutritional value\(^1\)-\(^3\). The oil content of peanut is as high as 45\% to 50\%. And the peanut oil contains mostly monounsaturated and polyunsaturated fats, which are beneficial to human cardiovascular systems and can reduce hyperlipidemia and harmful cholesterol effectively\(^4\),\(^5\). Peanut also contains a good source of protein, different vitamins and essential trace minerals\(^6\),\(^7\).

After harvest, the moisture content of the peanut was very high, ranging from 30\% to 55\% on wet basis (w. b.). Peanut must be dried in time to ensure its safe storage and usage. If peanut was not dried to moisture content lower than 10\% w. b.\(^8\)-\(^10\), it was susceptible to mold development and toxin production\(^11\).

The peanut drying process can be performed based on many drying methods, such as solar radiation, hot air drying, microwave and radio frequency heating etc.\(^12\). But the most commonly used methods were solar radiation and hot air drying\(^13\). Drying by sun usually took a long time and was affected by weather. Hot air drying process can be performed by traditional bin dryers or semitrailers with heated air passing through the bed of peanuts\(^14\). Studies on peanut drying by hot air mainly focused on drying parameters\(^7\), the uniformity of peanut drying\(^15\), the effective diffusion coefficient and the main thermodynamic properties\(^16\), the mathematical model of thin layer drying\(^12, 18\), the non-isothermal drying models\(^14\).

In addition to the above researches on peanut drying, there were also some studies on the quality of raw peanut

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and peanut products. Juhaimi et al. investigated the effects of storage and oven roasting on peanut qualities, such as oil yield, peroxide value, acidity, protein content and tocopherol content etc. Idrus\(^{15}\) and Hu\(^{16}\) et al. reported that different peanut oil extraction methods induced different oil extraction ratio and oxidation quality changes. Moreover, the peanut protein isolate (PPI) was also discussed in literatures\(^{17-19}\). The factors, e.g., pH, ionic strength, temperature, growth environment and grain variety, can introduce significant changes in composition, structure and functionality of PPI\(^{20}\). The influences of different dried methods (spray-dried PPI and freeze-dried PPI) and high pressure treatment on the physicochemical and functional properties of PPI were also investigated\(^{21,22}\).

However, even after decades of investigating peanut drying and peanut quality, the effect of hot air drying temperatures on the degree of changes of peanut qualities had not yet been entirely clarified. Araujo\(^{23,24}\) focused on physical properties of peanut after drying at 40°C, including bulk density, true density, intergranular porosity, thousand grain weight, sphericity, circularity, projected area, surface area and surface/volume ratio. And there were few studies on the effects of drying temperatures on the quality of peanut used as sources of seed, oil and protein. Therefore, this paper aimed to investigate these quality characteristics of peanut under different drying temperatures and provide a reference for peanut drying.

## 2 Materials and Methods
### 2.1 Materials
Samples of wet peanut Tianfu No. 3 were harvested in Weihui County, Henan Province, China.

### 2.2 Peanut drying
Hot air drying. A custom-designed heating system was applied for the drying process (shown in Fig. 1). During the process, air was heated (air temperature can be controlled by heating power) and conveyed into the air distribution chamber. Then the hot air was delivered to the drying chamber through orifice plate to dry the wet peanut. Approximately 30 kg wet peanut was placed in the drying chamber and dried at different temperatures (35, 40, 45, 50, 55 and 60°C) and relative humidities (19.7, 18.8, 17.0, 17.0, 17.0 and 8.0 RH%) with volumetric flow rate 565 m\(^3\)·h\(^{-1}\). The drying aeration was stopped when the moisture content of peanut reduced below 10%. The terminal moisture contents of the peanut dried at 35, 40, 45, 50, 55 and 60°C were 10.0%, 9.8%, 9.7%, 9.9%, 9.8% and 9.0% respectively. After drying, the dried peanuts were cooled to room temperature and dehulled by a dehusking machine (Henan Yuexin Industrial Co., Ltd., China, 2.2 kW). 500 g dehulled peanut was sampled for the quality analysis.

Solar radiation. Wet peanuts (initial moisture content 22.1 ± 0.9%) were spread on the ground and dried by the sun. The drying time was between 9 a.m. to 17 p.m. in the daytime (temperature was 14-24°C, average relative humidity was 50-60 RH%). In the night (17 p.m. to 9 a.m.), the peanuts were piled up and covered to prevent the moisture

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**Fig. 1** Drying system.  
1. Fan, 2. Aeration duct, 3. Electrical heating apparatus, 4. Flowmeter, 5. Air distribution chamber, 6. Temperature and humidity sensor, 7. Orifice plate, 8. Drying chamber, 9. Wet peanuts
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2.3 moisture content determination (% wet basis)
the moisture content of peanut was determined according to the american society of agricultural and biological engineers (asabe) method s410.2 at 130℃ for 6 h.26,28.

2.4 physical characteristics
2.4.1 texture determination
the ta.xt plus texture analyzer (stable micro systems, ta.xt plus, uk) with a a/ecb blade was used. the peanut kernel was put on the platform of texture analyzer perpendicular to the blade. the parameters of the texture analyzer were as follows: trigger force, 5.0 g, pretest and blade movement speed, 1 mm·s⁻¹; post-test speed, 10 mm·s⁻¹; and strain, 50%. the data acquisition rate was set at 200 points per second. hardness (g) was the maximum amount of force required to fracture the kernel, which was recorded as the height of the maximum peak. brittleness (g) was the amount of force needed on the first fracture of the kernel, which was recognized as the height of the first peak.

2.4.2 damaged percentage of red testa (dp) and breakage percentage (bp) of peanut kernel
after drying, the peanuts were cooled to room temperature and were dehulled using the dehusking machine. 200 g dried peanuts were taken to test the dp and bp of peanut kernel. dp was defined as more than 20% of the testa or skin removed during dehulling. bp was considered as the two cotyledons separated or fragmented. each test at various drying temperatures was repeated five times. dp was expressed by the percentage of the weight of red testa damaged peanut kernel to the total weight. and bp was shown by the percentage of the weight of breakage peanut kernels to the total weight.

2.5 germination tests
according to chinese national standard gb/t 5520-2011, samples of 50 peanut kernels were sowed in wet sand and placed at 25℃ in a climate incubator. after 10 days, the number of spouted peanuts was counted. the germination percentage was defined as the number of successfully germinated kernels out of the total number of the peanut kernels.

2.6 vitamin e (ve) determination
the contents of ve in the peanut kernel were determined by ve test kits (nanjing jiangcheng bioengineering institute, china) according to the manufacturer’s protocol. this method was based on the reaction of ve with phenan-

throleine to form a pink complex, which can be read at 533 nm absorbance.

2.7 determination of aflatoxin b₁ (afb₁) content
the contents of afb₁ in peanut kernels were determined by elisa test kits (quantitative kit for afb₁, huaan magnech bio-tech co., ltd., china) as the manufacturer’s instructions. indirect competition elisa method was applied in this kit. briefly, the aflatoxin b₁ antigen was pre-coated on the micro-wells of the reaction plate. the pre-coated aflatoxin b₁ and aflatoxin b₁ from the sample would bind with the primary antibodies of aflatoxin b₁ competitively. the quantity of antibodies captured by the pre-coated aflatoxin b₁ depended on the concentration of the aflatoxin b₁ in the sample. the larger the concentration, the less the primary antibodies binding to the pre-coated aflatoxin b₁. then the complexes of the antibodies and pre-coated aflatoxin b₁ antigen were bond with horseradish peroxidase (hrp) -labeled secondary antibodies. subsequently, substrate (3,3',5,5'-tetracynethylbenzidine, tmb) was added and od₄₅₀ was measured. the absorbance was negatively correlated with the aflatoxin b₁ concentrations of the samples.

2.8 peanut oil analysis
2.8.1 peanut oil extraction
the oil contents in dried peanuts were determined according to chinese national standard gb/t 14488.1-2008. the dried peanut kernels were cut into thin slices (about 1 mm thickness) with dq-101 slicer (zhengzhou gashili machinery co., ltd., china), then the peanut thin slices were ground into granules by fz102 miniature plant sample pulveriser (beijing ever bright medical treatment instrument co., ltd., china) and passed through 3 mm sieve pores. in order to avoid the heating influence on the peanut quality during the slicing and smashing process, several minutes’ pause existed between each operation. peanut oil was extracted from peanut kernel granules with petroleum ether (boiling range 30-60℃, tianjin tianli chemical reagent co., ltd.) by soxhlet extraction for 8 h. the mass fraction of the obtained extract in the original sample was the oil content.

the peanut oil was extracted by the above extraction method by petroleum ether. then the solvent was evaporated using a rotary vacuum evaporator (re-2000a, china) with a water bath temperature not higher than 30℃. the extracted oil was immediately used for chemical analysis, including acidity values (av), iodine values (iv), peroxide values (pv) and fatty acid composition (fac).

2.8.2 chemical analysis
acidity values, iodine values and peroxide values were tested based on chinese national standard gb 5009.229-2016, gb 5009.227-2016 and gb/t 5532-2008, respectively. fatty acid composition of peanut oil was measured according to chinese national standard gb 5009.168-2016 using
gas chromatography (7890 B, Agilent Technologies, USA) equipped with a capillary column (100 m × 0.25 mm × 0.20 μm) and a flame ionization detector.

2.9 Peanut protein analysis

2.9.1 Preparation of peanut protein isolate (PPI)

PPI was prepared using isoelectric precipitation, as described by Gong et al.21 with some modification. The defatted sample was mixed with water in the ratio of 1/10 (w/v). The pH of the mixture was adjusted to 9 with 1 M sodium hydroxide (NaOH, Tianjin Kemiou Chemical Reagent Co., Ltd.) solution to dissolve the peanut protein. After stirring for 1 h, the mixture was centrifuged to obtain the supernatant as peanut protein solution. The supernatant was adjusted with 1 M hydrochloric acid (HCl, Luoyang Haohua Chemical Reagent Co., Ltd.) to pH 4.5 to precipitate the peanut protein. Then the suspension was centrifuged and the precipitate was dried by a freeze drier (LGJ-10C, Four-Ring Science Instrument Plant Beijing CO., LTD, China).

2.9.2 Determination of the functional properties of peanut protein

The protein solubility in water, emulsifying and foaming properties were calculated at pH 9 using the method of Jamdar et al.28. Water-holding capacity (WHC) and oil-binding capacity (OBC) of samples were determined as described by He et al.22.

2.10 Data analysis

Data processing was used by Origin (version 9.0) and statistical analysis was performed by SPSS (version 21.0). One-way analysis of variance (ANOVA) was employed to determine significant differences and Duncan’s test was used to perform multiple comparisons between means. Two-sided in which p < 0.05 were considered to be significant.

3 Results and Discussion

3.1 Moisture content (M.C., % dry weight)

As a control, the moisture content of wet peanuts decreased from 22.1% to 10.0% in 3 days by solar radiation. The drying curves of wet peanuts at different drying temperatures were illustrated in Fig. 2, where the increase of the hot air temperature considerably reduced the drying time. At the drying temperatures of 35, 40, 45, 50, 55 and 60°C, the initial moisture contents were 22.9%, 19.5%, 18.6%, 17.7%, 20.4% and 18.8%, the final moisture contents were 10.0%, 9.8%, 9.7%, 9.9%, 9.8% and 9.0%, and the drying time were 18.0 h, 13.5 h, 10.0 h, 8.0 h, 5.5 h and 4.7 h, respectively. The rise of the drying temperature increased the difference between the partial steam pressure of the drying air and the peanut during the water removal, which led to higher drying rate and reduced drying time. Therefore, compared with solar radiation, hot air drying could improve drying efficiency effectively.

3.2 Physical, physiological, and chemical characteristics

Texture determination. Texture characteristics, hardness and brittleness, of dehulled peanut dried at different temperatures were shown in Fig. 3. It can be seen from Fig. 3 that there was no significant change in hardness and brittleness when the drying temperatures were equal to or less than 50°C (p < 0.05). When the drying temperatures were higher than 50°C, the hardness exhibited a downward trend, but the brittleness showed an upward trend. The
results illustrated that air temperature influenced the texture of peanut kernel. It may be due to that hot air with higher temperature could accelerate the heat and mass transfer rates, which led to the microstructure disrupted \(^{29,30}\). Moreover, higher temperature may affect the structures and the intermolecular forces of protein, starch and fat in the peanut kernel, which resulted in the texture changes of peanut kernels.

Damaged percentage of red testa (DP) and breakage percentage (BP). **Figure 4** displayed the DPs and BPs of peanut kernels under different drying temperatures. The DP and BP of peanut kernels with solar radiation were 0.29% and 1.19%, respectively. And hot air drying can lead to significant increases of the DPs and BPs of dried peanut kernels \((p<0.05)\). When the hot air temperatures were 35°C, 40°C and 45°C, DPs and BPs rose slightly, and all were less than 5%. The DP increased to 11.06%, 14.08%, 15.76%, and BP ascended to 10.06%, 14.08% and 17.19% respectively as the drying temperatures were 50°C, 55°C and 60°C. When the hot air temperatures were higher than or equal to 50°C, mechanical shelling would seriously affect the integrity of peanut kernels. This phenomenon may be also owing to the higher heat and mass transfer rates in the peanut kernel at higher drying temperatures, which caused the disruption of the kernel microstructure. Therefore, drying temperature can have remarkable impacts on the appearance quality and commercial value of peanuts. The quality of peanut kernel with higher DP and BP would deteriorate more easily during storage because the broken kernels lost the protection of red testa and could be oxidized more easily than the sound kernels.

Germination. Germination was an important indicator of peanut seed vigor. Seed viability can be affected by several factors such as, moisture content, cracks in the seed coat, fungal attacks, mechanical injuries in the seed harvesting or processing operations \(^{31}\). It can be seen from **Fig. 5** that the germination percentage of peanut seeds were significantly affected by drying temperatures above 55°C \((p<0.05)\). The germination percentage of peanut kernel were not influenced by solar radiation and by hot air at 35°C, 40°C, 45°C and 50°C, which were 96%, 95%, 95%, 96% and 95%, respectively. However, as compared to the control, the germination percentage dropped to 74% and 11% correspondingly when the hot air temperatures were 55°C and 60°C. It was because that the higher drying temperature denatured the enzymes related to seed germination, thus reducing the germination rate of peanut seeds.

The contamination of aflatoxin B\(_1\) (AFB\(_1\)). Peanut were susceptible contaminated by AFB\(_1\) during harvest, storage, drying and processing. And AFB\(_1\) was toxic with strong carcinogenic properties \(^{32}\). The optimum temperature and water activity for aflatoxin production were 33°C and 0.99 \(^{30}\). Therefore, levels of AFB\(_1\) contamination were also monitored after the drying and were presented in **Fig. 5**. The contents of AFB\(_1\) of the dried peanut kernel samples with different drying temperatures were all below 2.00 \(\mu\)g·kg\(^{-1}\). The level detected were much lower than 20 \(\mu\)g·kg\(^{-1}\), which was the limit the AFB\(_1\) quantity according to the Chinese National Standard GB 2761-2017.

Vitamin E (VE) contents in the peanut kernel. The antioxidant activity in peanut kernel was attributed to VE
The effect of solar radiation and hot air drying on the VE content in peanut kernel was shown in Fig. 6. It can be seen from Fig. 6 that the VE content of peanut dried by solar radiation was 104.9 ± 1.2 μg·g⁻¹, and that dried by hot air at 35°C, 40°C, 45°C, 50°C, 55°C, 60°C were 110.1 ± 0.6 μg·g⁻¹, 109.9 ± 0.8 μg·g⁻¹, 107.6 ± 1.2 μg·g⁻¹, 104.2 ± 0.8 μg·g⁻¹, 103.5 ± 0.8 μg·g⁻¹ and 102.0 ± 0.9 μg·g⁻¹, respectively. From the statistical analysis, drying at 35°C, 40°C and 45°C were significantly (p < 0.05) beneficial to protect the antioxidant activity of peanut kernel than other drying conditions. Hence, exposure to the sun for a long time and higher temperatures would damage the antioxidant activity of peanut kernel to some extent. Martín et al. also demonstrated the effectiveness of oxygen isolation and low temperature environment in protecting the quality of tocopherols.

### 3.3 Chemical analysis of peanut oil extracted from dried peanut kernels

#### 3.3.1 Oil content, Acid value (AV), Iodine value (IV) and Peroxide value (PV)

Oil content is one of the key indexes to evaluate the production efficiency of oil from oilseeds. As can be seen from Table 1, the contents of the peanut oil extracted from dried peanut kernels obtained by solar radiation and hot air were between 46.67% and 47.24%, which showed no significant difference (p > 0.05).

The acid value (AV) represented the level of free fatty acids in oil, which was an indicator of oil rancidity. The variations of the AV of peanut oil were exhibited in Table 1. The results indicated that drying temperatures higher than 50°C had a negative effect on the AV of peanut oil compared to the control and low temperature drying groups. The reason was that the fat hydrolysis reaction, which made the decomposition of glycerides, developed rancidity, led to the formation of free fatty acids in peanut oil, was closely related to temperature and can be accelerated at higher temperatures. Although the AV values of peanut were affected by drying temperature, the AV values after drying at higher temperatures were still far below the limit in the Chinese National Standard GB/T 1534-2017, which allowed for the presence of AV up to 2.0 mg NaOH g⁻¹ in leaching peanut oil.

Iodine value (IV) is an indicator which showed the unsaturation degree of the peanut oil, a greater degree of unsaturation was accompanied by a higher IV. It can be seen from Table 1 that drying temperature did not cause significant changes in IV (p > 0.05), which were at the range of 94.2 - 96.9 g·100 g⁻¹ and not significantly different from the control 97.8 ± 1.4 g·100 g⁻¹ (p > 0.05). Hence, peanut drying using hot air within 60°C did not cause unacceptable results in terms of unsaturated fatty acids of peanut oil.

Peroxide value (PV) measured the quantity of peroxides in the oil, which served as an indicator index of the primary oxidation product formation. It was widely employed as a measure of oil oxidative rancidity. As illustrated in Table 1, the drying temperatures displayed a little influence on PV of peanut oil obtained after hot air drying above 50°C. The above results showed that higher drying temperature could produce more peroxides and increase the oxidation rate of peanut oils. It was because more peroxide were produced at higher drying temperature, which led to

### Table 1 Effects of drying temperature on chemical properties of peanut oil extracted from peanut kernel after drying at different temperatures.

| Drying temperature (°C) | solar radiation | 35     | 40     | 45     | 50     | 55     | 60     |
|--------------------------|----------------|-------|-------|-------|-------|-------|-------|
| Oil content (%)          |                | 47.24 ± 0.61ᵇ | 46.74 ± 0.10ᵇ | 47.06 ± 0.40ᵇ | 46.71 ± 0.16ᵇ | 46.67 ± 0.14ᵇ | 46.87 ± 0.12ᵇ | 46.68 ± 0.18ᵇ |
| Acid value (mg NaOH g⁻¹ oil) |            | 0.087 ± 0.004ᵇ | 0.090 ± 0.003ᵇ | 0.085 ± 0.004ᵇ | 0.093 ± 0.003ᵇ | 0.124 ± 0.002ᵇ | 0.118 ± 0.004ᵇ | 0.122 ± 0.002ᵇ |
| Iodine number (g I₂ 100 g⁻¹ oil) |            | 97.8 ± 1.4ᵇ | 94.3 ± 1.7ᵇ | 95.9 ± 1.5ᵇ | 94.2 ± 2.4ᵇ | 96.1 ± 0.8ᵇ | 96.9 ± 1.5ᵇ | 96.7 ± 1.8ᵇ |
| Peroxide value (mmol O₂ kg⁻¹ Oil) |        | 0.24 ± 0.02ᵇ | 0.24 ± 0.02ᵇ | 0.24 ± 0.01ᵇ | 0.24 ± 0.01ᵇ | 0.26 ± 0.01ᵇ | 0.27 ± 0.02ᵇ | 0.27 ± 0.02ᵇ |

Data were expressed as means ± standard deviations. Different superscript letters in the same row show a significant difference (p < 0.05).
higher PV values.\(^{39}\)  

3.3.2 Fatty Acid Composition  
Analysis of the fatty acid composition (FAC) was a useful tool for detecting classes of lipids which were involved in the oxidative changes.\(^ {40}\) From Table 2, it can be seen that the major FAC in peanut oil were oleic acid (18:1-9), linoleic acid (18:2-6) and palmitic acid (16:0), whose ratio were ranged between 43.74% and 44.22%, between 34.35% and 35.69%, between 10.85% and 11.27%, respectively. A large proportion (about 80%) of unsaturated fatty acids, including monounsaturated fatty acids and polyunsaturated fatty acids, was detected in peanut oil. And the total amounts of unsaturated fatty acids in peanut did not undergo obvious oxidation deterioration (\(p < 0.05\)) in the process of hot air drying at 35-60°C for 5-18 h (Fig. 2). Abbas et al.\(^ {41}\) reported that the FAC did not change with roasting in peanut oil at 170°C for 7.5 min. Therefore, it can be concluded that drying temperature had no significant effect on FAC of peanut oil during the peanut drying process (\(p < 0.05\)).

### Table 2  Fatty acid composition of peanut oil extracted from peanut kernel after drying at different temperatures.

| Fatty acids composition (%) | Solar radiation | 35       | 40       | 45       | 50       | 55       | 60       |
|-----------------------------|----------------|---------|---------|---------|---------|---------|---------|
| Palmitic acid C16:0         | 10.85 ± 0.47\(^a\) | 11.27 ± 0.05\(^b\) | 11.16 ± 0.06\(^c\) | 11.17 ± 0.03\(^d\) | 11.02 ± 0.01\(^e\) | 11.20 ± 0.04\(^f\) | 11.18 ± 0.05\(^g\) |
| Stearic acid C18:0          | 2.48 ± 0.22\(^a\) | 2.77 ± 0.31\(^b\) | 2.56 ± 0.01\(^c\) | 2.60 ± 0.01\(^d\) | 2.60 ± 0.01\(^e\) | 2.57 ± 0.01\(^f\) | 2.47 ± 0.01\(^g\) |
| Oleic acid C18:1-9          | 44.08 ± 0.69\(^a\) | 43.96 ± 0.06\(^b\) | 43.90 ± 0.02\(^c\) | 43.99 ± 0.01\(^d\) | 44.22 ± 0.02\(^e\) | 43.77 ± 0.01\(^f\) | 43.74 ± 0.06\(^g\) |
| Linoleic acid C18:2-6       | 35.71 ± 0.42\(^a\) | 34.35 ± 1.21\(^b\) | 35.15 ± 0.01\(^c\) | 35.02 ± 0.01\(^d\) | 35.06 ± 0.01\(^e\) | 35.23 ± 0.05\(^f\) | 35.29 ± 0.01\(^g\) |
| Arachidic acid C20:0        | 1.28 ± 0.13\(^a\) | 1.48 ± 0.22\(^b\) | 1.37 ± 0.01\(^c\) | 1.38 ± 0.01\(^d\) | 1.37 ± 0.01\(^e\) | 1.37 ± 0.01\(^f\) | 1.35 ± 0.01\(^g\) |
| Gadoleic acid C20:1-9       | 1.09 ± 0.05\(^a\) | 1.12 ± 0.02\(^b\) | 1.13 ± 0.01\(^c\) | 1.18 ± 0.05\(^d\) | 1.15 ± 0.01\(^e\) | 1.17 ± 0.02\(^f\) | 1.2 ± 0.01\(^g\) |
| Behenic acid C22:0          | 2.83 ± 0.07\(^a\) | 2.97 ± 0.23\(^b\) | 2.9 ± 0.02\(^c\) | 2.93 ± 0.02\(^d\) | 2.87 ± 0.01\(^e\) | 2.94 ± 0.03\(^f\) | 2.99 ± 0.01\(^g\) |
| Lignoceric acid C24:0       | 1.4 ± 0.18\(^a\) | 1.71 ± 0.31\(^b\) | 1.55 ± 0.03\(^c\) | 1.55 ± 0.01\(^d\) | 1.52 ± 0.01\(^e\) | 1.56 ± 0.01\(^f\) | 1.59 ± 0.01\(^g\) |
| \(\Sigma\)SFA               | 19.17 ± 0.60\(^a\) | 19.16 ± 0.36\(^b\) | 19.54 ± 0.01\(^c\) | 19.62 ± 0.06\(^d\) | 19.38 ± 0.01\(^e\) | 19.63 ± 0.03\(^f\) | 19.57 ± 0.04\(^g\) |
| \(\Sigma\)UFA               | 80.83 ± 0.60\(^a\) | 80.84 ± 0.36\(^b\) | 80.46 ± 0.01\(^c\) | 80.38 ± 0.06\(^d\) | 80.62 ± 0.01\(^e\) | 80.37 ± 0.03\(^f\) | 80.43 ± 0.04\(^g\) |

Data were expressed as means ± standard deviations. Different superscript letters in the same row show a significant difference (\(p < 0.05\)). SFA saturated fatty acids, UFA unsaturated fatty acids.

3.4 Functional properties of Peanut Protein Isolate (PPI)  
Protein solubility. Protein solubility was one of the most important physicochemical properties, which was closely related to the denaturation degree of protein\(^ {37}\). Protein solubility expressed as nitrogen solubility index (NSI). After hot air drying, NSI of peanut protein isolate (PPI) decreased significantly (\(p < 0.05\)) along with the increase of hot air temperature (Table 3), which was reduced to a minimum of 114.21 ± 0.69 mg N·100 g\(^{-1}\) at 60°C (\(p < 0.05\)) compared to the control (142.33 ± 0.58 mg N·100 g\(^{-1}\)). It implied that the hot air temperature had a negative influence on the solubility of PPI. The decreasing solubility of PPI may be due to the structure denaturation of PPI caused by high temperature drying, which increased exposure of hydrophobic groups and reduced the protein-water interactions. These results corresponded with the studies of Ziegler et al.\(^ {42}\) and Lee et al.\(^ {43}\).

Foaming properties. The effects of drying temperature on foaming capacity (FC) and foaming stability (FS) of peanut protein isolate (PPI) were presented in Table 3. The FC and FS were all significantly influenced by drying temperatures (\(p < 0.05\)). The FC of PPI was increased to 18.00%, 20.33%, 16.83%, 17.50%, 19.25% and 20.75% as the drying temperatures increased from 35°C to 60°C in comparison with the control 13.45%. In addition, the changes of FS of PPI showed a similar changing pattern. The FS increased overall, from 14.50% to 17.67% as drying temperature increased from 35°C to 60°C. These data demonstrated that heat-induced denaturation of PPI would favor the forming of air–trapping film and stabilizing the foam.\(^ {41}\)

Emulsifying properties. Emulsification activity index (EAI) represented the ability of a protein to promote emulsion formation. And emulsification stability (ES) indicated the ability of the emulsion to resist destabilizing variations.\(^ {41}\) Although there were some differences in values of EAI and ES at different drying temperatures, the changing trends of the EAI and ES with different drying temperatures was not obvious (Table 3). EAI varied between 59.80 ± 0.44 and 65.51 ± 0.87 m²·g\(^{-1}\), and ES varied between 92.09 ± 0.63 and 98.50 ± 0.94%. Hence, drying temperatures below 60°C had only a little effect on emulsifying properties of peanut protein isolate.
Table 3 Effects of drying temperature on functional properties of peanut protein extracted from peanut kernel after drying at different temperatures.

| Drying temperature (°C) | solar radiation | 35     | 40     | 45     | 50     | 55     | 60     |
|-------------------------|----------------|--------|--------|--------|--------|--------|--------|
| Nitrogen Solubility Index (mg N·100 g⁻¹) | 142.33 ± 0.58<sub>a</sub> | 136.25 ± 2.33<sub>b</sub> | 128.21 ± 1.34<sub>c</sub> | 117.50 ± 1.21<sub>d</sub> | 116.64 ± 0.60<sub>e</sub> | 115.36 ± 2.55<sub>f</sub> | 114.21 ± 0.69<sub>g</sub> |
| Emulsifying activity index (m²·g⁻¹) | 64.30 ± 1.05<sub>a</sub> | 64.96 ± 0.62<sub>b</sub> | 65.51 ± 0.87<sub>c</sub> | 63.60 ± 0.89<sub>d</sub> | 59.80 ± 0.44<sub>e</sub> | 60.49 ± 0.37<sub>f</sub> | 63.07 ± 0.12<sub>g</sub> |
| Emulsion stability (%) | 95.29 ± 0.94<sub>a</sub> | 96.97 ± 0.91<sub>b</sub> | 98.50 ± 0.94<sub>c</sub> | 97.97 ± 0.71<sub>d</sub> | 92.09 ± 0.63<sub>e</sub> | 93.91 ± 0.99<sub>f</sub> | 97.44 ± 0.46<sub>g</sub> |
| Foaming capacity (%) | 13.45 ± 0.58<sub>a</sub> | 18.00 ± 0.50<sub>b</sub> | 20.33 ± 0.58<sub>c</sub> | 16.83 ± 0.29<sub>d</sub> | 17.50 ± 0.50<sub>e</sub> | 19.25 ± 0.25<sub>f</sub> | 20.75 ± 0.66<sub>g</sub> |
| Foaming stability (%) | 12.62 ± 0.34<sub>a</sub> | 14.50 ± 0.50<sub>b</sub> | 18.17 ± 0.58<sub>c</sub> | 16.00 ± 0.50<sub>d</sub> | 17.17 ± 0.58<sub>e</sub> | 17.33 ± 0.29<sub>f</sub> | 17.67 ± 0.76<sub>g</sub> |
| Water holding capacity (%) | 114.42 ± 0.98<sub>b</sub> | 118.11 ± 0.59<sub>c</sub> | 116.50 ± 2.23<sub>d</sub> | 103.99 ± 1.96<sub>e</sub> | 92.48 ± 0.93<sub>f</sub> | 88.26 ± 1.72<sub>g</sub> | 81.50 ± 1.47<sub>g</sub> |
| Oil binding capacity (%) | 140.65 ± 1.08<sub>e</sub> | 127.29 ± 1.00<sub>d</sub> | 148.51 ± 0.65<sub>f</sub> | 154.44 ± 1.06<sub>g</sub> | 167.99 ± 1.64<sub>a</sub> | 164.55 ± 1.08<sub>e</sub> | 163.75 ± 1.09<sub>a</sub> |

Data were expressed as means ± standard deviations. Different superscript letters in the same row show a significant difference (p < 0.05).
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