



The effects of infrared and hot air drying on some properties of corn (*Zea mays*)

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Abstract

Due to being one of the most important dietary staple foods in the world, corn (*Zea mays*) has gained considerable attention. Drying is an essential procedure for safe storage of corn. The objectives of the present study were to investigate the effects of infrared (IR), hot air (HA) and infrared-hot air combined (IR-HA) drying on some properties of corn and to offer an alternative drying procedure with low energy costs. Crude protein, total carotenoid, phenolic acid composition, color parameters (L , a +, b +, chroma, Hue angle, ΔE) and energy expenses of the drying techniques in terms of specific energy consumption (SEC) for unit evaporated water were evaluated. Dent corn samples were hand harvested at regular intervals of fortnight at maturity and the initial moisture contents were 24, 16 and 15%, respectively. Preparation was included kernel manual trimming and granulating. Kernels were dried until the moisture content comes down to 13% with IR, HA and IR-HA combination techniques except for control. All drying treatments were conducted at 45°C. It was observed that IR radiation did not cause any negative impact on the stated properties of corn in noted conditions. Besides, IR and IR-HA drying methods dramatically reduced the drying time. Specific energy consumption values showed that IR and IR-HA combined systems are more effective and economic when the initial moisture content of corn is above 16%. Evaporation of unit water took 12 and 40% less energy in IR drying of corn samples with the initial moisture content of 24 and 16%, respectively, as compared to HA drying alone. Hence, IR drying is considered to be a promising alternative for corn drying.

Key words: Infrared, hot air, drying, specific energy consumption, corn, HPLC, phenolic acids, total carotenoid, crude protein, color.

Introduction

Corn is one of the most widely grown cereal crop in the world. A number of food ingredients are produced from corn, among them corn flour, corn-germ oil, corn grits and corn-sugar molasses. Corn is rich in vitamins, especially A and E, and has a high nutritional value. Yellow corn is the main source of β -carotene, a precursor of vitamin A among the major food grains ¹. Also it has been reported that corn has three times more phenolic acids compared to wheat, rice and rye ². Phenolic acids are group of natural products that have been found to be strong antioxidants against free radicals and other reactive oxygen species, the major cause of many chronic human diseases such as cancer and cardiovascular diseases ^{3,4}. Carotenoids and phenolic compounds are synthesized in the plant by secondary metabolism and interest in antioxidant and bioactive properties has increased due to their health benefits ⁵.

Corn reaches physiological maturity (blacklayer) and can be harvested at 29-31% moisture content ⁶. Unless quickly dried, high moisture corn is subject to rapid deterioration. Corn is a good source for microorganisms. Peculiarly moulds and mould toxins are commonly isolated from it. Therefore, corn must be dried to the safe storage moisture level of 13%.

Drying is the most energy intensive process of food processing industry. In Turkey, open-air and hot air drying methods are frequently used for corn drying. Open-air drying is preferred at rural areas whereas hot air drying is the most common technique being used in industrial applications for corn drying. Hot air drying

method has some disadvantages such as low thermal conductivity, long drying time and quality degradations in terms of nutritional values, color, shrinkage and other organoleptic properties. Therefore, new techniques that increase drying rates and enhance product quality are trying to be improved ^{7,8}. Infrared technology became a practical alternative due to the versatility, simplicity of the required equipment, fast response of heating and drying, easy installation and low capital cost ⁹. Moreover, combinations of infrared and hot air drying reported to be more efficient than irradiation or hot air drying alone, presumably providing a synergistic effect ^{10,11}. Although many studies have been reported on infrared drying of various food materials we could not reach to any study about dent corn drying with irradiation. To the best of our knowledge only Pan *et al.* have a research on infrared drying of sweet corn ¹².

In addition to minimized processing and low energy costs, product quality has also acquired considerable attention. Therefore, it is important to evaluate the effects of IR drying on physical, chemical, nutritional, sensory and microstructural quality of foods and to make its comparison with other existing common methods.

The objectives of the present study were to discuss the effects of infrared (IR), hot air (HA) and infrared-hot air combined (IR-HA) drying on some properties such as crude protein, total carotenoid, color (L , a +, b +, Chroma, Hue angle and ΔE) and phenolic acid composition of corn harvested at different initial

moisture contents and to compare the drying methods by evaluating the differences between control and dried corns. However, the influence of the noted drying techniques in terms of drying efficiency and specific energy consumption was discussed.

Materials and Methods

Harvest and sample preparation: Dent corn samples were hand harvested randomly at regular intervals of fortnight at maturity, and the initial moisture contents were 24, 16 and 15%, respectively. Moisture level was measured gravimetrically according to ICC¹³.

After harvest, husks were removed immediately. Sample preparation included kernel manual trimming and granulating. All kernels were pooled, homogenized and divided into subsamples, each of which contained an amount of 200±2 g. All drying experiments were triplicated and kernels were dried until the moisture content came down to 13% with IR, HA and IR-HA combination techniques except control. Control represents the samples which are not subjected to any drying treatment. Samples were dried as early as possible and kept at 4°C before the analysis.

Drying conditions and specific energy consumption: The drying system used for the experiments was the same as reported by Kocabiyik and Tezer¹⁴. Heating cabinet included two infrared lamps (General Electric, D = 125 mm, Hungary) each of them had a maximum power of 0.25 kW. Infrared radiation intensity and air velocity were kept constant at 0.5 kW and 1 m/s, respectively, throughout the experiments. The distance between the infrared heat source and drying surface was 90 mm. Inner sides of the system were covered with an aluminum foil. Digital balance with the accuracy of ±0.01 g was combined with the computer, and weight loss of the samples was recorded at 3 minutes interval with Balint Interface Software (Precisa Instruments AG, Zürich, Switzerland) during the drying period. For the application of hot air drying, there was an electrical heater which had a maximum power of 1 kW. Regulating the voltage through a variac could control the level of the heat coming from the electrical heater. Hot air and/or infrared drying experiments were carried out at 45°C. Temperature of the drying chamber was controlled with thermocouple (Testo 110, England). Raw corn is affected by high temperature, and 50°C or higher temperatures are not recommended for corn drying due to the undesirable effects on some quality parameters⁶.

Total energy consumed was defined as the energy consumed by the infrared source and/or electrical heater during whole drying process. The energy consumed by fans was negligible. Specific energy consumption (SEC) during drying was expressed in MJ/kg for unit water evaporated, and calculated according to Equation 1^{10, 15, 16}.

$$\text{Specific Energy Consumption} = \frac{\text{Total Energy Consumption}}{\text{Removed Water Mass}} \quad (1)$$

For IR drying, two infrared lamps with a total power of 0.5 kW were used. For HA drying, the electrical heater operated with a power of 0.3 kW when the air temperature coming out of the fans was 45°C. For the combined mode, total power was 0.8 kW. Drying time was defined as the time required to reduce the moisture content of the product to 13% (w.b.).

Chemical analysis: The crude protein content of the control and dried samples was calculated by multiplying the nitrogen (N) content by the factor of 5.75 which was determined by the Kjeldahl method¹⁷.

Total carotenoid analysis was performed at 450 nm spectrophotometrically according to Hulshof and others¹⁸. Calculations of crude protein and total carotenoid content were done on dry basis.

Physical analysis: Color measurement of the control and dried samples was performed using a Minolta CR-400 model colorimeter (Minolta Co., Osaka, Japan) before and after drying. *L* (lightness/luminance), *a*+ (from red to green) and *b*+ (from yellow to blue) values, adopted by the Commission Internationale d'Eclairage (CIE), were measured in each experiment. Chroma, Hue angle and Δ*E* were calculated according to Eq. 2-4, respectively.

$$C = \sqrt{a^2 + b^2} \quad (2)$$

$$\text{Hue angle} = \tan^{-1}\left(\frac{b}{a}\right) \quad (3)$$

$$\Delta E = \sqrt{(L_t - L_i)^2 + (a_t - a_i)^2 + (b_t - b_i)^2} \quad (4)$$

Chromatographic analysis: Phenolic acid analysis was carried out according to the validated high pressure liquid chromatography (HPLC) method reported by Öztürk *et al.*¹⁹. Fifteen g ground corn was weighed, defatted with petroleum ether and extracted with methanol:acetone (50:50, v/v) in Soxhlet system for 6 and 4 hours, respectively. Solvents were removed by rotary evaporator (Heidolph, Laborota 4001, Germany). The temperature of the Soxhlet system and water bath (evaporator) was 45°C. The relevant extracts were redissolved in 5 mL methanol and water solution (1:1 v/v), 0.2 mL concentrated HCl was added into it and vortexed.

For cleaning up materials, a Superclean (C-18) (Sigma Aldrich, St. Louis, MO, USA) solid phase extraction (SPE) cartridge was employed. SPE cartridges were conditioned with 3 mL methanol and 3 mL aqueous solution of 2% HCl, respectively. Five mL of extract was passed through the cartridges. Impurities were washed out with 3 mL of 2% HCl. Retained phenolic acids of corn were eluted with 5 mL of methanol, propylparaben (internal standard) was added and directly injected into the HPLC system.

Phenolic acids, namely gallic acid (GA), protocatechuic acid (protoCA), *p*-hydroxy benzoic acid (*p*-hydBA), vanillic acid (VA), caffeic acid (CA), chlorogenic acid (ChA), syringic acid (SA), *p*-coumaric acid (*p*-COU), ferulic acid (FA), *o*-coumaric acid (*o*-COU) and *trans*-cinnamic acid (*tr*-CIN), were determined by an HPLC system consisting of a Model 600 E HPLC pump, a Model 717 plus autosampler and a Model 996 photodiode array detector (PAD). Data processor of a Millennium 32 and a reverse phase C18 Ultrasphere column (100 mm x 4.6 mm inner diameter 3 μm) (Teknocroma, Barcelona, SP) was employed for the HPLC (all Waters Corp. Massachusetts, USA) analysis of phenolic acids. All reagents and solvents were of analytical grade.

Chromatographic separation was carried out using two solvents system [A methanol:water:formic acid (10:88:2 v/v/v); B methanol:water:formic acid (90:8:2 v/v/v)]. The analysis was performed by using a linear gradient program. Initial condition

was 100% A; 0-15 min, changed to 100% A; 15-20 min, to 85% A; 20-30 min, to 50%; 30-35 min to 0% A; 36-42 min, went back to 100% A. The flow rate was 1 mL/min and the injection volume was 10 μ L. Signals were detected at 280 nm.

All of the phenolic acids were resolved entirely from each other. Propylparaben was used as an internal standard (IS) to increase the repeatability of the method. The integrated peak areas and their retention times were computed to get the rate of peak normalization (peak area/peak retention time) of the relevant phenolic acids, and their amounts were calculated in the related extracts via their calibration curves.

Statistical analysis: Analysis of one-way ANOVA was conducted to compare the control and dried samples among the treatments of the same initial moisture contents. Also blocked ANOVA was used to analyse the effects of drying methods on phenolic acid contents using Minitab for Windows (R.13). Only drying methods were evaluated as a factor. Duncan's multiple range tests were used to compare the differences of the mean values among drying procedures ($p < 0.05$).

Results and Discussion

The drying curves of corn samples, which have the initial moisture content of 24, 16 and 15%, are presented in Figs 1-3, respectively. The drying time to reduce the moisture content to the safe levels of 13% ranged from 15 to 84 min, 21 to 153 min and 9 to 60 min for IR, HA and IR-HA combined drying, respectively (Table 1). It was observed that IR-HA combined drying considerably reduced the drying time. The time required for drying increased by nearly 155, 260 and 133% with HA drying alone when compared to IR-HA combined drying for corns with the initial moisture content of 24, 16 and 15%, respectively. The longest drying time was observed at HA drying for all drying experiments (Table 1). IR drying followed a pattern between HA and IR-HA combined drying in terms of drying time. Although high drying temperatures have the advantage of reducing drying time, it can not be used for corn drying and depends on the final product. Hall²⁰ recommended a maximum air drying temperature of 53 and 82°C for commercial grains and animal feed corn, respectively.

Specific energy consumption (SEC) values varied between 86 and 191 MJ/kg evaporated water for all the drying conditions (Table 1). When the drying methods were compared with respect to SEC, the highest SEC occurred at HA drying when the initial moisture contents of corn samples were 24 and 16%. Due to its high inputs, SEC during IR-HA combined drying was higher than in IR drying alone, while the shortest drying time was observed at combined drying. However, the lowest SEC observed at HA

drying of corns with the initial moisture content of 15%, while the highest occurred at IR drying (Table 1). These results suggest IR drying is no more advantageous when the moisture content of corn is below 16%. On the other hand, Afzal *et al.* reported that

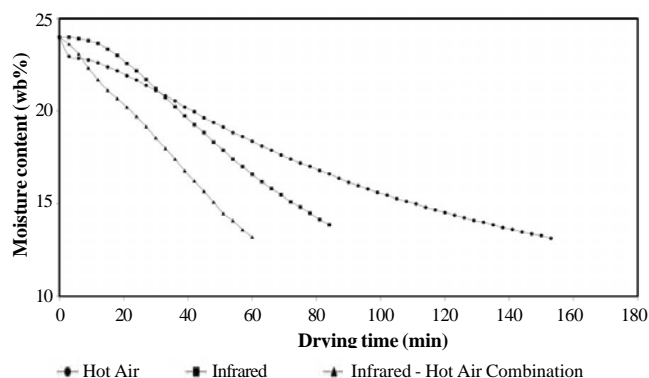


Figure 1. Drying curves of corns with the initial moisture content of 24%.

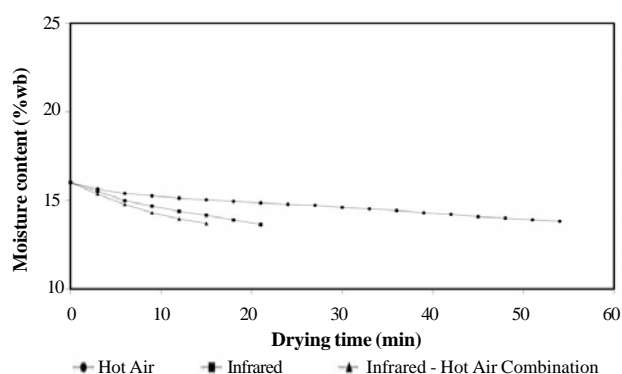


Figure 2. Drying curves of corns with the initial moisture content of 16%.

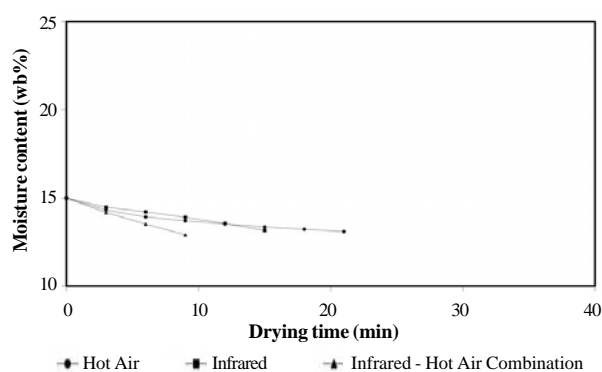


Figure 3. Drying curves of corns with the initial moisture content of 15%.

Table 1. Drying time and specific energy consumption (SEC) values.

Initial moisture content (%)	Drying method	Drying time (min)	SEC (MJ/kg evaporated water)
24	IR	84	106
	HA	153	121
	IR-HA	60	116
16	IR	21	115
	HA	54	191
	IR-HA	15	133
15	IR	15	107
	HA	21	86
	IR-HA	9	90

during the combined convective and IR drying process of barley, the total energy required was reduced by about 156, 238 and 245% as compared with convection drying alone at 40, 55 or 70°C, respectively²¹. Hebbar and others found that the evaporation of water took 48% less time and 63% less energy in combined mode drying as compared to convective drying⁷. Energy consumption during drying is affected by many parameters including drying temperature, infrared power, air velocity and structure (porosity, absorption ability, surface properties, etc.), moisture content and amount of the material. Thus, energy consumption values can vary but the results agreed well with the available experimental data and demonstrated that IR drying has a good potential for application in grain and food drying with or without convective drying as compared to HA drying alone.

In the case of biomaterials, their phytochemical content and quality must be maintained during drying²². Drying procedures are generally applied at temperatures that not exceeding 80°C. Therefore, no significant carotenoid losses or generation of isomers are expected²³. On the other hand, Lozano-Alejo and others found that nixtamalization and frying 60 s at 200-210°C reduced the amount of carotenoids by 36% on average²⁴. Eckhoff stated that the drying of wet corn kernels above 70°C can result in denaturation of proteins and endogenous proteolytic enzymes²⁵.

Owing to the low drying temperatures of 45°C there were no significant differences between control and dried samples in terms of total carotenoid content ($p > 0.05$). Only the carotenoid amount of IR-HA combined dried corns with the initial moisture content of 15% was significantly higher than that of the others ($p < 0.05$). Also there were slight differences between crude protein content of control and dried corn samples (Table 2). These results are in an agreement with Krishnamurthy *et al.* who reported that IR treatment does not change significantly the quality attributes of foods, such as vitamins, protein, and antioxidant activities²⁶.

One of the most important quality criteria of food is color. L , $a+$ and $b+$ values were measured to discuss the differences between control and dried samples. Also hue angle and chroma values, which indicate the intensity of color saturation, were evaluated.

When the control and dried samples were compared among the treatments of the same initial moisture contents, L , $a+$ and $b+$ values were not significantly different except for $b+$ values of the hot air dried corns with the initial moisture content of 15% ($p > 0.05$) (Table 2). Similar to other color characteristics, total color difference (ΔE) indicated no significant variation for all treatments except the third harvest corns ($p > 0.05$). Total color difference of HA dried corns with the initial moisture content of 15% was significantly higher than that of the others ($p < 0.05$).

The HPLC chromatograms of the sample and phenolic acid standards are demonstrated in Fig. 4. It may be seen that no additional clean-up step to purify the extracts is necessary and all phenolic acids could be quantified. Phenolic acid composition of corn samples are shown in Table 3. Totally, ferulic acid was the most dominant phenolic acid in dent corn, followed by *o*-coumaric and *p*-coumaric acids (Table 3). The effect of drying and the difference between the drying techniques on phenolic acid content were not statistically significant ($p > 0.05$). It was ascribed to different initial phenolic acid content of corns and low drying temperatures.

Conclusions

Finally, drying methods of IR, HA and IR-HA were evaluated in terms of their effects on some properties of corn harvested at 24, 16 and 15% initial moisture content. We observed that IR radiation did not cause any negative impact on crude protein, total carotenoid, color characteristics and phenolic acid content of corn in noted conditions. Besides, IR and IR-HA drying methods dramatically reduced the drying time. Evaporation of unit water took 12 and 40% less energy in IR drying of corn samples with the moisture content of 24 and 16%, respectively, as compared to HA drying alone. Thus, IR drying is considered to be a promising alternative for drying of corn with the initial moisture content above 16%.

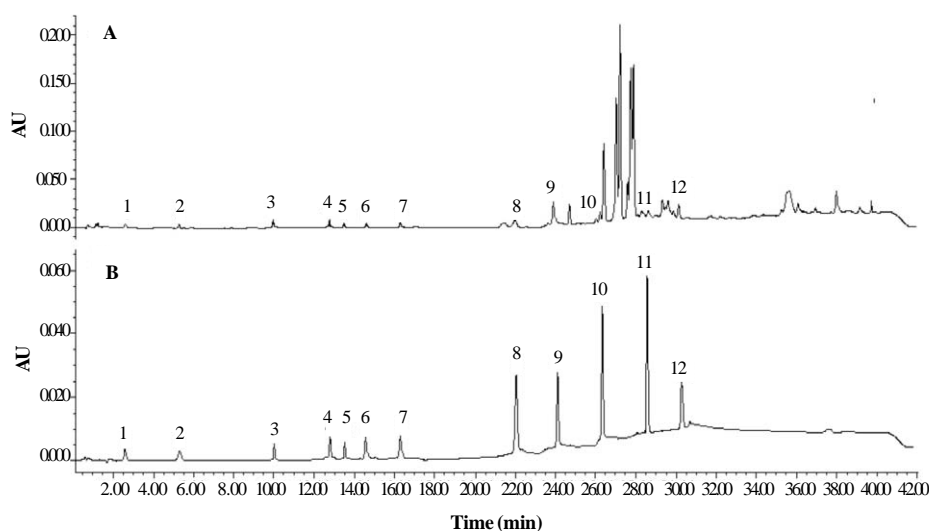


Figure 4. HPLC chromatograms of the IR-HA dried corns with the initial moisture content of 24 % (A) and phenolic acid standards (B).

Table 2. Some properties of corn dried with IR, HA and IR-HA combined drying methods.

Initial moisture content (% w.b.)	Drying method	Crude protein % (N*5.75)	Total carotenoid (µg/g)	L		a+	b+	ΔE	Chroma	Hue angle
				Control	IR-HA					
24	Control	9.5 ± 0.0 ^B	37.5 ± 0.8	63.07 ± 0.41	9.64 ± 0.23	32.37 ± 0.98	-	33.78 ± 1.01	73.40 ± 0.11	
	IR	10.1 ± 0.2 ^A	38.8 ± 2.3	66.22 ± 2.18	9.75 ± 1.32	35.25 ± 3.39	4.26	36.62 ± 3.57	74.80 ± 0.98	
	HA	9.6 ± 0.1 ^B	37.3 ± 0.2	67.41 ± 0.50	6.25 ± 0.51	27.82 ± 3.26	7.13	28.52 ± 3.29	77.22 ± 0.58	
	IR-HA	9.8 ± 0.1 ^{AB}	36.8 ± 2.8	65.73 ± 0.95	8.89 ± 0.94	34.33 ± 0.51	3.38	35.49 ± 0.61	75.50 ± 1.40	
16	Control	10.7 ± 0.3 ^A	36.8 ± 1.3	64.29 ± 4.42	7.39 ± 2.27	26.26 ± 4.53	-	27.31 ± 4.97	74.93 ± 1.98	
	IR	9.2 ± 0.1 ^B	36.6 ± 2.0	63.81 ± 1.93	7.92 ± 0.53	32.90 ± 0.80	6.68	33.85 ± 0.87	76.47 ± 0.69	
	HA	9.3 ± 0.3 ^B	32.2 ± 2.2	61.78 ± 4.00	12.33 ± 1.24	38.85 ± 4.79	13.75	40.78 ± 4.88	72.21 ± 1.14	
	IR-HA	9.8 ± 0.1 ^B	33.3 ± 0.7	65.13 ± 1.46	7.98 ± 0.54	38.56 ± 4.76	12.34	39.39 ± 4.75	78.12 ± 0.66	
15	Control	10.3 ± 0.1 ^A	33.4 ± 0.8 ^B	53.40 ± 2.26	5.96 ± 1.34	22.27 ± 2.73 ^B	-	23.07 ± 2.99 ^B	75.36 ± 1.40	
	IR	10.3 ± 0.0 ^A	36.3 ± 2.2 ^B	53.29 ± 2.28	5.97 ± 0.83	22.70 ± 2.33 ^B	0.43 ^B	23.51 ± 2.46 ^B	75.53 ± 0.70	
	HA	9.7 ± 0.0 ^B	36.0 ± 0.2 ^B	63.30 ± 3.96	10.70 ± 1.64	38.60 ± 4.76 ^A	19.67 ^A	40.09 ± 4.92 ^A	74.52 ± 1.51	
	IR-HA	10.5 ± 0.0 ^A	41.5 ± 0.5 ^A	56.80 ± 3.47	8.99 ± 1.44	30.29 ± 1.10 ^{AB}	9.22 ^{AB}	31.64 ± 1.45 ^{AB}	73.74 ± 1.93	

*Means followed by different capital letters are significantly different (p<0.05).

Table 3. Phenolic acid composition of corns harvested at different times and dried with IR, HA and IR-HA combined drying methods.

Initial moisture content	Phenolic acids (mg/100 g com)	24% (1 st harvest)		16% (2 nd harvest)		15% (3 rd harvest)						
		Control	IR	HA	IR-HA	Control	IR	HA	IR-HA			
	Galic acid	0.233	0.095	0.252	0.150	0.100	0.187	n.d.	0.202	0.238	0.152	0.195
	Protocatechuic acid	0.143	0.170	n.d.	0.229	0.207	0.303	0.283	0.275	n.d.	0.309	n.d.
	p-hydroxy benzoic acid	n.d.	0.606	n.d.	0.629	0.460	0.846	n.d.	n.d.	n.d.	n.d.	n.d.
	Vanillic acid	n.d.	n.d.	n.d.	0.305	0.142	n.d.	n.d.	0.187	n.d.	n.d.	n.d.
	Caffeic acid	n.d.	n.d.	n.d.	0.113	0.099	0.150	n.d.	0.223	0.180	0.207	n.d.
	Chlorogenic acid	n.d.	n.d.	n.d.	0.193	0.090	0.221	n.d.	n.d.	n.d.	n.d.	n.d.
	Syringic acid	n.d.	n.d.	0.237	0.503	0.435	0.665	0.243	0.265	0.248	0.345	0.160
	p-coumaric acid	0.593	0.111	0.384	0.806	0.541	0.575	0.196	0.240	0.525	0.154	0.574
	Ferulic acid	0.863	0.252	0.509	1.125	2.062	2.680	1.614	1.874	0.786	1.320	1.150
	o-coumaric acid	1.274	0.387	0.492	0.345	0.201	0.199	1.860	1.123	0.220	1.087	2.042
	Trans-cinnamic acid	n.d.	0.178	n.d.	0.366	0.335	0.515	n.d.	0.307	0.438	0.418	0.574

* n.d. means not detected and considered as zero for statistical analysis.

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