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Comparative study of colour, pasting and antioxidant properties of different wheat cultivars as affected by toasting and roasting

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ABSTRACT

Wheat has been reported to contain a variety of bioactive compounds which have health benefits. The bioactive compounds, however, are affected by the different processing conditions applied to wheat flour during the manufacture of different products. Milled wheat is used to produce a variety of baked products, but the effect of toasting and roasting before milling has not been examined. Therefore, the effects of mild (toasting) and strong (roasting) heat treatments on the Hunter Lab colour, pasting and antioxidant properties of flours from commercially important wheat cultivars grown in India were investigated. Antioxidant properties including total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity (AOA), metal chelating activity (MCA) and $ABTS^+$ scavenging activity were studied. Both heat treatments resulted in a reduction in bulk density (BD) and Hunter L* values. However, Hunter a* and b* values were increased. The AOA, MCA and $ABTS^+$ scavenging activity of flours increased after both treatments, while TFC was decreased and TPC was increased after toasting but decreased after roasting. All pasting parameters except pasting temperature increased with toasting but decreased after roasting. Flour from cv.WHD-943 showed the highest AOA, TPC and $ABTS^+$ scavenging activity both before and after the two heat treatments.

Keywords
Wheat
Pasting
Antioxidant activity
Total flavonoids content
Total phenolic content

Introduction

Some foods need to be processed before consumption in order to ensure their preservation, microbiological safety and enzymatic inactivation and to destroy toxic substances, as well as to enhance aromas, colours and flavours, and hence palatability [1]. However, processing may result in the appearance of new substances, whose nutritive consequences and biological effects must then be considered. Some food processing methods, together with the composition of the food, facilitate the development of the Maillard reaction and the formation of browning products, which improve food palatability [2].

Wheat is the main cereal grain used to produce different food products [3]. India ranks third in the world regarding wheat production, which occupies nearly 29,650,000 ha with a total annual production of 935,100 tonnes in 2013 [4].

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Wheat flour contains significant levels of antioxidants and biologically active dietary substances, such as carotenoids, flavonoids and phenolic acids, but these are unevenly distributed in the kernel [5]. The antioxidants in wheat are concentrated in the outermost layers of wheat grain, especially in bran, which is generally removed during product formulation to increase the acceptability of the product. Therefore, processing methods should be employed which increase antioxidants in the inner layers of grains or at least cause minimum damage to them.

Toasting (mild heat treatment) has been reported to induce significant changes in the carbohydrate and antioxidant profiles of chickpea flours, while enhancing the overall nutritional profile [6]. Mild processing methods are also recommended in order to increase the dietary bioactive compounds beneficial to health [7]. Sandhu *et al.* [8] studied the effect of toasting on the physical, functional and antioxidant properties of flour from oat cultivars and found that toasting had a significant effect on different bioactive properties. Roasting (strong heat treatment) is a rapid processing method that uses dry heat for short periods of time. Roasted grains have been reported to exhibit improved texture, enhanced crispness and greater volume due to puffing [9]. Roasting also improves digestibility, colour, flavour and shelf-life, and reduces the antinutritional factors in cereals and legumes [10]. Milled wheat is used to produce a variety of baked products, but the effect of toasting and roasting prior to milling has not been examined. The present investigation thus aimed to study the effect of toasting and roasting on the physical, pasting, colour and antioxidant properties of flours from different wheat cultivars grown in India.

Materials and methods

Procurement of wheat samples

Six wheat varieties (PBW-343, WH-1080, PBW-590, WH-283, WH-896 and WHD-943) were collected from Haryana Agricultural University, Hisar, India. The grains of each cultivar were cleaned and stored for further evaluation.

Reagents

Standard gallic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferrozine, Folin–Ciocalteu reagent, $ABTS^+$ and catechin were purchased from Sigma-Aldrich (Steinheim, Germany). All chemicals were of analytical grade.

Toasting, roasting and milling of wheat

Toasting

Wheat cultivars were toasted according to the method of Fares and Menga [6]. Wheat samples (200 g each) were conditioned to a moisture content of 10% in order to maintain uniformity during the toasting process and then toasted at 115±2°C for 3 h in an oven (NSW-143; NSW, New Delhi, India).

Roasting

Different wheat cultivars (200 g samples) were conditioned to a moisture content of 10% in order to maintain uniformity during the roasting process and roasted at 280±5°C for 15 s in a traditional sand roaster as described by Sharma and Gujral [11]. The roaster consisted of a pan which contained 1.75 kg of sand with a diameter and depth of 850 mm and 550 mm, respectively. Sand roasting was carried out carefully so as not to burn the grain.

Flours from control, toasted and roasted samples were prepared by milling grains in a grinder (Khera Enterprises, Delhi, India) and sieving the flours through a 250 mm sieve.

Bulk density of wheat grains

The bulk density of wheat grains was measured by gently filling a previously tared 100 ml graduated cylinder with grain. The bottom of the cylinder was gently tapped several times on a laboratory bench until there was no further settling of the sample level after filling to the 100 ml mark. Bulk density was calculated as weight of sample per unit volume of sample (g/ml). All measurements were done in triplicate.

Pasting properties

The pasting properties of flours were studied using the starch cell of an MCR 52 rheometer (Anton Paar, Graz, Austria). Wheat flour (1.2 g) was placed in the cell and 13.8 g water was added to it. The suspension was mixed thoroughly with a plastic paddle to prevent lump formation before pasting analysis using a heating step of 50–95°C at 6°C/min, a holding phase at 95°C for 5 min, a cooling step from 95°C to 50°C at 6°C/min, and a holding phase at 50°C for 2 min. The peak viscosity (PV), breakdown viscosity (BV), final viscosity (FV), setback viscosity (SV) and pasting temperature (PT) were recorded.

Hunter Lab colour characteristics

The colour of flours was measured using a Hunter Colorimeter fitted with an optical sensor (Hunter Associates Laboratory, Restan, VA, USA) and using the L*, a*, b* colour system.

Total phenolic content

Total phenolic content (TPC) was determined using the Folin–Ciocalteu method as described by Gao *et al*. [12]. Wheat flour samples (200 mg) were extracted with 4 ml acidified methanol (HCl/methanol/water, 1:80:10, v/v/v) at room temperature (25°C) for 2 h using a wrist action shaker (Narang Scientific Works, New Delhi, India). The mixture was centrifuged at 3000 rpm for 10 min on a centrifuge (Remi, Mumbai, India) and the supernatant used for the determination of TPC. An aliquot of extract (200 µl) was added to 1.5 ml freshly diluted (20-fold) Folin–Ciocalteu reagent. The mixture was allowed to equilibrate for 5 min and then mixed with 1.5 ml of sodium carbonate solution (60 g/l). After incubation at room temperature (25°C) for 90 min, the absorbance of the mixture was read at 725 nm. Acidified methanol was used as blank. The results were expressed as µg of gallic acid equivalents (GAE)/g of flour.

Antioxidant activity

Antioxidant activity (AOA) was measured by following a modified version of the method described by Brand-Williams *et al*. [13] using 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution in methanol. Milled wheat samples (100 mg) were extracted with 1 ml methanol for 2 h and centrifuged at 3000 rpm for 10 min. The supernatant (100 µl) was reacted with 3.9 ml of a 6×10^{-5} mol/l DPPH solution. Absorbance

(A) at 515 nm was read at 0 and 30 min using methanol as blank. AOA was calculated as % discoloration as follows: % AOA=(1–(A of sample^{t}=30/A of sample^{t}=0))×100.

Total flavonoid content

Total flavonoid content (TFC) was determined by following the method described by Jia *et al*. [14]. Wheat extract (250 µl) was diluted with 1.25 ml of distilled water. Sodium nitrite (75 µl of a 5% solution) was added and the mixture was allowed to stand for 5 min. Then, 150 µl of a 10% aluminium chloride solution was added and the mixture was allowed to stand for another 5 min. Next, 0.5 ml of 1 M sodium hydroxide was added and the solution was mixed well. The absorbance was measured immediately at 510 nm using a spectrophotometer (Systronics, Ahmadabad, India). Catechin was used as standard and the results were reported as µg of catechin equivalents (CE)/g of flour.

Metal chelating (Fe^{2+}) activity

The metal chelating (Fe^{2+}) activity (MCA) of wheat extract was measured by following the method described by Dinis *et al*. [15]. The extract (0.5 ml) was mixed with 50 µl of ferrous chloride (2 mM/l) and 1.6 ml of 80% methanol was added. After 5 min, the reaction was initiated by the addition of 5 mM/l ferrozine (100 µl) and the mixture was shaken in a vortex mixer. The mixture was incubated at room temperature (25°C) for 10 min. Absorbance of the solution was measured at 562 nm on a spectrophotometer. The chelating activity of the extract for Fe^{2+} was calculated as follows: Iron (Fe^{2+}) chelating activity (%)= [1–(Absorbance of sample/Absorbance of control)]×100.

ABTS$^+$ scavenging activity

ABTS$^+$ scavenging activity was measured by following the method described by Re *et al*. [16] and using 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) diammonium salt. ABTS$^+$ was generated by oxidation of ABTS with potassium persulfate. A 3 ml aliquot of ABTS cation solution was mixed with 30 µl extract in a disposable microcuvette and the decrease in absorption measured after 1 min of incubation. A standard curve was prepared by using different concentrations of vitamin C, similar to the DPPH assay. ABTS$^+$ scavenging activity was expressed as vitamin C in µmol/g of wheat.

Statistical analysis

The data reported in all tables are an average of triplicate observations and were subjected to one-way analysis of variance (ANOVA) using Minitab statistical software version 14 (Minitab, State College, PA, USA).

Results and discussion

Bulk density of grains

The bulk densities of grains from control, toasted and roasted wheat cultivars are summarized in Table 1. Heat treatment resulted in grain expansion and thus lowered the bulk density of grains from both toasted and roasted wheat cultivars in comparison to their control counterparts. Roasting caused a greater decrease in bulk density of 27.4–35% compared to toasting, which reduced bulk density only by 1.5–2.2%. The maximum effect of toasting and roasting was observed for cv.PBW-590. The decrease in bulk density after roasting may be caused by a loss of integrity between starch–starch and starch–protein matrices and/or due to the formation of spaces in the starchy endosperm [17].

Pasting properties of flours from roasted wheat cultivars

The pasting properties of flours from control, toasted and roasted cultivars are presented in Tables 2–4. The PV of

Wheat cultivar	Bulk density (control) (g/ml)	Bulk density (toasted) (g/ml)	Bulk density (roasted) (g/ml)
PBW-343	$0.746±0.02^{an}$	$0.729±0.02^{am}{}_{\downarrow 2.2}$	$0.541±0.01^{cdl}{}_{\downarrow 27.4}$
WH-1080	$0.788±0.01^{abn}$	$0.774±0.01^{dm}{}_{\downarrow 1.7}$	$0.513±0.01^{bl}{}_{\downarrow 34.8}$
PBW-590	$0.768±0.02^{abn}$	$0.749±0.01^{bm}{}_{\downarrow 2.4}$	$0.499±0.02^{al}{}_{\downarrow 35}$
WH-283	$0.781±0.01^{bn}$	$0.769±0.02^{cm}{}_{\downarrow 1.5}$	$0.545±0.01^{dl}{}_{\downarrow 30.2}$
WH-896	$0.767±0.01^{abn}$	$0.751±0.03^{bm}{}_{\downarrow 2}$	$0.539±0.03^{cl}{}_{\downarrow 29.7}$
WHD-943	$0.799±0.02^{bn}$	$0.783±0.01^{em}{}_{\downarrow 2}$	$0.568±0.04^{el}{}_{\downarrow 28.9}$

a, b, c, d and e superscripts in the same column indicate significant ($p<0.05$) differences within different cultivars, while l, m and n superscripts in the same row indicate significant ($p<0.05$) differences within a cultivar. Subscripts denote the percentage decrease (↓) from control samples for corresponding properties

Table 1 - Bulk density of flours from control, toasted and roasted wheat cultivars

Wheat cultivar	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Pasting temperature (°C)
PBW-343	363^d	314^c	49^c	859^e	545^d	54^b
WH-1080	330^c	310^c	19^a	822^d	512^c	60.8^c
PBW-590	526^e	464^d	62^e	1160^f	696^e	61.8^d
WH-283	171^b	115^b	55^d	623^b	452^b	49.9^a
WH-896	136^a	100^a	36^b	465^a	329^a	64.8^e
WHD-943	165^b	108^{ab}	56^d	683^c	518^c	60.3^c

Values are means. Those with the same superscript within the same column do not differ significantly ($p<0.05$)

Table 2 - Pasting properties of flours from different wheat cultivars

Wheat cultivar	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Pasting temperature (°C)
PBW-343	$668^{d}_{\uparrow 84}$	$613^{d}_{\uparrow 95.2}$	$55^{b}_{\uparrow 12.2}$	$1216^{c}_{\uparrow 41.5}$	$603^{b}_{\uparrow 10.6}$	$53.1^{b}_{\downarrow 1.6}$
WH-1080	$846^{e}_{\uparrow 156}$	$775^{e}_{\uparrow 150}$	$71^{d}_{\uparrow 273}$	$1719^{e}_{\uparrow 109}$	$944^{f}_{\uparrow 84.3}$	$57.4^{c}_{\downarrow 5.4}$
PBW-590	$850^{e}_{\uparrow 61.5}$	$786^{e}_{\uparrow 69.3}$	$64^{c}_{\uparrow 3.2}$	$1682^{d}_{\uparrow 45}$	$896^{e}_{\uparrow 28.7}$	$60.2^{e}_{\downarrow 2.5}$
WH-283	$566^{c}_{\uparrow 230}$	$501^{c}_{\uparrow 335}$	$65^{c}_{\uparrow 18.1}$	$1219^{c}_{\uparrow 95.6}$	$718^{d}_{\uparrow 58.8}$	$48.4^{a}_{\downarrow 2.8}$
WH-896	$240^{a}_{\uparrow 76.4}$	$202^{a}_{\uparrow 102}$	$38^{a}_{\uparrow 5.5}$	$846^{b}_{\uparrow 81.9}$	$644^{c}_{\uparrow 95.7}$	$61.3^{f}_{\downarrow 5.3}$
WHD-943	$387^{b}_{\uparrow 134}$	$274^{b}_{\uparrow 153}$	$83^{e}_{\uparrow 48.2}$	$797^{a}_{\uparrow 16.6}$	$523^{a}_{\uparrow 0.9}$	$59.4^{d}_{\downarrow 1.4}$

a, b, c, d, e and f superscripts in the same column indicate significant (p<0.05) differences within different cultivars. Subscripts denote the percentage increase (↑) or decrease (↓) from control samples for corresponding properties

Table 3 - Pasting properties of flours from toasted wheat cultivars

Wheat cultivar	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	Pasting temperature (°C)
PBW-343	$235^{e}_{\downarrow 35.2}$	$195^{d}_{\downarrow 37.8}$	$40^{c}_{\downarrow 18.3}$	$475^{b}_{\downarrow 44.7}$	$280^{d}_{\downarrow 48.6}$	$57.0^{b}_{\uparrow 5.5}$
WH-1080	$196^{d}_{\downarrow 40.6}$	$164^{c}_{\downarrow 47}$	$32^{b}_{\downarrow 68.4}$	$268^{a}_{\downarrow 67.3}$	$104^{a}_{\downarrow 79.6}$	$62.8^{c}_{\uparrow 3.2}$
PBW-590	$335^{f}_{\downarrow 36.3}$	$279^{e}_{\downarrow 39.8}$	$56^{d}_{\downarrow 9.6}$	$668^{c}_{\downarrow 42.4}$	$389^{f}_{\downarrow 44.1}$	$63.5^{d}_{\uparrow 2.7}$
WH-283	$151^{c}_{\downarrow 11.6}$	$105^{b}_{\downarrow 8.6}$	$46^{cd}_{\downarrow 16.3}$	$468^{b}_{\downarrow 24.8}$	$363^{e}_{\downarrow 19.6}$	$55.9^{a}_{\uparrow 12}$
WH-896	$117^{a}_{\downarrow 13.9}$	$90^{a}_{\downarrow 10}$	$27^{a}_{\downarrow 25}$	$265^{a}_{\downarrow 43}$	$175^{b}_{\downarrow 46.8}$	$66.8^{f}_{\uparrow 3}$
WHD-943	$132^{b}_{\downarrow 20}$	$105^{b}_{\downarrow 2.7}$	$27^{a}_{\downarrow 51.7}$	$264^{a}_{\downarrow 61.3}$	$259^{c}_{\downarrow 50}$	$64.3^{e}_{\uparrow 6.6}$

a, b, c, d, e and f superscripts in the same column indicate significant (p<0.05) differences within different cultivars. Subscripts denote the percentage increase (↑) or decrease (↓) from control samples for corresponding properties

Table 4 - Pasting properties of flours from roasted wheat cultivars

flours from different control wheat cultivars ranged from 136 to 526 cP, the highest being for cv.PBW-590 and the lowest for cv.WH-896. Both PV and FV increased significantly (p<0.05) upon toasting, but decreased after roasting compared to the control counterpart flour. A decrease in PV may be due to the presence of pre-gelatinized starch in the flour after thermal treatment [18]. Zhang *et al.* [19] reported that thermal treatment reduced the viscous properties of flour. Loosely packed starch granules with high levels of damaged starch hydrate easily and swell more rapidly in the presence of heat and consequently have lower PV values [20, 21]. The BV of flours from different control cultivars ranged from 19 to 62 cP, with cv.WH-1080 showing the lowest value, indicating its paste stability. The BV of flours was increased after toasting but decreased after roasting for all cultivars in comparison to controls. The SV was also increased after toasting, whereas the reverse was observed after roasting. The trends in pasting parameters of flours from toasted wheat cultivars were completely opposite those of flours from roasted cultivars. Except for PT, all pasting parameters of flours showed increases when toasted, whereas PT increased and other properties decreased when grains were roasted.

Hunter Lab colour characteristics of flours

The colour properties of flours from control, toasted and roasted wheat cultivars were evaluated using the Hunter Lab colour system (Table 5). The L* value of flours from control cultivars ranged from 55.9 to 78.8; the highest L* value for cv.PBW-590 flour indicated that it was lighter in colour than all other flours. Both toasting and roasting significantly (p<0.05) affected the colour of the flours. Lightness was reduced by 4.2–12.8% upon toasting and by 6.9–20.2% upon roasting. After toasting, the L* values ranged from 49.3 to 68.7, while for roasted wheat flours the values varied from 47.3 to 66.3. A higher a* value indicates more redness. The a* value ranged from 1.55 to 2.62 for flours from control cultivars with cv.WHD-943 and cv.WH-283 showing the highest and the lowest values, respectively. Redness (a*) increased by 5.72–38.8% upon toasting and by 9.5–71.6% upon roasting. The b* value indicates the degree of yellow-blue colour, with values ranging from 8.49 to 13.30 for flours from control cultivars. The b* value increased by 1.34–15%, with values ranging between 9.91 to 13.6 upon toasting, and by 6–18.8%, with values ranging between 10.09 to 14.6 upon roasting. The results observed (increased a* and b* values and decreased L* value) in the colour parameters are due to the Maillard reaction [22] and browning reaction that produce brown pigments with low and high molecular weights in advanced stages of the browning reaction [23].

Wheat cultivar	L*			a*			b*		
	Control	Toasted	Roasted	Control	Toasted	Roasted	Control	Toasted	Roasted
PBW-343	71.2^{b}	$68.2^{d}_{\downarrow 4.2}$	$66.3^{e}_{\downarrow 6.9}$	1.62^{a}	$2.25^{b}_{\uparrow 38.8}$	$2.78^{c}_{\uparrow 71.6}$	9.31^{b}	$10.1^{a}_{\uparrow 8.48}$	$10.7^{a}_{\uparrow 14.9}$
WH-1080	75.2^{d}	$67.2^{c}_{\downarrow 10.6}$	$65.2^{d}_{\downarrow 13.3}$	2.08^{b}	$2.44^{c}_{\uparrow 17.3}$	$2.64^{b}_{\uparrow 26.9}$	10.44^{c}	$10.3^{a}_{\uparrow 1.34}$	$11.23^{b}_{\uparrow 7.5}$
PBW-590	78.8^{e}	$68.7^{e}_{\downarrow 12.8}$	$62.9^{b}_{\downarrow 20.2}$	2.26^{c}	$2.48^{c}_{\uparrow 9.73}$	$2.88^{d}_{\uparrow 27.4}$	10.69^{c}	$11.5^{b}_{\uparrow 7.57}$	$11.76^{b}_{\uparrow 10}$
WH-283	55.9^{a}	$49.3^{a}_{\downarrow 11.8}$	$47.3^{a}_{\downarrow 15.4}$	1.55^{a}	$2.11^{a}_{\uparrow 36.1}$	$2.21^{a}_{\uparrow 42.5}$	8.49^{a}	$9.91^{a}_{\uparrow 16.7}$	$10.09^{a}_{\uparrow 18.8}$
WH-896	74.4^{c}	$66.3^{b}_{\downarrow 11.4}$	$63.3^{b}_{\downarrow 15}$	2.57^{d}	$2.79^{d}_{\uparrow 8.56}$	$2.99^{e}_{\uparrow 16.3}$	13.23^{d}	$13.6^{c}_{\uparrow 2.79}$	$14.6^{c}_{\uparrow 10.3}$
WHD-943	75.8^{d}	$68.2^{d}_{\downarrow 10}$	$64.3^{c}_{\downarrow 15.2}$	2.62^{d}	$2.77^{d}_{\uparrow 5.72}$	$2.87^{d}_{\uparrow 9.5}$	13.30^{d}	$11.3^{b}_{\uparrow 15}$	$14.11^{c}_{\uparrow 6}$

a, b, c, d, e and f superscripts in the same column indicate significant (p<0.05) differences within different cultivars. Subscripts denote the percentage increase (↑) or decrease (↓) from control samples for corresponding properties

Table 5 - Hunter colour characteristics of flours from control, toasted and roasted wheat cultivars

TPC of flours

The TPC of flours from control cultivars ranged between 974 to 1399 µg GAE/g (Table 6). The highest TPC was observed for flour from cv.WHD-943, while cv.PBW-343 flour had the lowest values. Toasting caused an increase in TPC of 12.0–55.9%, with values ranging from 1267 to 1801 µg GAE/g. Cv.PBW-590 and cv.PBW-343 had the highest and the lowest TPC values, respectively. Gallegos-Infante *et al*. [24] reported that the TPC of a barley sample was increased after heat processing. The increase in TPC after toasting (which is less severe heat treatment) may be due to the release of bound phenolic compounds. Dewanto *et al*. [25] explained that thermal processing might release more bound phenolic acids from the breakdown of cellular constituents. Roasting resulted in a significant (p<0.05) decrease in TPC for all cultivars compared to control counterparts. Values of TPC after roasting ranged from 734 to 910 µg GAE/g, with the highest and the lowest being observed for cv.WHD-943 and cv.WH-283, respectively. Increases in TPC values of up to 43.1% were observed in roasted flours, with cv.WH-283 showing the highest and cv.PBW-343 showing the lowest TPC values. A reduction of 50% in the phenolic content of oat extrudates following thermal treatment has also been reported [26]. The decrease in TPC could be attributed to the oxidation and degradation of heat susceptible phenolic compounds during roasting [27, 28].

Wheat cultivar	Total phenolic content (µg GAE/g)		
	Control	Toasted	Roasted
PBW-343	974±6.1^{am}	1267±11.7$^{an}_{\uparrow 30}$	765±8.3$^{bl}_{\downarrow 21.4}$
WH-1080	1116±3.7^{cm}	1674±9.8$^{dn}_{\uparrow 50}$	802±2.9$^{cl}_{\downarrow 28.1}$
PBW-590	1155±9.1^{dm}	1801±11.1$^{en}_{\uparrow 55.9}$	837±4.9$^{cl}_{\downarrow 27.5}$
WH-283	1290±7.8^{em}	1445±19.7$^{bn}_{\uparrow 12.01}$	734±3.7$^{al}_{\downarrow 43.1}$
WH-896	1069±9.4^{bm}	1522±8.5$^{cn}_{\uparrow 42.3}$	788±9.6$^{bl}_{\downarrow 26.2}$
WHD-943	1399±12.1^{fm}	1698±10.1$^{dn}_{\uparrow 21.3}$	910±6.6$^{dl}_{\downarrow 34.9}$

a, b, c, d, e and f superscripts in the same column indicate significant (p<0.05) differences within different cultivars, while l, m and n superscripts in the same row indicate significant (p<0.05) differences within a cultivar. Subscripts denote the percentage increase (↑) or decrease (↓) from control samples for corresponding properties

Table 6 - Total phenolic contents of flours from control, toasted and roasted wheat cultivars

AOA (%) of flours

The AOA of flours from control, toasted and roasted cultivars is reported in Table 7. The DPPH radical scavenging capacity of flours from control cultivars ranged from 13.2% to 21.6%. The AOA of all cultivars increased following both toasting and roasting, with increases of 36.2–87.2% and 82.4–122%, respectively (Table 7). The AOA of flours after toasting and roasting also differed significantly (p<0.05) among cultivars, with values of 20.5–34.5% and 29.4–41.8%, respectively. Cv.WH-283 and cv.WHD-943 exhibited the highest values after both toasting and roasting. Randhir *et al*. [29] reported that the increase in AOA after thermal processing could be attributed to the formation of brown pigments. Flours obtained from roasted grains exhibited higher AOA values than those obtained from toasted grains. Increased AOA activity may be due to the formation of non-enzymatic browning products, especially melanoids, at the high temperatures [30]. Pradeep and Guha [31] reported that roasted millet had higher antioxidant properties than unroasted millet and attributed this to the formation of higher Maillard products by the high temperature during a short time processing.

TFC of flours

Flavonoids account for approximately two-thirds of dietary phenols [32]. The TFC differed significantly (p<0.05) among flours from different wheat cultivars, with values ranging from 75 to 102 µg CE/g (Table 8). Toasting and roasting caused significant (p<0.05) decreases in the TFC of 16.1–54.6% and 52.9–77.9%, respectively. After toasting, the TFC significantly (p<0.05) varied among flours from different cultivars and ranged from 39 to 76 µg CE/g, with the highest and the low-

Wheat cultivar	Antioxidant activity (%)		
	Control	Toasted	Roasted
PBW-343	13.2±0.64^{al}	20.5±0.64$^{am}_{\uparrow 55.3}$	29.4±1.3$^{an}_{\uparrow 122}$
WH-1080	15.7±0.91^{bl}	29.4±0.71$^{bcm}_{\uparrow 87.2}$	32.2±0.63$^{cn}_{\uparrow 105}$
PBW-590	19.2±0.49^{dl}	30.8±1.23$^{cm}_{\uparrow 60.4}$	36.8±1.27$^{bcn}_{\uparrow 91.6}$
WH-283	21.6±0.72^{fl}	34.5±0.94$^{dm}_{\uparrow 59.7}$	39.4±0.71$^{dn}_{\uparrow 82.4}$
WH-896	16.8±0.50^{cl}	31.2±0.71$^{cm}_{\uparrow 85.7}$	36.2±0.74$^{bn}_{\uparrow 115}$
WHD-943	20.4±0.64^{el}	27.8±0.58$^{bm}_{\uparrow 36.2}$	41.8±0.71$^{en}_{\uparrow 104}$

a, b, c, d, and e superscripts in the same column indicate significant (p<0.05) differences within different cultivars, while l, m and n superscripts in the same row indicate significant (p<0.05) differences within a cultivar. Subscripts denote the percentage increase (↑) from control samples for corresponding properties

Table 7 - Antioxidant activity (%) of flours from control, toasted and roasted wheat cultivars

Wheat cultivar	Total flavonoid content (µg GAE/g)		
	Control	Toasted	Roasted
PBW-343	98±5.2^{cdn}	61±4.3$^{cm}_{\downarrow 37.7}$	43±4.5$^{bcl}_{\downarrow 56.1}$
WH-1080	75±6.4^{an}	49±4.9$^{bm}_{\downarrow 34.6}$	28±6.1$^{al}_{\downarrow 62.6}$
PBW-590	91±6.6^{cn}	58±6.1$^{cm}_{\downarrow 36.2}$	32±4.3$^{cl}_{\downarrow 64.8}$
WH-283	102±5.1^{dn}	76±6.3$^{dm}_{\downarrow 25.4}$	48±2$^{dl}_{\downarrow 52.9}$
WH-896	87±7.2^{bn}	73±7.1$^{dm}_{\downarrow 16.09}$	37±2.0$^{bl}_{\downarrow 57.4}$
WHD-943	86±9.6^{bn}	39±6.9$^{am}_{\downarrow 54.6}$	19±1.7$^{bl}_{\downarrow 77.9}$

a, b, c and d superscripts in the same column indicate significant (p<0.05) differences within different cultivars, while l, m and n superscripts in the same row indicate significant (p<0.05) differences within a cultivar. Subscripts denote the percentage decrease (↓) from control samples for corresponding properties

Table 8 - Total flavonoid content of flours from control, toasted and roasted wheat cultivars

est values seen for cv.WH-283 and cv.WHD-943, respectively. The TFC of flours from cultivars after roasting differed significantly (p<0.05) among cultivars, with values ranging from 19 to 48 μg CE/g. The highest and the lowest TFC values were observed for flour from cv.BH-283 and cv.WHD-943, respectively. Gujral *et al.* [18] reported that roasting significantly (p<0.05) decreased the TFC of oats by 22.7–49.9%. Flavonoids are a group of phenolic compounds which are more sensitive to and are destroyed by thermal processing [33]. Zhang *et al.* [34] reported that flavonoids are heat labile compounds that are easily destroyed by heat during roasting.

MCA of flours

The transition metals have been reported to be catalysts for the initial formation of free radicals. Metal chelators may stabilize metal ions in living systems and inhibit radical producers, thereby reducing free radical damage [35]. The MCA of flours from wheat cultivars ranged from 22% to 42% with the highest and the lowest values observed for cv.WH-283 and cv.WH-896, respectively (Table 9). After both toasting and roasting, the MCA of flours increased significantly (p<0.05) in comparison to their control counterpart flours. There were increases of 33.3–90.9% after toasting and 57.8–123% after roasting. The increase in MCA after heat treatment may be due to alterations in phenolic structure and/or degradation of phenolic compounds to different Maillard reaction products such as melanoids which could also act as antioxidants [28, 36]. The increase in MCA may also be due to the formation of Maillard browning pigments through the interaction of carbohydrates (especially reducing sugars) and proteins during cooking [7, 37]. Siddhuraju [38] and Duenas *et al.* [39] reported that the higher antioxidant properties of thermally processed foods could be due to the formation of products such as 5-hydroxymethyl-2-furaldehyde.

Wheat cultivar	Metal chelating activity (%)		
	Control	Toasted	Roasted
PBW-343	24 ± 3^{abl}	$41\pm3.4^{bm}\uparrow70.8$	$47.3\pm1.8^{bn}\uparrow97$
WH-1080	28 ± 3.4^{bl}	$39\pm4.1^{am}\uparrow39.2$	$53.2\pm1.6^{cn}\uparrow90$
PBW-590	31 ± 3.6^{bcl}	$48\pm2^{bcm}\uparrow54.8$	$58.9\pm1.2^{an}\uparrow90$
WH-283	42 ± 3.4^{dl}	$56\pm2.6^{cm}\uparrow33.3$	$66.3\pm0.7^{en}\uparrow57.8$
WH-896	22 ± 3^{al}	$43\pm2.6^{bm}\uparrow90.9$	$49.2\pm0.7^{an}\uparrow123$
WHD-943	36 ± 2.6^{cl}	$49\pm2.6^{bcm}\uparrow36.1$	$59.9\pm0.6^{dn}\uparrow66.3$

a, b, c, d, and e superscripts in the same column indicate significant (p<0.05) differences within different cultivars, while l, m and n superscripts in the same row indicate significant (p<0.05) differences within a cultivar. Subscripts denote the percentage increase (↑) from control samples for corresponding properties

Table 9 - Metal chelating activity of flours from control, toasted and roasted wheat cultivars

Wheat cultivar	$ABTS^+$ scavenging activity (μmol/g)		
	Control	Toasted	Roasted
PBW-343	3.06 ± 0.22^{al}	$7.91\pm0.54^{am}{}_{\uparrow58.4}$	$10.6\pm0.96^{bn}{}_{\uparrow246}$
WH-1080	6.32 ± 0.63^{cl}	$9.86\pm0.94^{bm}{}_{\uparrow56.01}$	$12.6\pm1.04^{dn}{}_{\uparrow99.3}$
PBW-590	6.45 ± 0.60^{cl}	$12.3\pm0.47^{dm}{}_{\uparrow90.6}$	$13.8\pm1.08^{en}{}_{\uparrow113}$
WH-283	8.11 ± 0.23^{el}	$14.7\pm0.49^{em}{}_{\uparrow81.2}$	$16.7\pm0.85^{fn}{}_{\uparrow105}$
WH-896	4.15 ± 0.24^{bl}	$10.4\pm0.66^{cm}{}_{\uparrow50.6}$	$11.8\pm0.98^{cn}{}_{\uparrow184}$
WHD-943	7.12 ± 0.25^{dl}	$16.6\pm0.98^{fm}{}_{\uparrow33.1}$	$17.9\pm1.15^{an}{}_{\uparrow109}$

a, b, c, d, and e superscripts in the same column indicate significant (p<0.05) differences within different cultivars, while l, m and n superscripts in the same row indicate significant (p<0.05) differences within a cultivar. Subscripts denote the percentage increase (↑) from control samples for corresponding properties

Table 10 - $ABTS^+$ scavenging activity of flours from control, toasted and roasted wheat cultivars

$ABTS^+$ scavenging activity of flours

The ability of antioxidants to quench the $ABTS^+$ radical cation was measured. The reaction of an antioxidant compound with $ABTS^+$ scavenging activity occurs rapidly and can be assessed by following the decrease in sample absorbance at 734 nm. $ABTS^+$ scavenging activity among flours from control wheat cultivars differed significantly (p<0.05), with values ranging from 3.06 to 8.11 μmol/g. Toasting resulted in a significant (p<0.05) increase in $ABTS^+$ scavenging activity of 31.3–90.6%, with the largest and smallest increases observed for cv.PBW-590 and cv.WHD-943, respectively (Table 10). $ABTS^+$ scavenging activity of flours from toasted wheat varied significantly (p<0.05) among cultivars, with values ranging from 7.91 to 17.9 μmol/g, the highest and the lowest being observed for cv.WHD-943 and cv.PBW-343, respectively. Upon roasting, $ABTS^+$ scavenging activity increased among cultivars, with values ranging from 10.6 to 17.9 mol/g, and cv.WHD-943 and cv.PBW-343 showing the highest and the lowest values, respectively. $ABTS^+$ scavenging activity for flours from roasted cultivars increased by up to 246% compared to their control counterparts.

In conclusion, significant effects were observed on flours from wheat cultivars after both toasting and roasting for the various properties studied. Some properties (bulk density and Hunter L* value) decreased, while Hunter a* and b* values increased after both toasting and roasting. The values of the antioxidant properties studied also varied in terms of increases or decreases after heat treatment. AOA, MCA and $ABTS^+$ scavenging activities increased, while TFC decreased after both heat treatments. The TPC of flours after toasting was increased, but after roasting was decreased in comparison to the control counterpart flours. The highest AOA, TPC and $ABTS^+$ scavenging activity was seen in control and heat-treated cv.WHD-943 flour. Therefore, the type of heat treatment can increase or decrease the antioxidant compounds in wheat. Establishing the effect of different types of thermal processing on antioxidant compounds as well other properties will be helpful in formulating products with improved antioxidant properties.

Conflict of interest

The authors declare no conflict of interest.

Human and animal rights

This article does not contain any studies with human and animal subjects performed by any of the authors.

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