Annexure – VIII

UNIVERSITY GRANTS COMMISSION BAHADUR SHAH ZAFAR MARG NEW DELHI

**FINAL REPORT OF THE WORK DONE ON THE PROJECT**

1. NAME AND ADDRESS OF THE PRINCIPAL INVESTIGATOR: Hardeep Singh Gujral, Associate Professor, Department of Food Science & Technology, Guru Nanak Dev University, Amritsar

2. NAME AND ADDRESS OF THE INSTITUTION: Department of Food Science & Technology, Guru Nanak Dev University, Amritsar

3. UGC APPROVAL NO. AND DATE: F.No.34-110/2008(SR), 31 Dec 2008

4. DATE OF IMPLEMENTATION: 1-2-2009

5. TENURE OF THE PROJECT: 3 years

6. TOTAL GRANT ALLOCATED: Rs. 1081800/-

7. TOTAL GRANT RECEIVED: Rs. 973434/-

8. FINAL EXPENDITURE: Rs. 966001/-

9. TITLE OF THE PROJECT: Processing and utilization of oat into high β-glucan Foods

10. OBJECTIVES OF THE PROJECT: Annexure I

11. WHETHER OBJECTIVES WERE ACHIEVED: Annexure II(GIVE DETAILS)

12. ACHIEVEMENTS FROM THE PROJECT: Annexure III

13. SUMMARY OF THE FINDINGS : Annexure IV ( IN 500 WORDS )

14. CONTRIBUTION TO THE SOCIETY : Annexure V ( GIVE DETAILS )

15. WHETHER ANY PH.D. ENROLLED/PRODUCED OUT OF THE PROJECT: None

16. NO. OF PUBLICATIONS OUT OF THE PROJECT ( PLEASE ATTACH RE-PRINTS): 2


1. Gujral HS, Sharma P, Gill BS and Kaur S. Effect of incorporating hydrothermal, kilned and defatted oats on antioxidant and chapatti making properties of wheat flour. Food Chemistry (in press).
2. Gujral HS, Paras Sharma & Rachna (2011). Effect of roasting on beta glucan extractability, physiochemical and antioxidant properties of oats. *LWT- Food Science & Technology*, 44, 2223-2230.


HS Gujral 18/11/12
(PRINCIPAL INVESTIGATOR)

BS Gill
(CO-INVESTIGATOR)

(REGISTRAR)
Registrar
Guru Nanak Dev University,
Amritsar.

ਗੁਰੂ ਨਾਨਕ ਦੇਵ ਯੂਨੀਵਰਸਿਟੀ, ਅੰਮ੍ਰਿਤਸਰ

**Guru Nanak Dev University, Amritsar**

*(Established by the State Legislature Act No. 21 of 1969)*

# Expenditure Statement

Statement showing expenditure incurred out of the grant sanctioned by **University Grants Commission, New Delhi** for major research project entitled, **"Processing and utilization of oats into high B-glucan foods"** undertaken by **Dr. Hardeep Singh Gujral, Department of Food Science & Technology**, Guru Nanak Dev University, Amritsar **for the period 01-02-2009 to 31-07-2012**.

| Grant received | Amount (Rs.) |
|---|---|
| 2008-09 | 8,62,800/- |
| 2011-12 | 1,10,634/- |
| Total | 9,73,434/- |

| S. No. | Particulars | Amount Allocated (Rs.) | Expenditure (Rs.) |
|---|---|---|---|
| A. | **NON-RECURRING** | | |
| 1. | Equipment | 6,00,000.00 | 5,94,554.00 |
| | **Total** | **6,00,000.00** | **5,94,554.00** |
| B | **RECURRING** | | |
| 1. | Project Fellow | 2,16,260.00 | 1,83,062.00 |
| 2. | Contingency | 50,000.00 | 49,363.00 |
| 3. | Chemicals | 1,00,000.00 | 95,222.00 |
| 4. | Overhead Charges | 43,800.00 | 43,800.00 |
| | **Total** | **4,10,060.00** | **3,71,447.00** |
| | **Grand Total of (A) and (B)** | **10,10,060.00** | **9,66,001.00** |

**(Rupees Nine Lac Sixty Six Thousand One only)**

**Deputy Controller (Local Audit Deptt., Punjab)**
**Guru Nanak Dev University**
**Amritsar**

Deputy Controller,
(Local Audit) Finance Deptt., Pb.
Guru Nanak Dev University,
Amritsar

**Registrar**
**Guru Nanak Dev University**
**Amritsar**

Registrar
Guru Nanak Dev University,
Amritsar

# GURU NANAK DEV UNIVERSITY, AMRITSAR

*(Established by the State Legislature Act No. 21 of 1969)*

## UTILISATION CERTIFICATE

Certified that an amount of Rs. 9,66,001/- (Rupees Nine Lac Sixty Six Thousand One Only) out of the grant of Rs. 9,73,434/- sanctioned to Guru Nanak Dev University, Amritsar by the University Grants Commission, New Delhi vide letter Nos.: -

| S. No. | Sanction Letter No. | Amount (Rs.) |
|---|---|---|
| 1. | F.34-110/2008(SR), dated 31-12-2008 | 8,62,800.00 |
| 2. | F.34-110/2008(SR), dated 15-03-2012 | 1,10,634.00 |
| | **Total** | **9,73,434.00** |

pertaining to Research Project entitled, "**Processing and utilization of oats into high B-glucan foods**" undertaken by **Dr. Hardeep Singh Gujral, Department of Food Science & Technology**, has been utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the Commission.

The unspent balance of Rs. 7,433/- is being refunding vide Demand Draft No. 920139 dated 11-02-2013.

**Deputy Controller**
**(Local Audit Deptt., Punjab)**
**Guru Nanak Dev University,**
**Amritsar.**

Deputy Controller,
(Local Audit) Finance Deptt., Pb.
Guru Nanak Dev University,
Amritsar

**Registrar**
**Guru Nanak Dev University**
**Amritsar**

Registrar
Guru Nanak Dev University,
Amritsar

**UNIVERSITY GRANTS COMMISSION**

**MAJOR RESEARCH PROJECT**

**Project title**

# "Processing and utilization of oats into high β-glucan foods"

**UGC Grant number: F.No.34-110/2008 (SR)**

**FINAL REPORT**

2009-2012

**Principal Investigator:**

Hardeep Singh Gujral
Associate Professor
Department of Food Science and Technology

**GURU NANAK DEV UNIVERSITY, AMRITSAR -143005**

**Introduction:**

Oats (*Avena sativa*) ranks sixth in the world cereal production following wheat, maize, rice, barley and sorghum. Mostly it is used as animal feed and principally fed to dairy cattle, mules and turkeys and to a lesser extent to hogs, beef cattle and sheep. In India it is grown as a fodder crop in the states of Uttar Pradesh, Madhya Pradesh, Haryana, Punjab, Himachal Pradesh, Rajasthan, Bihar, Gujarat and Tamil Nadu. Almost 1.0 lakh hectare of land is under oat cultivation as a fodder crop with an average yield of 42 tons/ hectare (ICAR 2006).

Today foods are regarded as more than sources of energy and essential nutrients by nutritionists and the general public. Certain minor components of food are recognized for their health promoting properties. Oats have become important these days due to their high content of β-glucan (Gray et al 2000, Peterson et al 2001). The use of oats as human food is increasing and this is attributed to the acceptance of health claims related especially to the soluble fibers in the oats.

The health effects of the soluble fiber β-glucan are related to cholesterol reduction, improved gastrointestinal function and glucose metabolism. The Food and Drug Administration (FDA) of the USA has allowed a health claim that oat β-glucan may lower the risk of coronary heart disease (FDA 1997). It has concluded that oats lower serum cholesterol levels specifically low-density lipoprotein cholesterol. The low allergenicity of oats makes them suitable for celiac patients. Oats need to be milled into fractions high in β-glucan and from these fractions products need to be developed that the consumers find attractive.

The lowering of blood cholesterol is related to the mixed linked (1→3), (1→4)- β-D-glucan that is the major component of the soluble dietary fiber of the oats. This nutraceutical effect is due to the viscosity increase brought about by the β-glucan. To achieve the desired physiological effects the amount and $M_W$ of the β-glucan must be at levels high enough to produce the viscosity needed for these effects (Wood 2004).

Oats are harvested as a covered caryopsis in which the grain is tightly enclosed by a husk just like in paddy and barley. The husk makes up 30% of the total kernel weight. The husk has to be removed because they are tough, lack flavour and are unpalatable for human consumption. Impact type hullers are used for the removal of hull. The kernel after removal

of the hull is called a groat. Groat percent and milling yield are related to oat quality traits that are indicators of the value of the oat crop. The groats consist of three distinct parts bran, endosperm and germ. The outer branny portions contain higher levels of β-glucan. The production of oat fractions enriched in β-glucan is therefore required in order to help meet the daily requirements for β-glucan. Oat dry milling operations need to be studied leading to the production of value added oat bran and / or endosperm rich fractions. The oats milling fractions should be made available that can be converted into food products having nutraceutical value. In oats the β-glucan is present in the pericarp, aleurone and sub aleurone layer , these layers can be removed by pearling to obtain β-glucan rich fractions. Pearling will also be beneficial in removing the trichomes from the surface of the groats that are irritants for the throat, nose and eyes. Oats can be processed into fractions high in β-glucan that can be used in the production of value added products or nutraceutical foods. Pearling has originated from rice polishing and can be used on oats to produce bran rich fractions varying in β-glucan content.

Oats have a soft endosperm along with high lipid content therefore oats are more difficult to mill than wheat (Paton and Lenz 1993). The major problem with oat processing is that the moment the oat structure is broken the lipase and lipoxygenase enzymes along with the atmospheric oxygen bring about rapid release of the free fatty acids and formation of oxidized products with unpleasant flavour. Oats have a high lipase activity and stabilization of products made from oats relies on inactivation of lipase. Unless stabilized rapid hydrolysis and formation of bitter taste renders the milling fractions unusable. The high amount of unsaturated fatty acids present in oats makes them nutritionally beneficial but at the same time make the products made from oats highly susceptible to rancidity. Heat induced enzyme inactivation on the formation of free fatty acids and volatile oxidation products upon storage need to be explored.

Oats undergo different types of treatments before being converted into a finished product. These treatments include steaming, kilning, baking and fermentation. These processes affect the extractability and $M_w$ of the β-glucan. Chapatti could be a delivery vehicle for β-glucan for the Indian population and the effects of baking chapatti from wheat/oat composite flour need to be explored.

**Origin of research problem**:

Traditionally oats have been used in amimal feeding. Very little is being used as a human food in our country. Since oats have a high β-glucan content and the nutraceutical value of this fiber has been well established. Therefore research needs to be carried out on this cereal crop so that it can be processed into functional foods high in nutraceutical value.

Oat is hulled and this hampers the milling process. Hulled oats is harvested with the husk or hull intact and the hull of oat is strongly attached to the pericarp making dehulling very difficult. Oat cultivars containing high levels of β-glucan need to be identified and oats need to be utilized in traditional foods like chapatti and dalia where this polysaccharide may act as a functional ingredient. Oat flour may be used to replace part of the wheat flour in traditional products such as chapatti. β-glucan has water-binding properties and can be used as a moisturizer and stabilizer therefore the effect on the quality of food needs to be investigated. β-glucan may have an antistaling effect in chapatti. More and more oats should be utilized as human food so that its nutraceutical potential can be exploited.

**Interdisciplinary relevance**

- Food Chemistry is involved as the study will involve the extraction and quantification of β-glucan.
- The results will be helpful in identifying varieties rich in dietary fiber especially β-glucan and this has potential industrial application.
- The results would be very useful for plant breeders involved in breeding of oat varieties.
- Nutrition and Dietetics discipline in incorporating oats in the daily diet so as to take advantage of the nutraceutical constituents in oats.

**Review of Research and development in the subject**

**International status**

The value of the oat crop is indicated by groat percent and milling yield (Doehlert and Mc Mullen , 2001). Groat percent refers to the proportion of kernels (groats) by weight in a sample of oats. The higher the groat percent and milling yield the better the quality of the oats. Milling yields refers to the proportion of undamaged groats obtained after mechanically dehulling a given quantity of oats. It can be expressed as a ratio of the weight of oats required to produce 100 gm of undamaged groats. The major problem with oat

processing is that the moment the oat structure is broken the lipase and lipoxygenase enzymes along with the atmospheric oxygen bring about rapid release of the free fatty acids and formation of oxidized products with unpleasant flavour.

Roasting or kilning is a thermal treatment that is used to stabilize the oats by inactivating enzymes especially lipase and peroxidase. Roasting can be done before or after hulling and it also modifies the flavour of the oat grain. Steaming is used in the processing of oats to inactivate lipolytic enzymes and facilitate flaking to reduce breakage (Ganssmann and Vorwerck, 1995).

American Association of Cereal Chemists has defined oat bran as the fraction that is not more than 50% of the original starting material, total β-glucan content not less than 5.5% (dry weight basis) and total dietary fiber content of at least 16.0% (dry weight basis) such that one third of the total dietary fiber is soluble dietary fiber (Fulcher and Miller 1993). Conventional oat based products contain 35-57 g β-glucan per kg of product (Asp et al 1992) and the health benefits can be achieved if 10 g oat β-glucan is consumed daily. The therapeutic and cosmitic benefits associated with the consumption or application of oat bran has attracted research into the development of oat fractionation processing strategies for the production of various value added products (Gray et al 2000).

The effects of processing on oat β-glucan has been reported by some researchers. Anderson et al (2004) reported that dough making and baking did not affect the cellotriosyl/cellotetraosyl ratio of barley β-glucan but β-glucan may be degraded by the endogenous enzymes in the barley flour used in baking. Beer et al (1997) reported that baking of muffins increased the extractability but decreased the $M_w$ of β-glucan however cooking of porridge did not affect the extractability or $M_w$ of β-glucan. $M_w$ of β-glucan was lowered by baking but not by freezing (Kerkhoff et al 2003). Lambo et al (2005) reported a decrease in the amount of soluble β-glucan and loss of insoluble β-glucan in oats caused by fermentation. Johansson et al (2007) reported that cooking released more soluble β-glucan while baking decreased the amount of soluble β-glucan probably due to the enzymatic activity in the wheat flours towards β-glucan. The effects of processing on the extractability and $M_W$ of β-glucan have been studied (Robertson et al 1997). The mode of action of the β-glucan is related to its ability to increase solution viscosity but the effects of processing and cooking on solubility are not well understood.

**National status**

No work has been reported on the milling behaviour and on β-glucan content of Indian oat cultivars. The use of oat milling fractions in Traditional Indian food products like chapatti has not been investigated.

**Significance of the study**

The milling performance of oats has received little attention in our country. The study will identify the oat varieties most suited for milling into groats or developing fractions high in β-glucan. Milling fractions from various oats varieties will be studied for compositional and functional properties. Varieties high in β-glucan will also be identified. The potential industrial application of these fractions will be explored. Food products containing oats milling fractions high in β-glucan, which can be labeled as having nutraceutical value, would be developed.

**Annexure I**

## Objectives of the project

Proposed objectives of the project were:

1. Physicochemical properties of oat milling fractions.
2. Quantification of β-glucan in oat milling fractions.
3. Roasting behaviour of different oat varieties and effects on β-glucan extractability.
4. Development of nutraceutical foods from oats like oat porridge, cookies, chapaties high in β-glucan content.

**Annexure II**

Objectives were achieved:

Details:

Within cereals, oats (*Avena sativa*) rank sixth in world produc- tion and in India almost 1.0 lakh hectares of land is under oat cultivation as a fodder crop with an average yield of 42 tons/hectare (ICAR, 2006). It is mainly grown as a fodder crop for feeding farm animals. However today oats are receiving increased interest because of their excellent health related properties. They are a rich source of soluble fiber, balanced proteins, vitamins and minerals, which are essential for human health (Brindzova et al., 2008).

When used as a human food they are rolled or crushed into oatmeal and eaten as porridge or ground into oat flour and used in baked goods and baby foods. Oats have been labeled as a functional food as they contain b-glucan, minerals and antioxidants. b-glucan has been reported to be effective in reducing serum cholesterol concentration and postprandial blood glucose level (Tiwari & Cummins, 2009). b-glucan also has good water binding and emul- sion stabilizing properties thus it has been used in different food products to improve the textural and rheological properties (Lazaridou & Biliaderis, 2007). Phenolic compounds are important
phytochemicals in oats and function as free radical scavengers and are involved in reducing the risk of atherosclerosis, prevent some forms of cancer and coronary heart disease (Emmons & Peterson, 1999).

Sand roasting is a traditional method of grain processing in India. A variety of whole grains like black gram, barley, rice, corn, groundnuts etc are roasted in hot sand at temperatures varying from 250 to 350 $^{\circ}$C to produce ready to eat snack food (Sharma & Gujral, 2011; Sharma, Gujral, & Rosell, 2011). Flour made from roasted grain popularly referred to as *Sattu,* is widely consumed as a health food. Subjecting oats to a high temperature is an important step in its processing as heating produces a characteristic flavor by maillard browning and also terminates the activity of lipolytic enzymes (Klensporf & Jelen, 2008).

## Materials and methods

*Oats samples*

Ten commonly grown hulled oat cultivars namely OL-1682, OL-1683, OL-1684, OL-125, OL-1528, IOM-6, Kent, OS-342, OL-9 and OL-1678 were collected from Punjab Agricultural University, Ludhiana, Punjab, India. The grain was cleaned and stored in PET jars at 4 °C in a refrigerator for further evaluation.

*Reagents*

Standard ferulic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferrozine and catechin were procured from SigmaeAldrich (Stein- heim, Germany). L-ascorbic acid, potassium ferricyanide, ferric chloride, ferrous chloride, trichloroacetic acid, sodium carbonate and Folin-Ciocalteu's reagent were procured from Loba Chemie, Mumbai, India. All chemicals were of analytical grade.

*Roasting of oats*

T The sand roasting treatments were carefully optimized in such a way that it resulted in grain with maximum expansion and no burning. Different oat cultivars (200 g each) conditioned to a moisture content of 10% so as to eliminate the effect of differences in moisture content on roasting behavior were roasted at 280 5 °C for 15 s in a traditional sand roaster as described by Sharma and Gujral (2011) and Sharma et al. (2011).

The dehulling of the control and roasted oats was carried out in a laboratory impact huller (Lab Impact 1, Creative India, Mohali, Punjab). The hulls and groats were separated manually and weighed. 10 g of oats were dehulled manually and the groat content was reported as weight of groats divided by the weight of oats. For converting groats into flour the groats were ground in a Super Mill 1500 (Newport Scientific, Australia) and passed through 60 (BSS) sieve. Any fraction retained on the sieve was

reground till all of it passed through the sieve so as to obtain a flour of 100% extraction.

*Physical properties of oat samples*

The bulk density was evaluated by measuring the weight of known volume of control and roasted groats. Sample were poured into a graduated cylinder, gently tapped ten times and filled to 250 ml. Results were expressed as g/ml. Length/breadth ratio was reported by measuring length and breadth of ten kernels. The puffing index was calculated by dividing the bulk density of control groats with bulk density of roasted groats.

*Hardness of groats*

The hardness was determined on a Texture Analyzer (Model TA- $HD_i$ Stable Microsystems, Surrey, U.K). The force required to compress the groats by 1 mm was reported in Newtons. The cylindrical probe used had a diameter of 25 mm, a 50 kg load cell was used and the pre, post test and test speed was 1.5, 10 and 1 mm $s^{-1}$, respectively.

*Color characteristics of* flour

Color measurements were carried using a Hunter Colorimeter fitted with an optical sensor (Hunter Associates Laboratory Inc. Restan VA., USA) on the basis of CIE *L**, *a**, *b** color system.

*Water absorption capacity and water solubility index*

Water absorption capacity and solubility index of flour was measured by the centrifugation method of Anderson, Conway, Pfeifer, and Griffin (1969). The results were reported as g/100 g of oat flour.

*Pasting properties*

Pasting properties of flours were studied using a Rapid Visco Analyzer (Newport Scientific Pty Ltd., Australia) using the Standard profile 1 with flour (3 g on 14% moisture basis) and 25 ml water (Sharma & Gujral, 2010a). The peak viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature were reported.

*Damaged starch content*

Damaged starch was measured enzymatically using the 'Starch Damage Assay Kit' (Megazyme International Ireland Ltd., Wicklow, Ireland). The results were reported as g/100 g oat flour.

*Extractable* beta-*glucan*

Extraction of b-glucan was carried out as reported by Temelli (1997). Whole oat flour (50 g on dry weight basis) was extracted in water, pH lowered to remove proteins and b-glucan precipitated by ethanol, air dried to a constant weight and reported as extractable b-glucan.

*Total phenolic content (TPC)*

The total phenolic content was determined according the Folin- Ciocalteu spectrophotometric method explained by Sharma and Gujral (2010b). Acidified methanol was used as a blank. The results were expressed as mg of ferulic acid equivalents per gram of flour.

*Antioxidant activity (AOA)*

Antioxidant activity was measured using a modified version of the method

explained by Brand-Williams, Cuvelier, and Berset (1995). This involved the use of free radical 2,2-diphenyl-1- picrylhydrazyl (DPPH) solution. Absorbance (A) at 515 nm was read at 0 and 30 min using a methanol blank. Antioxidant activity was calculated as % discoloration.

*Reducing power*

Oat flour (0.5 g) was extracted with 70% methanol and the supernatant was mixed with phosphate buffer and potassium ferricyanide followed by involving trichloroacetic acid solution and ferric chloride and absorbance measured at 700 nm as described by Zhao et al. (2008) and Sharma and Gujral (2011). A standard curve was prepared using various concentration of ascorbic acid equiva- lents/g of flour.

*Metal chelating ($Fe^{þ2}$) activity*

The metal chelating activity of oat extract was measured as reported by Dinis, Madeira, and Almeidam (1994) and Sharma and Gujral (2011).

*Total flavonoids content (TFC)*

The total flavonoids content was determined as previously described by Jia, Tang, and Wu (1998) and Sharma and Gujral (2011). The absorbance was measured at 510 nm using a spectro- photometer (Shimadzu, UV-1800, Japan). Catechin was used as standard and results were reported as microgram CE/g of flour.

*Nonenzymatic browning (NEB) index*

Nonenzymatic browning index of oat samples was carried out by the method of Palombo, Gerter, and Saguy (1984) and Sharma and Gujral (2011).

*Statistical analysis*

Analysis of variance (ANOVA) was carried out and Fishers least significant difference (LSD) test was used to describe means with 95% confidence. The Pearson correlation coefficients were calcu- lated by SPSS statistical software (SPSS Inc., Chicago, Illinois, USA) at a probability level of $p < 0.05$. Each test was performed in triplicates on dry weight basis.

## Results and discussion

*Physical properties of control and roasted oats*

The groat content within the cultivars varied significantly and ranged from 6.59 to 7.76 g/10 g oats respectively (Table 1¼) with OL-9 having the highest groat content. The length/breadth ratio of control groats ranged from 3.1 to 3.5 however the differences were not statistically significant. Upon roasting the length/breadth ratio was lowered by 3.13 -19.0% which is attributed to the greater expansion of the groats along its breadth. The bulk density of control groats ranged from 0.65 to 0.73 g/ml and was significantly lowered upon roasting in all the cultivars with a decrease of 31-44% being observed in the roasted groats. Doehlert, Ohm, McMullen, and Riveland (2009) have reported similar results for eighteen different oat cultivars. A positive correlation (*R* 0.64) was exhibited between bulk density and groat content (%) of control oats while upon roasting this correlation increased (*R* 0.84). The puffing index of roasted groats varied significantly and ranged from 1.44 to 1.80. The hardness of the groats was lowered significantly after roasting in all the cultivars and ranged from 43.9 to 87.2%. Roasting significantly changed the physical properties of the groats which is attributed to the expansion of grain, that occurred due to the disorganization of starchy endo- sperm and expansion of cavities present in the endosperm (Mariotti, Alamprese, Pagani, & Lucisano, 2006).

*Color characteristic of flour*

The lightness of the flour ($L^*$) from control oat groats did not vary significantly within the cultivars, however, after roasting the $L^*$ decreased. The redness ($a^*$) varied significantly within the cultivars and ranged from 1.4 to 2.1 and after roasting the redness significantly increased by 1.5-46.7%. The yellowness ($b^*$) of flours from control groats varied significantly within the cultivars and ranged from 10.6 to 12.5 and upon roasting the yellowness increased by 1.8-15.6%. The total color difference ($\Delta E$) of control flour did not vary significantly within the cultivars however roasting significantly decreased $\Delta E$. Cenkowski, Ames, and Muir (2006) reported significant effect on all the color characteristics after heating oats in a electric micronizer to temperatures of 160 °C.

*Water absorption capacity and water solubility index*

The water absorption capacity (WAC) did not vary significantly within cultivars except for OL-9 that showed the highest WAC (115.2 g/100 g flour) within the control oat flours (Table 2). Roasting significantly increased the WAC from 15.0 to 59.3%. Increase in WAC after roasting of different cereals and legumes has been reported by Griffith, Castell-Perez, and Griffth(1998). The increase can be attributed to starch damaged due to gelatinization and formation of porous structure in the endosperm, which imbibes and holds water by capillary action (Mariotti, Alamprese et al., 2006; Mariotti, Lucisano, & Pagani, 2006). The water solubility index (WSI) of control flours varied significantly within cultivars and ranged from
6.1 to 7.9 g/100 g flour. Upon roasting, the WSI significantly decreased and ranged from 36.7 to 56.7%. The decrease in WSI can be attributed to the formation of amylose lipid complexes during the roasting process, which have been reported to reduce the water solubility (Shamekh, Forssel, & Poutanen, 1994).

*Pasting properties*

The peak (PV) and final viscosity (FV) of control groat flour varied significantly within the cultivars and ranged from 997 to 1420 cP and from 2285 to 2890 cP,

respectively. Zhou, Robards, Glennie-Holmes, and Helliwell (1999) reported similar pasting behavior for oats flour. After roasting both the peak and final viscosity decreased significantly which can be attributed to the presence of pre gelatinized starch in the roasted flour (Table 3). Zhang, Doehlert, and Moore (1997) reported that after roasting at 155 °C for 2 h the viscous properties of oat flour were greatly reduced. Both the breakdown viscosity (BDV) and setback viscosity (SV) were lowered after roasting. The decrease in pasting temper- ature of roasted oat flour can be attributed to the presence of pre gelatinized starch which hydrates rapidly and provides higher viscosity at a lower temperature that is detected by the RVA as pasting temperature. Cenkowski et al. (2006) reported decrease in the peak and final viscosity for micronized oats. The loosely packed starch granules with high level of damaged starch in gun puffed cereal grains easily hydrate and swell more rapidly in the presence of heat and consequently produce less peak viscosity (Mariotti, Alamprese et al., 2006; Mariotti, Lucisano et al., 2006). The extractable b-glucan content of the control and roasted oats did not correlate with any of the pasting parameters obtained from the RVA, because it is the starch in the sample that dictates the pasting behavior of flour slurry during heating and cooling.

*Extractable* b-*glucan*

The extractable b-glucan in control flour varied significantly within cultivars and ranged from 1.79 to 3.33 g/100 g oat flour (Fig. 1). Roasting lead to a significant increase in the extractable b-glucan and this increase ranged from 9.8 to 61.1 g/100 g oat flour. The increase in the extractable b-glucan may be attributed to the thermal effect of roasting. b-glucan is found in the cell wall of grains with cellulose and other noncellulosic polysaccharides and heating releases it from the matrix and this could have lead to the increase in the b-glucan extractability after roasting (Buckeridge, Rayon, Urbanowicz, Tine, & Carpita, 2004; Fincher & Stone, 1986). Andersson, Andersson, and Aman (2007) reported that the b- glucan extractability increases during the baking of the bread.

*Damaged starch content*

The grinding of control oats into flour produced some damaged starch that ranged from 0.5 to 4.9 g/100 g oat flour (Fig. 2). Roasting lead to a significant increase in the damaged starch content that varied from 72 to 82 g/100 g oat flour within the cultivars. This increase in the damaged starch content can be attributed to the bursting of the starch granules due to the high temperature of roasting. Similar increase in the damaged starch content of 80.4, 72.5 and 83.1 g/100 g oat flour has been reported by Mariotti, Alamprese et al. (2006); Mariotti, Lucisano et al. (2006) in puffed common wheat, rye and barley.

*Total phenolic content*

The total phenolic content (TPC) in control samples varied significantly within cultivars and ranged from 1754 to 3579 mg FAE/ g (Table 4). Hodzic et al. (2009) reported a TPC ranging from 13.85 to 17.1 mg/l of extract in different oat cultivars. Roasting lead to a significant decrease in the TPC and this decrease ranged from 11.4 to 50.2%. Bryngelsson, Dimberg, and Kamal-Eldin (2002) reported that drum drying of oats lead to a decrease in phenolic compounds with a significant decrease in caffeic acid, ferulic acid, *p*-coumaric acid and vanillin. The decrease in TPC could be attributed to the oxidation and degradation of heat susceptible phenolic compounds during roasting (Bryngelsson et al., 2002; Randhir, Kwon, & Shetty, 2008). Sharma and Gujral (2011) have reported a significant decrease in TPC upon roasting in different barley samples. On the other hand many researchers have reported a significant increase in TPC upon heat treatment (Gahler, Otto, & Bohm, 2003; Jiratanan & Liu, 2004; Zielinski, Kozlowska, & Lewczuk, 2001) due to release of bound phenolic compounds. The short heating time in the present study (15 s) must have been insufficient to release the bound phenolic compounds but sufficient to decrease the free phenolic compounds.

*Reducing power*

Reducing power of control oats varied significantly within the cultivars and ranged from 15.9 to 25.5 mmol AAE/g (Table 4). Xu et al. (2009) reported a ferric reducing antioxidant power of 14.67 mmol of $Fe^{þ2}$/g in raw oats. Roasting lead to a significant increase in the reducing power that ranged from 1.0 to 38.0%. Lu et al. (2007) reported a sharp increase in the reducing power after kilning of barley. This increase in reducing power may be attributed to production of Maillard reaction products that contribute to antioxidant properties after roasting (Woffenden, Ames, Chadra, Anese & Nicoli, 2002). Reducing power exhibited a positive correlation (*R* ¼ 0.61) with antioxidant activity and metal chelating activity (*R* ¼ 0.64) of roasted oats.

*Metal chelating activity*

Metal chelating activity of control samples varied significantly within the cultivars (Table 4) and ranged from 26.3 to 72.6%. The metal chelating activity increased significantly after roasting which is attributed to the formation of Maillard reaction products such as melanoids that may act as antioxidants, also the structure of some phenolic compounds is altered which could enhance the metal chelating activity (Nicoli, Anese, & Parpinel, 1999).

*Antioxidant activity (AOA)*

The antioxidant activity ranged from 6.3 to 10.2% and varied significantly within the cultivars (Table 4) and increased by upto 73% after roasting. Xu et al. (2009) reported higher value of DPPH scavenging activity (82.2%) in oats. Zielinski and Kozlowska (2000) reported an antioxidant activity of 0.082 mmol Trolox/mg of cereal lyophilizate. Similar increase in AOA was reported by Maillared and Berset (1995) after kilning of barley. Increase in AOA can again be attributed to the formation of brown pigments (Randhir, Kwon, Lin & Shetty, 2009). The maillard reaction products are widely reported to have antioxidant activity (Dvorakova, Maelle, Jurkova, Kellner & Dostalek, 2008; Sharma & Gujral, 2011).

*Total flavonoids content*

The total flavonoids content (TFC) varied significantly within cultivars and ranged from 732 to 1137 ¼ mg CE/g (Fig. 3). Roasting significantly decreased the TFC by 22.7e49.9%. Zhang, Chen, Li, Pei, and Liang (2010) reported a TFC of 0.992 mg rutin equivalent/g of buck wheat flour which after roasting was lowered by 33%. They also reported that the flavonoids are heat labile that are easily destroyed by heat during roasting. Flavonoids content exhibited a positive correlation (*R* 0.52) with reducing power of control sample while upon roasting the correlation increased to 0.62.

*Nonenzymatic browning (NEB) index*

Nonenzymatic browning index (NEB) of control oats varied significantly and ranged from 0.041 to 0.062/0.1 g within the cultivars (Fig. 4). The roasting significantly increased the NEB index by 331e612%. Duh, Yen, Yen, and Chang (2001) reported a NEB index of 0.048/0.1 g for unroasted barley that increased signifi- cantly after roasting. Proteins and sugars react and produce the Maillard products and this reaction is highly temperature depen- dent with higher roasting temperatures producing more browning.

**Justification of working on chapatti made with oat flour**

In India almost 1.0 lakh hectares of land is under oat cultivation as a fodder crop and very little is utilised in human foods (Gujral, Sharma, and Singh (2011). Today oats are receiving increased interest because of their excellent health related properties. They are a rich source of soluble fibre, balanced proteins, vitamins and minerals, which are essential for human health. When used as a human food they are rolled or crushed into oatmeal and eaten as porridge or ground into fine oat flour and used in a variety of baked goods, such as oatcakes, oatmeal cookies, and oat flour for baby foods. Oats contain high content of dietary fibre b-glucan, minerals and antioxidants (tocols, phytic acids, phenolic compounds and avenanthramides). High content of b-glucan in oats make it a func- tional and nutraceutical food as it has been reported to be effective in

reducing serum cholesterol concentration and postprandial blood glucose level. Phenolic compounds are important phyto- chemicals in grains and function as free radical scavengers and are involved in reducing the risk of atherosclerosis, prevent some forms of cancer and coronary heart disease (Emmons & Peterson, 1999).

Majority of the wheat grown in India i.e., nearly 80.7 million tonnes is consumed mainly in the form of unleavened flat bread known as chapatti (Gujral & Pathak, 2002; Gujral & Gaur, 2002). Chapatti is usually prepared from whole wheat flour and the desired quality parameters in chapatti are greater pliability, soft texture, light creamish brown colour, slight chewiness and baked wheat aroma (Gujral, 2010). Oat flour could be incorporated into wheat flour to make chapatties thus promoting consumption of oat and also increasing the nutraceutical potential of chapatti.

However the high fat content in oats make it particularly sensi- tive to oxidation, resulting in a rancid flavor caused by the non-vol- atile free fatty acids (Welch, 1995). The problem related to the high lipid content may be overcome by defatting the oat before process- ing. Alternatively, kilning and hydrothermal treatment may also be given to the oat before milling of groats to inactivate the lipase en- zyme. Thus oats could be subjected to treatments like defatting, hydrothermal treatment or kilning and the oat flour could be blended with wheat flour to make chapatti and chapatti used as a delivery vehicle for the bioactive components especially oat glu- cans and antioxidants.

*Samples and chemicals*

The oat variety OL-125 was collected from Punjab Agricultural University, Ludhiana, Punjab, India. The grain was cleaned before dehulling. The wheat flour of Ashirwad brand (ITC ltd, India) was procured from local market.

Standard ferulic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ferrozine, protease (from *Streptomyces griseus*) and catechin were procured from Sigma–Aldrich (Steinheim, Germany). L-ascorbic acid, potassium ferricyanide, ferric chloride, ferrous chloride, tri- chloroacetic acid, sodium carbonate and Folin Ciocalteu's

reagent were procured from Loba Chemie, Mumbai, India. All chemicals were of analytical grade. Each test was performed in triplicates on dry weight basis. The Milli Q water (Millipore, France) was used for all analytical tests.

*Defatted oat flour*

The dehulling of oat was carried out in an impact dehuller (Lab Impact 1, Creative India, Mohali, Punjab) as described by Gujral et al. (2011). Groats were separated from husk manually. The oat groats were coarsely ground to form grit in a Newport Super Mill. Grit was mixed with hexane (1:5) in volumetric flask and placed overnight on a shaker. The contents were allowed to settle and the supernatant layer of solvent discarded, followed by a washing with the solvent (1:2) The defatted grit was dried in oven at 50 °C to remove solvent and then ground to flour in Super Mill 1500 (Newport Scientific, Australia) and passed through 52 (BSS) sieve. Any fraction retained on the sieve was reground till all of it passed through the sieve so as to obtain a flour of 100% extraction and the flour was packed in airtight bags and stored at 4 °C.

*Hydrothermal treated flour*

The oats were conditioned to a moisture content of 25%, and then steamed at atmospheric pressure for 45 min in an autoclave (Narang Scientific, New Delhi, India). The steamed oats were then dried at 50 °C to remove moisture, dehulled in impact mill and then the groats milled into flour.

*Kilned oat flour*

The oats were conditioned to a moisture content of 25%, then kilned at 120 °C for 1 h in a hot air oven. The oats were cooled to room temperature and then dehulled in the impact mill and then the groats ground into flour as described above.

*Preparation of chapatti*

The flour blends were prepared by replacing wheat flour with control or treated flour at levels of 25% and 50%. Preliminary trials were carried out to determine the amount of water to be added to the flour to develop non sticky viscoelastic dough that could be easily rolled and sheeted to make a chapatti. The flour was mixed with optimum water for three minutes in a laboratory mixer (Na- tional Manufacturing Company, Lincoln, USA). The dough was left to rest for half an hour. Dough ball (50 g) was rounded and then placed on a rolling board and was sheeted. The dough was rolled in one direction, inverted, and then rolled in a perpendicular direc- tion, placed on an electric hot plate at 280 ± 5 °C and baked into chapatti. The baking time was 60 s for control, 73 s for defatted, 89 s for hydrothermal treated and 75 s for kilned oats. The chapatti was allowed to cool for 10 min at 25 °C and then freeze dried (Sim International, USA) finely ground and packed in polyethylene pouches and placed in an air tight container and stored at 4 °C till further analysis.

*Total phenolic content (TPC)*

The total phenolic content was determined according the Folin– Ciocalteu specterophotometric method explained by Gao, Wang, Oomah, and Mazza (2002). 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 wrist action shaker (Narang Scientific, Delhi, India). The mixture was centrifuged at 3000 g for 10 min on a centrifuge (Eltek, RC 4100 F, Mumbai, India). The supernatant was used for determination of total phenolic content. Aliquot of extract (200 ll) was added to 1.5 ml freshly diluted (10-fold) Folin–Ciocalteu reagent. The mixture was allowed to equili- brate 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 (Shi- madzu, UV-1800, Kyoto, Japan). Acidified methanol was used as a blank. The results were expressed as lg of ferulic acid equivalents per gram of flour.

*Antioxidant activity (AOA)*

Antioxidant activity was measured using a modified version of the method explained by Brand-Williams, Cuvelier, and Berset (1995). This involved the use of free radical 2,2-diphenyl-1-pic- rylhydrazyl (DPPH) solution in the methanol. Samples (100 mg) were extracted with 1 ml methanol for 2 h and centrifuged at 3000*g* for 10 min. The supernatant (100 ll) was reacted with 3.9 ml of a 6 $10^{-5}$ mol/L of DPPH solution. Absorbance (A) at 515 nm was read at 0 and 30 min using a methanol blank. Antiox- idant activity was calculated as% discoloration.

*Reducing power*

The reducing power was measured as described by Zhao et al. (2008). Flour blends (0.5 g) was extracted with 80% methanol on wrist action shaker for 2 h. The supernatant was collected after centrifugation at 10000*g* for 10 min. The supernatant (1 ml) was mixed with phosphate buffer (0.2 mol/l, pH 6.6) and 2.5 ml potas- sium ferricyanide (1%) was added. The mixture was allowed to stand for 20 min at 50 °C in an incubator. After incubation, 2.5 ml of trichloroacetic acid solution was added to mixture, which was then centrifuged at 10000*g* for 10 min. The upper layer of solution was mixed with 2.5 ml deionized water and 0.5 ml ferric chloride (0.1%). The absorbance of the mixture was measured at 700 nm. In- creased absorbance of the mixture indicated increased reducing power. A standard curve was prepared using various concentration of ascorbic acid. The results were expressed as lmol ascorbic acid equivalents/g.

*Metal chelating ($Fe^{+2}$) activity*

The metal chelating activity of extract was measured as re- ported by Dinis, Madeira, and Almeidam (1994). The extract was mixed with 50 ll of ferrous chloride (2 mM/l) and 1.6 ml distilled water was added. After 5 min, the reaction was initiated by the addition of ferrozine (100 ll) and the mixture was shaken on vor- tex. Further the mixture was incubated at room temperature (25 °C) for 10 min. Absorbance of

solution was measured at 562 nm on a spectrophotometer. The chelating activity of the ex- tract for $Fe^{+2}$ was calculated.

*Total flavonoids content (TFC)*

The total flavonoids content was determined as previously de- scribed by Jia, Tang, & Wu, (1998). The extract (250 ll) was diluted with 1.25 ml distilled water. Then 5% solution of sodium nitrite was added, and the mixture was allowed to stand for 6 min. Further, 150 ll of a 10% aluminium chloride was added and the mix- ture was allowed to stand for 5 min. After that, 0.5 ml of 1 M sodium hydroxide was added and solution was mixed well. The absorbance was measured immediately at 510 nm using a spectrophotometer. Catechin was used as standard and results were reported as lg cat- echin equivalents/g of sample.

*Nonenzymatic browning (NEB) index*

Nonenzymatic browning index of samples was carried out by the method of Palombo, Gerter, and Saguy (1984). Barley flour (100 mg) was mixed with 1 ml of deionised water. An aliquot (200 ll) of the mixture was transferred to a test tube which con- tained 200 ll of protease solution (enzyme was dissolved in Tris buffer pH-7 and 50 mM of calcium chloride.). The test tubes were incubated for 2 h at 45 °C, in a water bath (NSW-125, Narang Scientific Works, New Delhi, India). The test tubes were cooled on ice water bath and 300 ll trichloroacetic acid (100%) was added to each tube. Then tubes were centrifuged at 7000*g* for 20 min. The absorbance of supernatant was measured at two wavelengths (420 and 550 nm) on a spectrophotometer. The browning index (DA) was calculated.

## Results and discussion

*Physical characteristics of chapatties*

The water absorption for dough making was 62.0% for wheat flour while substituting the wheat flour with oat flour (control) at levels of 25% and 50% decreased the

water absorption capacity up to 6.12% (Table 5). On the other hand incorporation of defatted oat flours into wheat flour at levels of 25% and 50% significantly in- creased the water absorption capacity up to 66.1%. This increase may be attributed to the fact that fat is hydrophobic in nature and its removal increases the water absorption capacity. Incorporating hydrothermal treated and kilned oat flour signifi- cantly increased the water absorption capacity and when the level of hydrothermal treated flour increased from 25% to 50% there was 17% increase in water absorption capacity. Increasing levels of kil- ned flour did not significantly increase the water absorption capac- ity. This increase might be attributed to increased level of damage starch that is known to have higher water absorption capacity as compared to native starch (Gujral et al., 2011; Sharma, Gujral, & Rosell, 2011). Blends containing hydrothermal processed oat flour showed higher water absorption capacity (up to 85.3%) as com- pared to flour from kilned oats (only 67.1%); this may be attributed to the fact that the gelatinisation of starch and starch damage is higher when sample is heated in presence of water i.e., hydrother- mal treatment as compared to dry heat only as in kilining (Adebo- wale, Olu-Owolabi, Olayinka, & Lawal, 2005). Puffing is a highly desirable characteristic of chapatti during baking and this quality attribute is preferred by consumers. A sig- nificant decrease in puffing was observed upon incorporation of all type of oat flours to wheat flour. Incorporation of the control and treated oat flours (defatted, hydrothermal treated and kilned) at 25% decreased the puffing by 12.5%, 25.0%, 62.5% and 75%, respec-tively and at 50% decreased the puffing by 89.7%, 37.5%, 80% and 90%, respectively. Gill, Vasanthan, Ooarikul, and Rossnagel (2002) reported that incorporation of flour from barley in cooked form lead to a significant decrease in loaf volume of bread. The puffing is caused by separation of upper and lower layers of the chapatti caused by steam generated during baking and it is also related to protein quality and quantity (Gujral, 2010). Replacement of wheat flour with oat flour lead to dilution of gluten and disruption of glu- ten network lowering the puffing ability of chapatti.

Bake loss is an indicator of the amount of water lost from the chapatti during baking. The chapatti prepared from wheat flour exhibited a bake loss of 12.3%. Incorporation of oat flour (control) into wheat flour at levels of 25% and 50% lead to a significant in- crease in bake loss by 2.37% and 7.14%, respectively. On the other hand, incorporating

defatted oat flour at both levels did not affect the bake loss significantly (Table 5). Furthermore, substitution of wheat flour with hydrothermal treated oat flour at levels of 25% and 50% levels lead to significant increase in bake loss by 2.0% and 10.5%, respectively. On the other hand substitution of wheat flour with flour from kilned oat at levels of 25% did not affect the bake loss significantly however incorporation at 50% significantly increased the bake loss up to 16.6%. The higher bake loss upon incorporation of oat flour to wheat flour may be attributed to high- er water absorption capacity of blends containing oat flour and longer baking time required for baking the chapatti. Percentage shrinkage of chapatti prepared from wheat flour was 3.10% while incorporation of oat flour, defatted oat flour, hydro- thermal treated and kilned oat flour in wheat flour at levels of 25% lowered the shrinkage by 1.20%, 1.85%, 1.20% and 2.01% while further increasing the proportion of oat flour (all types) lead to fur- ther decrease in shrinkage of chapatti. Decrease in shrinkage might be attributed to the dilution of wheat gluten proteins (Gujral & Pathak, 2002; Gujral, Sharma, Bajaj, & Solah, 2012).

*Total phenolic content (TPC)*

The total phenolic content of wheat flour was observed to be 1410 lg FAE/g where as oat flour; defatted oat flour, hydrothermal oat flour and kilned oat flour exhibited the total phenolic content of 2023, 1620, 1946 and 2002 lg FAE/g. Incorporation of all type of oat flour to wheat flour significantly increased the TPC. Among the blends containing 25% oat flour, the highest TPC was exhibited by blend containing kilned oat flour and oat flour (control) (1979 and 1964 lg FAE/g, respectively, not statistically different), followed by hydrothermal treated oat flour (1560 lg FAE/g) and defatted oat flour (1453 lg FAE/g) (Table 6). Baking of blends containing 25% oat flour into chapatti lead to a significant decrease in TPC and it ranged from 6.5% to 28.8%, the highest and the lowest decrease was observed for the chapatti containing flour from kil- ned oats while the lowest was observed for chapatti containing flour from defatted oats. The chapatti containing flour from hydro- thermal treated oats did not exhibit significant affect. The TPC varied significantly among the blends containing 50% oat

flour. The highest TPC was exhibited by blends containing con- trol oat flour (2003 lg FAE/g) and flour from kilned oat (1997 lg FAE/g) followed by blend containing flour from hydrothermal trea- ted oats (1594 lg FAE/g) and flour from defatted oat (1551 lg FAE/ g). Baking into chapatties exhibited a significant decrease in TPC and it ranged from 1.7% to 23.1%, the highest and the lowest decrease was noticed for chapatti containing flour from hydrothermal treated oats and flour from kilned oats, respectively. The decrease in TPC of chapatti containing flour from defatted oats and flour from control oats was 12.6% and 6.6%, respectively. Alvarez-Jubete, Wijngaard, Arendt, and Gallagher (2010) also reported a similar decrease in TPC upon baking of bread. Similarly, Gujral et al. (2011) reported that the roasting of oats significantly decreased the TPC. Gujral et al. (2012) reported similar results upon baking of chapatties containing flour from germinated brown rice. The reduction in TPC upon baking may be attributed either to decom- position of phenolic compounds or alteration in molecular struc- ture of phenolic compounds that may lead to reduction in the chemical reactivity of phenolic compounds or decrease their extractability due to certain degree of polymerisation (Altan, McCarthy, & Maskan, 2009).

*Antioxidant activity*

Estimation of the antioxidant activity (AOA) by scavenging of stable radicals such as the chromogen radical DPPH in inorganic media has been extensively used for comparison of homogeneous series of antioxidants. This procedure measures the hydrogen donating capacity of the target substances in a methanolic media. The AOA of wheat flour was 13.5% while the AOA of oat flour (con- trol), flour from defatted oat, hydrothermal treated oats and kilned oats were 13.1%, 11.6%, 10.3% and 12.2%, respectively. The antioxidant activity of blends prepared by incorporating 25% oat flour in different forms into wheat flour did not vary signif- icantly except for control oat flour and flour from hydrothermal treated oats that exhibited highest antioxidant activity of 13.0 and 13.1%, respectively. On the other hand, flour from defatted and kilned oats exhibited antioxidant activity of 12.2% and 11.6%, respectively (Table 6). Baking of chapatties lead to a significant de- crease in AOA as compared to their

corresponding blends and it ranged from 7.4% to 20.8%, the highest and the lowest decrease in AOA was observed for chapatti containing control oat flour and flour from defatted oats, respectively. The chapatti containing flour from hydrothermal treated oats and kilned oats showed a de- crease of 9.2% and 8.6%, respectively.

The AOA of blends containing 50% oat flour varied significantly among the blends, the highest (13.2%) and the lowest (12.1%) AOA was exhibited by blends containing flour from control oats and hydrothermal treated oats, respectively. The blends containing flour from defatted and kilned oats showed AOA of 13.0% and 12.7%, respectively. Baking of chapatties led to a significant de- crease in AOA and it ranged from 0.8% to 18.2%. The highest and the lowest decrease was observed for chapatti containing control oat flour and flour from kilned oats, respectively however chapat- ties containing flour from hydrothermal treated oats did not change significantly while chapatties containing flour from defat- ted oat exhibited a decrease of 13.4%. The phenolic compounds are heat labile (Sharma, Gujral, & Singh, 2012) and are less resis- tant to the heat, and heating over 80 °C may destroy or alter their nature (Zielinski, Kozlowska, & Lewczuk, 2001) therefore, decrease in AOA upon baking may be due to thermal destruction of phenolic compounds.

*Reducing power*

The reducing power is also an indicator of antioxidant activity. The electron donor compounds are considered as a reducing agent and can reduce the oxidised intermediates of the lipid peroxidation reactions therefore they may be primary or secondary antioxidants (Lee, Woo, Kim, Son, & Jeong, 2007). The reducing power of an anti- oxidant compound is associated with the presence of reductones. Further, the antioxidant capacity of reductones is based on the breaking of the free radical chain reaction by donating a hydrogen atom, and to prevent peroxide formation (Zhao et al., 2008). The reducing power of wheat flour was 7.7 lmol AAE/g whereas oat flour, flour from defatted oats, hydrothermal oat and kilned oat were 12.4, 12.0 15.1 and 16.6 lmol AAE/g, respectively. Reducing power of blends containing 25% oat flour varied significantly and ranged from 8.0 to 14.2 lmol AAE/g, the highest and the

lowest reducing power was exhibited by blends containing flour from kil- ned oats and defatted oats, respectively (Table 7). However there was no significant variation in reducing power of blends containing control oat flour and flour from defatted oat (8.2 and 8.0 lmol AAE/g, respectively) although blends containing flour from hydrothermal treated oat exhibited reducing power of 11.0 lmol AAE/g. Interestingly, baking of blends into chapatti showed a sig- nificant increase in reducing power, the highest percentage in- crease in reducing power was observed for chapatti containing defatted and control oat flour and lowest was observed for chapatti containing flour from kilned oats. Reducing power of blends containing oat flour at levels of 50% into wheat flour varied significantly and ranged from 11.7 to 15.5 lmol AAE/g. Blend containing flour from kilned oat showed the highest reducing power among the blends while the flour from defatted oat showed the lowest. Reducing power of blend contain- ing flour from control oats and hydrothermal treated oat was 11.9 and 13.6 lmol AAE/g. Also, baking of chapatti lead to a significant increase in reducing power. Chapatti from blends containing flour from control, defatted, hydrothermal and kilned oats showed in- crease in reducing power by 41.2%, 39.3%, 25.7% and 13.5% respec- tively. Similar increase in reducing power of chapatti upon baking has been reported by Gujral et al. (2012). Morales, Martin, Acar, Arribas-Lorenzo, and Gokmen (2009) also reported a significant in- crease in the ferrous reducing power of cookies upon baking. In- crease in reducing power of chapatti upon baking may be due to the formation of Maillard browning pigment (Nicoli, Anese, Parpi- nel, & Franceschi, 1999; Sharma & Gujral, 2011). The formation of Maillard products depends upon different factors such as baking time, baking temperature, composition of food material and water activity. The difference in water absorption of the flour may also be reason for production of different amount of Maillard products consequently difference in reducing power of different chapatties (Sharma et al., 2012).

*Metal chelating activity*

Metal chelating activity is one of the numerous methods used to evaluate antioxidant activity of foods and to explain how antioxi- dants function. (Amarowicz, Naczk, &

Shahidi, 2000). The interac- tion of $Fe^{+2}$ with ferrozine produces a dark colour complex that is decreased by the action of metal chelator compounds present in the reaction mixture. The metal chelating activity of wheat flour was 69.5% while the metal chelating activity of control oat, flour from defatted oats, hydrothermal treated oats and kilned oat was 58.4%, 56.0%, 80.8% and 72.3%, respectively. Metal chelating activ- ity of blends containing flour from control oats, defatted oats, hydrothermal treated oats and kilned oat at levels of 25% varied significantly and was observed to be 64.2%, 62.0%, 72.6% and 69.7%, respectively (Table 7). The highest and lowest metal chelat- ing activity among the blends was observed for blend containing flour from hydrothermal treated oats and flour from defatted oats, respectively. Baking of chapatties led to a significant increase in metal chelating activity. The chapatties containing flour from con- trol oats exhibited the highest (7.6%) increase in metal chelating activity while chapatties containing flour from hydrothermal trea- ted oats showed the lowest increase (0.3%). Chapatties containing flour from control and defatted oats exhibited increase in metal chelating activity by 4.0% and 4.9%, respectively.

Moreover, incorporating oat flour into wheat flour at level of 50% decreased the metal chelating activity in all the blends. The blends having flour from control oat, defatted oats, hydrothermal treated oats and kilned oats exhibited metal chelating activity of 58.0%, 57.4%, 73.8% and 70.6%, respectively. On the other hand, baking of chapatti led to a significant increase in metal chelating activity by 5.5%, 5.1%, 3.7 and 6.2% for chapatti containing flour from control oats, defatted oats, hydrothermal oats and kilned oats, respectively. These results are in agreement with those reported for chapatti and cookies upon baking (Gujral et al., 2012; Filipcev et al., 2011). It has been widely accepted that novel compounds are formed during thermal processing of food through Maillard reaction which have strong metal chelating activity (Kong & Xiong, 2006). The soluble part of Maillard reaction products is known to have metal chelating activity (Rufian-Henares & Delgado-Andrade, 2009). Formation of Maillard reaction products depends upon dif- ferent factors such as chemical composition of raw material (e.g., proteins, amino acids, reducing sugars, or carbohydrates and pH) process conditions (baking time, baking temperature) (Sharma et al., 2012) and water activity.

*Total flavonoid content (TFC)*

Flavonoids have generated interest because of their broad hu- man health promoting effects, most of which are related to their antioxidant properties and to synergistic effects with other anti-oxidants. The total flavonoids content of wheat flour was 382 lg CE/g while the TFC of flour from control oat, defatted oats, hydro- thermal treated oat and kilned oat were 414, 320, 400 and 401 lg CE/g, respectively. TFC varied insignificantly among the blends containing 25% oat flour in different forms except blend contain- ing flour from defatted oats that exhibited the lowest TFC (351 lg CE/g) (Fig. 5). However, the TFC of blends containing flour from control oats, hydrothermal treated oats and kilned oats exhibited the TFC of 387, 389 and 387 lg CE/g, respectively. Baking of cha- patties lead to a significant decrease in TFC as compared to their corresponding blends, the highest and the lowest decrease in TFC was observed for chapatti prepared by blends containing flour from hydrothermal treated oats (20.6%) and control oat (5.9%), respectively. On the other hand, chapatti containing flour from defatted oats and kilned oats exhibited decrease in TFC up to 12.3%. Furthermore, increasing the level of oat flour in the blends to 50% significantly increased the TFC. The TFC varied insignifi- cantly among the blends containing oat flour at levels of 50% except for blend containing flour from defatted oats that showed lowest TFC (372 lg CE/g) (Fig. 6). Also, the blend containing con- trol oat flour, hydrothermal treated oats and kilned oats showed the TFC of 404, 398 and 399 lg CE/g, respectively. Baking of cha- patties significantly lowered the TFC as compared to their corre- sponding blends. The chapatti prepared from blends containing control oats, defatted oats, hydrothermal treated oats and kilned oats showed a decrease in TFC by 3.7%, 8.1%, 7.3% and 8.0%, respectively. Similar decrease in flavonoids has been reported by Alvarez-Jubete et al. (2010) upon baking of bread. Gujral et al. (2012) reported a similar decrease in TFC upon chapatti baking. The flavonoids are considered to be thermally sensitive and the heat provided to food material during processing destroys the flavonoids (Xu & Chang, 2008) however the extent of degradation of flavonoids depends upon the factors such as the type of sub-

strate and the processing conditions, principally duration of heat- ing (Chlopicka, Pasko, Gorinstein, Jedryas, & Zagrodzki, 2012). The decrease in TFC may be attributed to the thermal destruction of flavonoids (Sharma et al., 2012).

*Non-enzymatic browning (NEB) index*

The NEB index of wheat flour was observed to be 0.107 whereas control oat flour, flour from defatted oats, hydrothermal treated oats and kilned oat showed NEB index of 0.389, 0.182, 0.420 and 0.454, respectively. Incorporating oat flour into wheat flour at lev- els of 25% lead to a significant increase in NEB index. The NEB index of blends containing 25% oat flour from control oats, defatted oats, hydrothermal treated oats and kilned oats varied significantly among blends and ranged from 0.116 to 0.199. The highest and the lowest was observed for blend containing flour from hydro- thermal treated oats and defatted oats, respectively while the blends containing flour from control oats and kilned oats showed a NEB index of 0.156 and 0.141, respectively (Table 8). Baking of chapatties significantly increased the NEB index in all the chapat- ties as compared to their corresponding blends. The highest in- crease was observed for chapatti containing flour from defatted oats (27.6%) while those containing flour from control oats, hydro- thermal treated oat and kilned oats exhibited increase in NEB in- dex of 19.2%, 20.1% and 19.9%, respectively. Moreover, increasing the level of oat flour into wheat flour significantly increased the NEB index of blends. The NEB index of blends containing oat flour at levels of 50% varied significantly and ranged from 0.160 to 0.398/0.1 g. The highest and the lowest NEB index was observed for blend containing flour from kilned oats and defatted oats, respectively. However, blends containing flour from control oats and hydrothermal treated oats showed a NEB index of 0.318 and 0.356/0.1 g., respectively. Furthermore, baking of chapatties signif- icantly increased the NEB index by 21.7%, 12.5%, 11.0% and 9.8% for chapatti containing flour from control oat, defatted oat, hydrother- mal treated oats and kilned oats, respectively. Similar increase in NEB index has been reported by Gujral et al. (2011) upon roasting of oats and by Sharma and Gujral (2011) and Duh, Yen, Yen, and Chang (2001) upon roasting of barley. Maillard reaction occurs be- tween free amino groups of protein and

carbonyl groups of reduc- ing sugars, and generates the brown pigments which are widely reported to contribute in the colour, aroma and taste (Singh, Gam- lath, & Wakeling, 2007).

Table 1
Physical properties of control and roasted oat groats.

| Cultivars | Bulk density (g/ml) | | length/breadth ratio | | Puffing index | Groat content (g/10 g) | Hardness (N) | |
|---|---|---|---|---|---|---|---|---|
| | Control | Roasted | Control | Roasted | Control | Control | Control | Roasted |
| OL-1682 | $0.71^{aq}$ | $0.45^{cp}$ | $3.4^{aq}$ | $2.9^{ap}$ | $1.59^{c}$ | $7.43^{g}$ | $33.2^{bq}$ | $18.6^{cp}$ |
| OL-1683 | $0.71^{aq}$ | $0.45^{cp}$ | $3.1^{ap}$ | $2.7^{ap}$ | $1.55^{b}$ | $7.10^{f}$ | $43.7^{bq}$ | $19.1^{dp}$ |
| OL-1684 | $0.67^{aq}$ | $0.47^{dp}$ | $3.3^{ap}$ | $2.8^{ap}$ | $1.44^{a}$ | $6.59^{a}$ | $31.2^{bq}$ | $11.3^{bp}$ |
| OL-125 | $0.66^{aq}$ | $0.38^{ap}$ | $3.3^{ap}$ | $3.0^{ap}$ | $1.73^{e}$ | $6.80^{c}$ | $35.5^{bq}$ | $5.7^{ap}$ |
| OL-1528 | $0.67^{aq}$ | $0.40^{ap}$ | $3.4^{ap}$ | $3.1^{ap}$ | $1.69^{d}$ | $6.79^{c}$ | $36.9^{bq}$ | $5.0^{ap}$ |
| IOM-6 | $0.65^{aq}$ | $0.37^{ap}$ | $3.5^{aq}$ | $2.8^{ap}$ | $1.74^{e}$ | $6.88^{e}$ | $27.8^{bq}$ | $9.6^{bp}$ |
| Kent | $0.71^{aq}$ | $0.42^{bp}$ | $3.5^{aq}$ | $3.1^{ap}$ | $1.70^{d}$ | $6.84^{d}$ | $39.1^{bq}$ | $11.4^{bp}$ |
| OS-342 | $0.69^{aq}$ | $0.39^{ap}$ | $3.1^{ap}$ | $2.9^{ap}$ | $1.77^{f}$ | $6.80^{c}$ | $19.2^{aq}$ | $3.6^{ap}$ |
| OL-9 | $0.73^{aq}$ | $0.40^{ap}$ | $3.2^{ap}$ | $3.1^{ap}$ | $1.80^{g}$ | $7.76^{h}$ | $38.7^{bq}$ | $7.4^{ap}$ |
| OL-1678 | $0.71^{aq}$ | $0.40^{ap}$ | $3.1^{ap}$ | $3.1^{ap}$ | $1.77^{f}$ | $6.75^{b}$ | $32.2^{bq}$ | $4.1^{ap}$ |

a, b, c, d, e, f, g and h superscripts are significantly ($p < 0.05$) different column wise within different cultivars and p and q superscripts are significantly ($p < 0.05$) different row wise within a cultivar.

Table 2

Colour characteristics and physicochemical properties of flour from control and roasted oats.

| Cultivars | $L^*$ | | $a^*$ | | $b^*$ | | $\Delta E$ | | Water absorption capacity (g/100 g flour) | | Water solubility index (g/100 g flour) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted |
| OL-1682 | $86.9^{a_1}$ | $85.1^{b_2}$ | $1.5^{a_2}$ | $1.8^{a_1}$ | $10.8^{a_2}$ | $12.1^{b_1}$ | $87.6^{a_1}$ | $86.0^{b_2}$ | $99.9^{a_2}$ | $154.8^{a_1}$ | $7.4^{a_1}$ | $3.8^{a_2}$ |
| OL-1683 | $87.2^{a_1}$ | $83.7^{b_2}$ | $1.4^{a_2}$ | $1.6^{a_1}$ | $10.6^{a_2}$ | $11.3^{a_1}$ | $87.8^{a_1}$ | $84.4^{b_2}$ | $102.9^{a_2}$ | $150.4^{a_1}$ | $7.6^{a_1}$ | $3.4^{a_2}$ |
| OL-1684 | $86.0^{a_2}$ | $86.0^{a_2}$ | $1.5^{a_2}$ | $1.6^{a_2}$ | $10.8^{a_2}$ | $11.4^{a_1}$ | $86.8^{a_2}$ | $86.7^{a_2}$ | $99.0^{a_2}$ | $144.6^{b_1}$ | $6.1^{a_1}$ | $3.7^{a_2}$ |
| OL-125 | $83.9^{a_2}$ | $82.0^{a_2}$ | $2.0^{a_2}$ | $3.0^{a_1}$ | $12.2^{a_2}$ | $14.2^{a_1}$ | $85.0^{a_2}$ | $83.3^{a_2}$ | $106.0^{a_2}$ | $183.0^{a_1}$ | $6.9^{a_1}$ | $3.4^{a_2}$ |
| OL-1528 | $85.0^{a_2}$ | $84.5^{a_2}$ | $2.1^{a_2}$ | $2.1^{a_2}$ | $12.2^{a_2}$ | $12.8^{a_1}$ | $86.0^{a_2}$ | $85.4^{a_2}$ | $102.3^{a_2}$ | $151.8^{a_1}$ | $6.2^{a_1}$ | $3.8^{a_2}$ |
| IOM-6 | $84.4^{a_1}$ | $83.5^{a_2}$ | $2.0^{a_2}$ | $2.4^{a_1}$ | $12.5^{a_2}$ | $13.5^{a_1}$ | $85.3^{a_1}$ | $84.6^{a_2}$ | $104.1^{a_2}$ | $151.2^{a_1}$ | $7.0^{a_1}$ | $3.9^{a_2}$ |
| Kent | $86.4^{a_2}$ | $85.7^{a_2}$ | $1.7^{a_2}$ | $1.7^{a_2}$ | $11.4^{a_2}$ | $11.6^{a_1}$ | $87.2^{a_1}$ | $85.3^{a_2}$ | $102.0^{a_2}$ | $135.6^{a_1}$ | $6.1^{a_1}$ | $3.9^{a_2}$ |
| OS-342 | $84.8^{a_1}$ | $84.6^{a_2}$ | $1.9^{a_1}$ | $2.1^{a_1}$ | $12.5^{a_2}$ | $12.8^{a_1}$ | $85.8^{a_1}$ | $85.5^{a_2}$ | $100.9^{a_2}$ | $139.0^{a_1}$ | $7.9^{a_1}$ | $4.3^{a_2}$ |
| OL-9 | $84.8^{a_2}$ | $87.0^{a_1}$ | $1.5^{a_2}$ | $1.9^{a_1}$ | $12.0^{a_2}$ | $12.5^{a_1}$ | $87.9^{a_1}$ | $86.6^{a_2}$ | $115.2^{a_2}$ | $132.5^{a_1}$ | $6.7^{a_1}$ | $3.9^{a_2}$ |
| OL-1678 | $86.0^{a_1}$ | $84.5^{a_2}$ | $2.1^{a_2}$ | $2.5^{a_1}$ | $12.5^{a_2}$ | $13.5^{a_1}$ | $85.6^{a_1}$ | $86.9^{a_2}$ | $107.2^{a_2}$ | $170.7^{a_1}$ | $7.4^{a_1}$ | $3.8^{a_2}$ |

a, b, c and d superscripts are significantly ($p < 0.05$) different column wise within different cultivars and p and q superscripts are significantly ($p < 0.05$) different row wise within a cultivar.

Table 3

Pasting properties of flour from control and roasted oats.

| Cultivars | Peak viscosity (cP) | | Breakdown viscosity (cP) | | Final viscosity (cP) | | Setback viscosity (cP) | | Peak time (min) | | Pasting temperature (°C) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted |
| OL-1682 | $1107^{b,q}$ | $1000^{d,p}$ | $283^{b,q}$ | $218^{c,p}$ | $2352^{a,q}$ | $1802^{f,p}$ | $1528^{a,q}$ | $1020^{c,p}$ | $6.1^{b,q}$ | $6.07^{d,p}$ | $94.4^{b,q}$ | $92.4^{b,p}$ |
| OL-1683 | $1237^{a,q}$ | $1016^{d,p}$ | $384^{a,q}$ | $229^{f,p}$ | $2890^{b,q}$ | $1774^{g,p}$ | $2037^{a,q}$ | $987^{d,p}$ | $5.9^{a,q}$ | $6.07^{d,p}$ | $94.5^{b,q}$ | $92.0^{a,p}$ |
| OL-1684 | $1247^{a,q}$ | $1012^{d,p}$ | $340^{a,q}$ | $221^{e,p}$ | $2597^{b,q}$ | $1753^{d,p}$ | $1690^{b,q}$ | $962^{c,p}$ | $6.2^{b,q}$ | $6.07^{d,p}$ | $94.0^{b,q}$ | $92.0^{a,p}$ |
| OL-125 | $1093^{b,q}$ | $579^{b,p}$ | $262^{a,q}$ | $38^{a,p}$ | $2773^{b,q}$ | $1567^{e,p}$ | $1943^{a,q}$ | $1026^{d,p}$ | $6.1^{b,q}$ | $6.47^{f,p}$ | $93.9^{b,q}$ | $92.7^{a,p}$ |
| OL-1528 | $1257^{a,q}$ | $613^{c,p}$ | $345^{a,q}$ | $145^{c,p}$ | $2653^{b,q}$ | $1349^{b,p}$ | $1742^{b,q}$ | $881^{b,p}$ | $6.1^{b,q}$ | $6.00^{c,p}$ | $93.2^{b,q}$ | $92.7^{a,p}$ |
| IOM-6 | $997^{a,q}$ | $1073^{f,p}$ | $263^{a,q}$ | $208^{d,p}$ | $2581^{b,q}$ | $2240^{i,p}$ | $1848^{a,q}$ | $1375^{f,p}$ | $5.9^{a,q}$ | $6.14^{e,p}$ | $93.2^{b,q}$ | $92.1^{a,p}$ |
| Kent | $1325^{a,q}$ | $1043^{e,p}$ | $344^{a,q}$ | $241^{g,p}$ | $2834^{b,q}$ | $1951^{h,p}$ | $1854^{a,q}$ | $1149^{h,p}$ | $6.2^{b,q}$ | $5.94^{b,p}$ | $93.6^{b,q}$ | $92.8^{a,p}$ |
| OS-342 | $1420^{a,q}$ | $1079^{f,p}$ | $547^{b,q}$ | $319^{g,p}$ | $2285^{b,q}$ | $1943^{h,p}$ | $1413^{a,q}$ | $1183^{g,p}$ | $6.1^{b,q}$ | $5.87^{a,p}$ | $93.6^{b,q}$ | $92.8^{a,p}$ |
| OL-9 | $1263^{a,q}$ | $1008^{d,p}$ | $343^{a,q}$ | $270^{h,p}$ | $2384^{a,q}$ | $1829^{g,p}$ | $1464^{a,q}$ | $1091^{g,p}$ | $6.1^{b,q}$ | $6.00^{c,p}$ | $92.8^{b,q}$ | $92.0^{a,p}$ |
| OL-1678 | $1272^{a,q}$ | $418^{a,p}$ | $288^{b,q}$ | $100^{b,p}$ | $2678^{b,q}$ | $1124^{a,p}$ | $1694^{b,q}$ | $806^{a,p}$ | $6.3^{b,q}$ | $6.03^{d,p}$ | $91.6^{a,q}$ | $94.5^{c,p}$ |

Superscripts (a-i) are significantly ($p < 0.05$) different column wise within different cultivars and p and q superscripts are significantly ($p < 0.05$) different row wise within a cultivar.

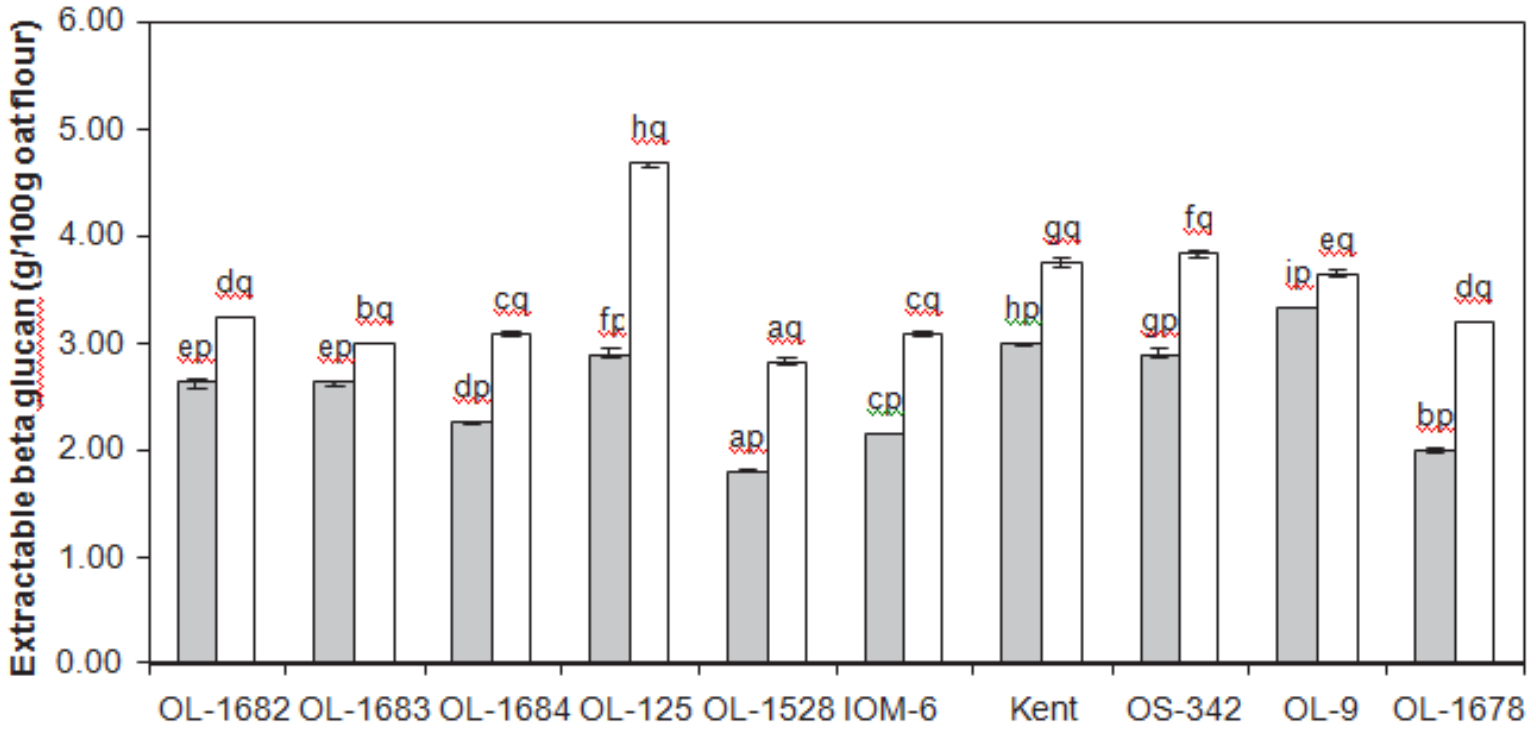


Fig. 1. Effect of roasting on extractability of b-glucan in different oats cultivars, superscripts (a**e**i) show significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars. Error bars represent standard deviation of three replicates; control ( grey ) and roasted () samples.

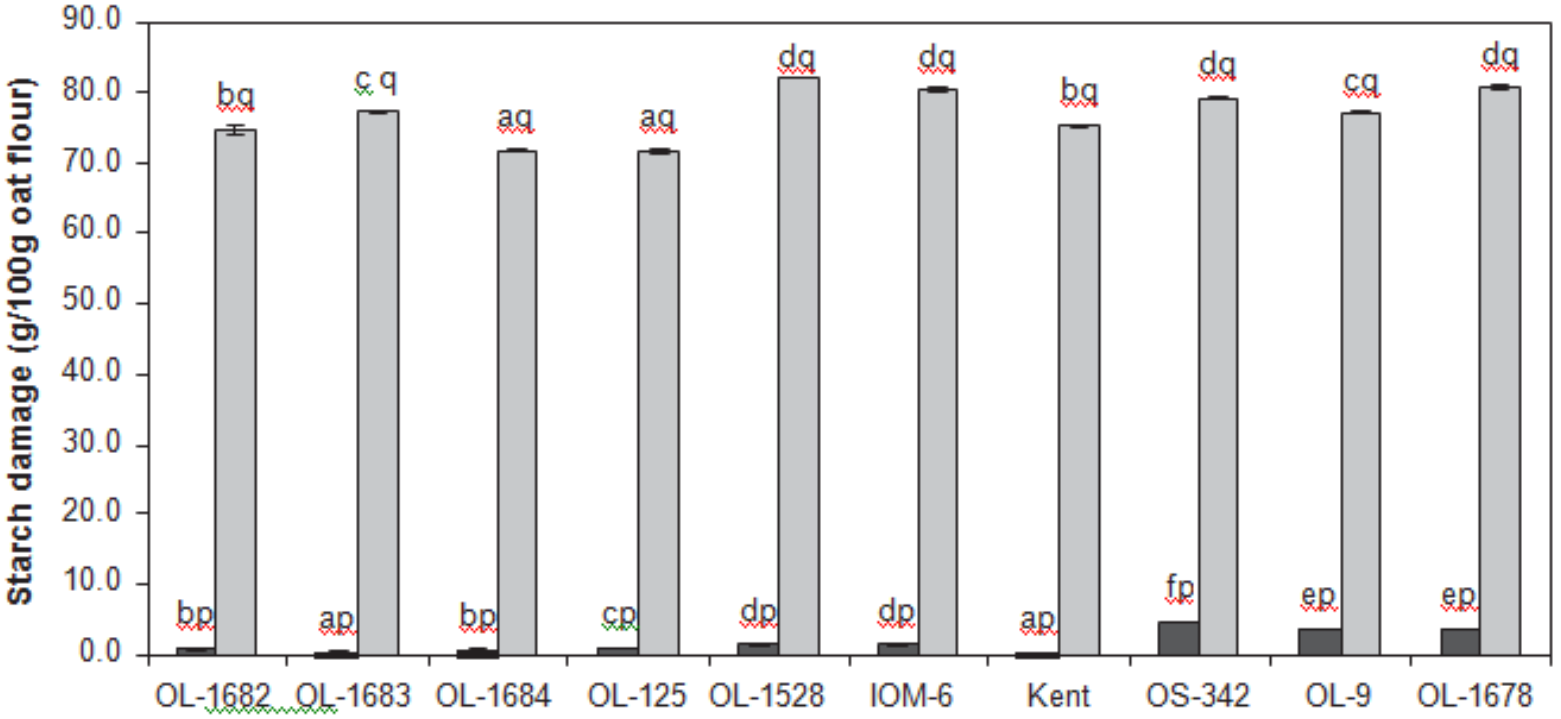


Fig. 2. Effect of roasting on starch damage in different oats cultivars, superscripts (a**e**f) show significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars. Error bars represent standard deviation of three replicates; control (grey) and roasted ( light ) samples.

Table 4

Total phenolic content, reducing power, antioxidant and metal chelating activity of control and roasted oats.

| Cultivars | Total phenolic content (mg FAE/g) | | Reducing power (mmol AAE/g) | | Metal chelating activity | | Antioxidant activity | |
|---|---|---|---|---|---|---|---|---|
| | Control | Roasted | Control | Roasted | Control | Roasted | Control | Roasted |
| OL-1682 | $3215^{q1}$ | $1774^{p0}$ | $22.5^{p0}$ | $23.2^{q1}$ | $26.3^{p0}$ | $73.7^{q1}$ | $8.1^{p0}$ | $11.6^{q1}$ |
| OL-1683 | $3579^{q1}$ | $2056^{p0}$ | $18.7^{p0}$ | $21.4^{q1}$ | $52.8^{p0}$ | $64.8^{q1}$ | $9.2^{p0}$ | $9.9^{q1}$ |
| OL-1684 | $2031^{q1}$ | $1800^{p0}$ | $19.5^{p0}$ | $22.1^{q1}$ | $52.0^{p0}$ | $67.1^{q1}$ | $9.7^{p0}$ | $10.8^{q1}$ |
| OL-125 | $1754^{q1}$ | $1359^{p0}$ | $18.1^{p0}$ | $24.8^{q1}$ | $49.4^{p0}$ | $79.7^{q1}$ | $8.4^{p0}$ | $11.8^{q1}$ |
| OL-1528 | $1969^{q1}$ | $1597^{p0}$ | $15.9^{p0}$ | $21.8^{q1}$ | $42.2^{p0}$ | $68.5^{q1}$ | $9.5^{p0}$ | $9.5^{p0}$ |
| IOM-6 | $1890^{q1}$ | $1615^{p0}$ | $23.1^{p0}$ | $28.2^{q1}$ | $72.6^{p0}$ | $82.2^{q1}$ | $10.2^{p0}$ | $12.8^{q1}$ |
| Kent | $2633^{q1}$ | $1310^{p0}$ | $24.5^{p0}$ | $24.8^{p0}$ | $37.1^{p0}$ | $76.9^{q1}$ | $8.7^{p0}$ | $9.1^{q1}$ |
| OS-342 | $3318^{q1}$ | $1974^{p0}$ | $25.5^{p0}$ | $28.7^{q1}$ | $47.8^{p0}$ | $71.8^{q1}$ | $8.5^{p0}$ | $12.0^{q1}$ |
| OL-9 | $1985^{q1}$ | $1697^{p0}$ | $17.5^{p0}$ | $23.6^{q1}$ | $46.1^{p0}$ | $68.6^{q1}$ | $6.3^{p0}$ | $10.9^{q1}$ |
| OL-1678 | $2690^{q1}$ | $1636^{p0}$ | $24.7^{p0}$ | $25.0^{p0}$ | $47.1^{p0}$ | $68.3^{q1}$ | $6.9^{p0}$ | $11.6^{q1}$ |

a, b, c and d superscripts are significantly ($p < 0.05$) different column wise within different cultivars and p and q superscripts are significantly ($p < 0.05$) different row wise within a cultivar.

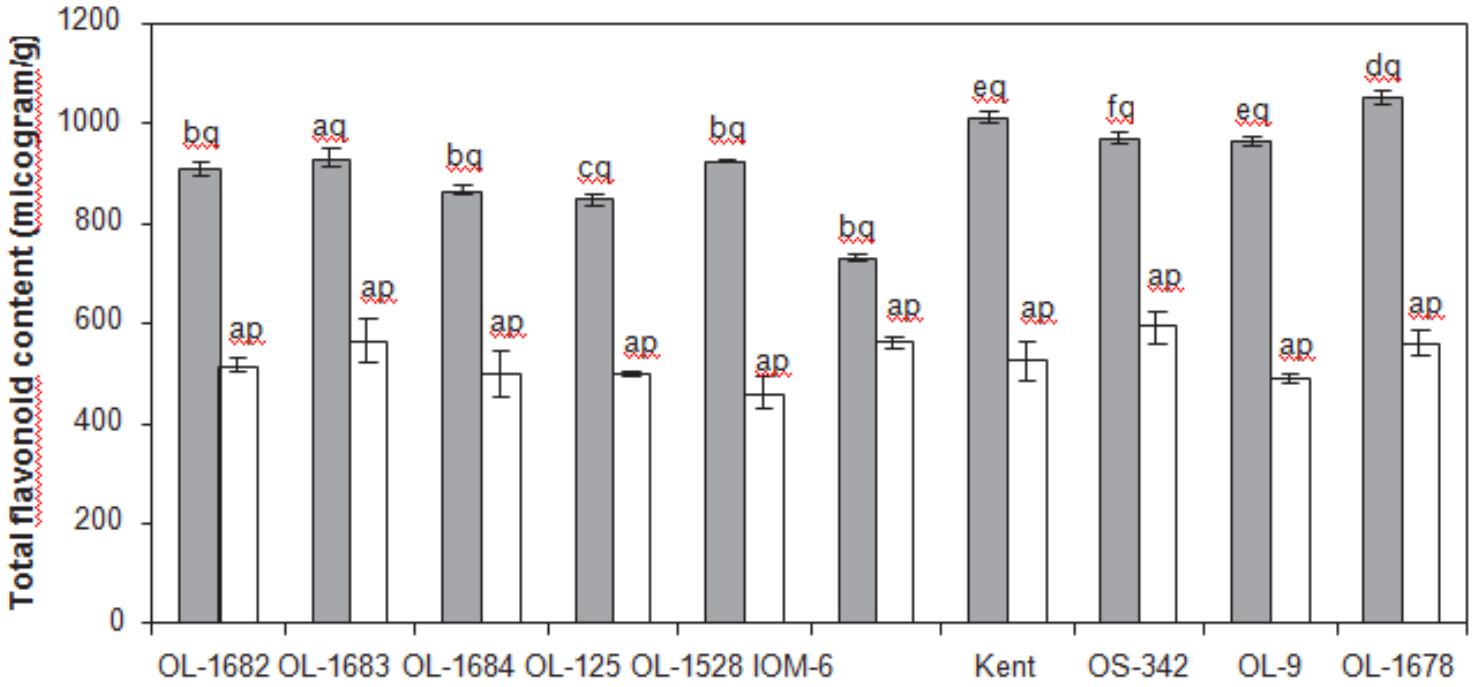


Fig. 3. Effect of roasting on total flavonoids content in different oats cultivars, superscripts (aef) show significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars. Error bars represent standard deviation of three replicates; control (grey ) and roasted () samples.

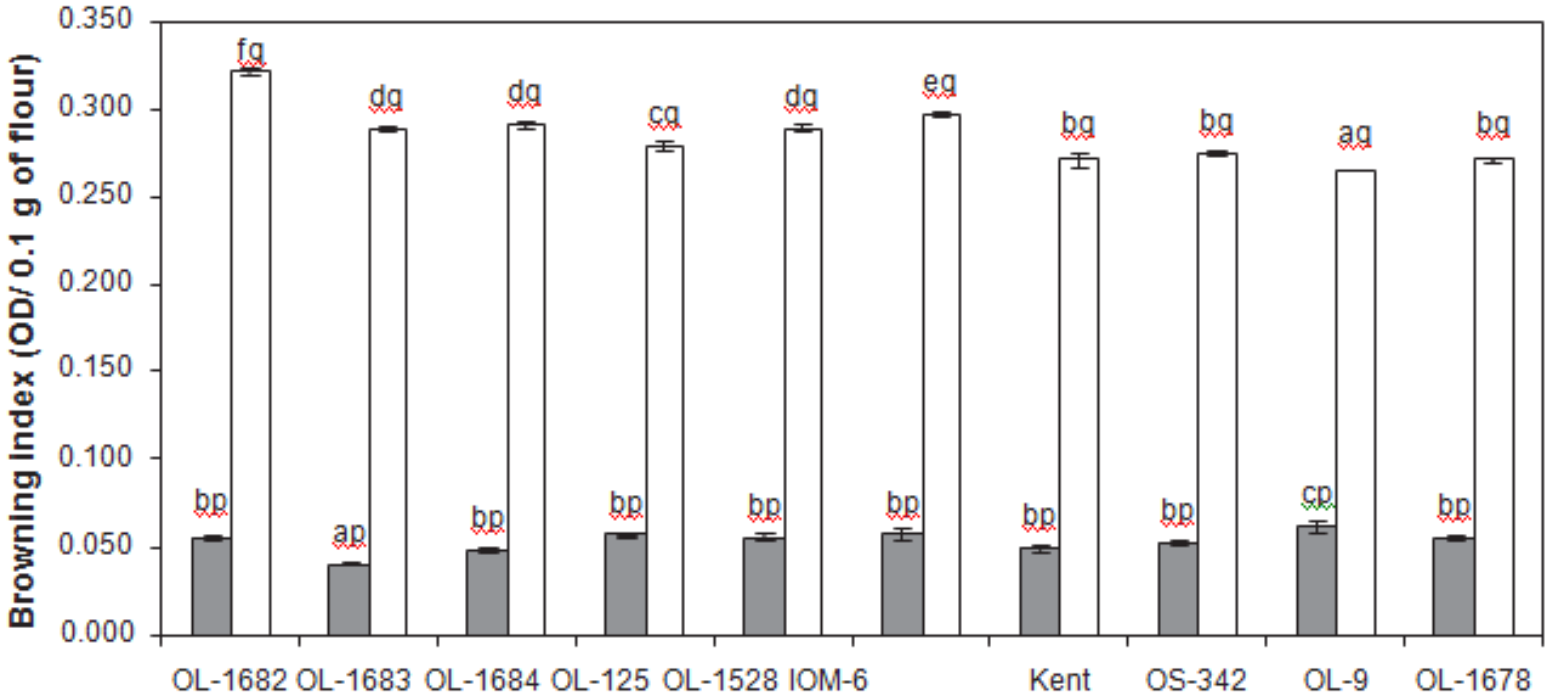


Fig. 4. Effect of roasting on browning index in different oats cultivars, superscripts (a to f) show significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars. Error bars represent standard deviation of three replicates; control (grey) and roasted () samples.

Table 5

Physical characteristics of chapatti.

Physical characteristics of chapattis.

| | Control (wheat flour) | Oat flour (control) | | Oat flour (defatted) | | Oat flour (hydrothermal treated) | | Oat flour (kilned) | |
|---|---|---|---|---|---|---|---|---|---|
| | | 25% | 50% | 25% | 50% | 25% | 50% | 25% | 50% |
| Water absorption for dough making (%) | $62.0^{b,m} \pm 1.10$ | $58.8^{a} \pm 0.80$ | $58.2^{a} \pm 0.90$ | $65.8^{x} \pm 0.70$ | $66.1^{x} \pm 1.20$ | $72.9^{q} \pm 1.10$ | $85.3^{r} \pm 1.30$ | $66.5^{k} \pm 0.80$ | $67.1^{k} \pm 0.60$ |
| Puffing (%) | $100.0^{c,n} \pm 5.00$ | $87.5^{b} \pm 5.00$ | $10.5^{a} \pm 15.00$ | $75.0^{w} \pm 5.00$ | $62.5^{v} \pm 5.00$ | $37.5^{q} \pm 15.00$ | $20.0^{p} \pm 5.00$ | $25.0^{k} \pm 5.00$ | $10.0^{j} \pm 15.00$ |
| Bake loss (%) | $12.3^{a,m} \pm 0.30$ | $13.7^{b} \pm 0.70$ | $16.7^{c} \pm 0.50$ | $12.8^{x} \pm 0.30$ | $13.2^{x} \pm 0.60$ | $13.5^{q} \pm 0.70$ | $18.8^{r} \pm 0.30$ | $12.8^{k} \pm 0.60$ | $16.6^{l} \pm 0.90$ |
| Shrinkage (%) | $3.10^{c,n,k} \pm 0.21$ | $2.35^{b} \pm 0.12$ | $2.00^{a} \pm 0.10$ | $1.95^{v} \pm 0.08$ | $1.40^{w} \pm 0.04$ | $2.35^{q} \pm 0.11$ | $1.90^{p} \pm 0.08$ | $1.85^{j} \pm 0.07$ | $1.80^{j} \pm 0.05$ |

Values represent mean ± standard deviation. The superscripts a, b, c; x, y, z; p, q, r; and j, k, l show the significant ($p < 0.05$) effect of incorporation of control, defatted, hydrothermal and kilned oat flour to wheat flour, respectively row wise among the blends.

Table 6

Effect of baking of chapatties on total phenolic content and antioxidant activity.

| Treatment | Total phenolic content (µg ferulic acid equivalents/g) | | | | Antioxidant activity (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 25% incorporation of oat flour | | 50% incorporation of oat flour | | 25% incorporation of oat flour | | 50% incorporation of oat flour | |
| | Before baking | After baking | Before baking | After baking | Before baking | After baking | Before baking | After baking |
| Oat flour (Control) | $1964^{aq} \pm 25$ | $1487^{ap} \pm 12$ | $2003^{aq} \pm 42$ | $1871^{ap} \pm 26$ | $13.0^{bq} \pm 1.2$ | $10.3^{ap} \pm 0.6$ | $13.2^{bq} \pm 0.5$ | $10.8^{ap} \pm 0.9$ |
| Oat flour (Defatted) | $1453^{ap} \pm 37$ | $1359^{ap} \pm 16$ | $1594^{bq} \pm 25$ | $1393^{ap} \pm 13$ | $12.2^{aq} \pm 0.3$ | $11.3^{ap} \pm 0.9$ | $12.7^{aq} \pm 0.4$ | $11.0^{ap} \pm 0.6$ |
| Oat flour (Hydrothermal treated) | $1560^{bq} \pm 15$ | $1566^{bq} \pm 29$ | $1551^{ap} \pm 38$ | $1525^{ap} \pm 34$ | $13.1^{bq} \pm 0.7$ | $11.9^{ap} \pm 1.1$ | $12.1^{ap} \pm 0.4$ | $12.2^{bp} \pm 0.2$ |
| Oat Flour (Kilned) | $1979^{aq} \pm 23$ | $1410^{ap} \pm 14$ | $1997^{aq} \pm 36$ | $1535^{ap} \pm 30$ | $11.6^{aq} \pm 0.7$ | $10.6^{ap} \pm 0.3$ | $13.0^{bq} \pm 0.7$ | $12.9^{cp} \pm 0.3$ |

Values represent mean ± standard deviation. a, b, c and d superscripts are significantly ($p < 0.05$) different column wise within different blends and p and q superscripts show significant effect of baking within a blend.

Table 7

Effect of baking of chapatties on reducing power and metal chelating activity.

| Treatment | Reducing power (µmol ascorbic acid equivalents) | | | | Metal chelating activity (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | 25% incorporation of oat flour | | 50% incorporation of oat flour | | 25% incorporation of oat flour | | 50% incorporation of oat flour | |
| | Before baking | After Baking | Before baking | After baking | Before baking | After baking | Before baking | After baking |
| Oat flour (Control) | $8.2^{ap} \pm 0.2$ | $14.0^{aq} \pm 1.1$ | $11.9^{ap} \pm 0.4$ | $16.8^{aq} \pm 0.4$ | $64.2^{ap} \pm 2.0$ | $69.1^{aq} \pm 2.5$ | $58.0^{ap} \pm 2.2$ | $61.3^{aq} \pm 1.1$ |
| Oat flour (Defatted) | $8.0^{ap} \pm 0.3$ | $13.7^{aq} \pm 0.7$ | $11.7^{ap} \pm 0.9$ | $16.3^{aq} \pm 0.7$ | $62.0^{ap} \pm 3.3$ | $64.5^{aq} \pm 6.6$ | $57.4^{ap} \pm 3.2$ | $60.3^{aq} \pm 2.8$ |
| Oat flour (Hydrothermal treated) | $11.0^{bp} \pm 0.3$ | $13.4^{aq} \pm 0.5$ | $13.6^{bp} \pm 0.5$ | $17.1^{aq} \pm 0.3$ | $72.6^{bp} \pm 4.1$ | $72.8^{aq} \pm 3.2$ | $73.8^{bp} \pm 1.3$ | $76.5^{bq} \pm 3.2$ |
| Oat Flour (Kilned) | $14.2^{cp} \pm 0.5$ | $14.3^{aq} \pm 1.0$ | $15.5^{cp} \pm 0.5$ | $17.6^{aq} \pm 0.8$ | $69.7^{cp} \pm 5.7$ | $73.1^{aq} \pm 1.0$ | $70.6^{bp} \pm 2.1$ | $75.0^{bq} \pm 1.9$ |

Values represent mean ± standard deviation. a, b, c and d superscripts are significantly ($p < 0.05$) different column wise within different blends and p and q superscripts show significant effect of baking within a blend.

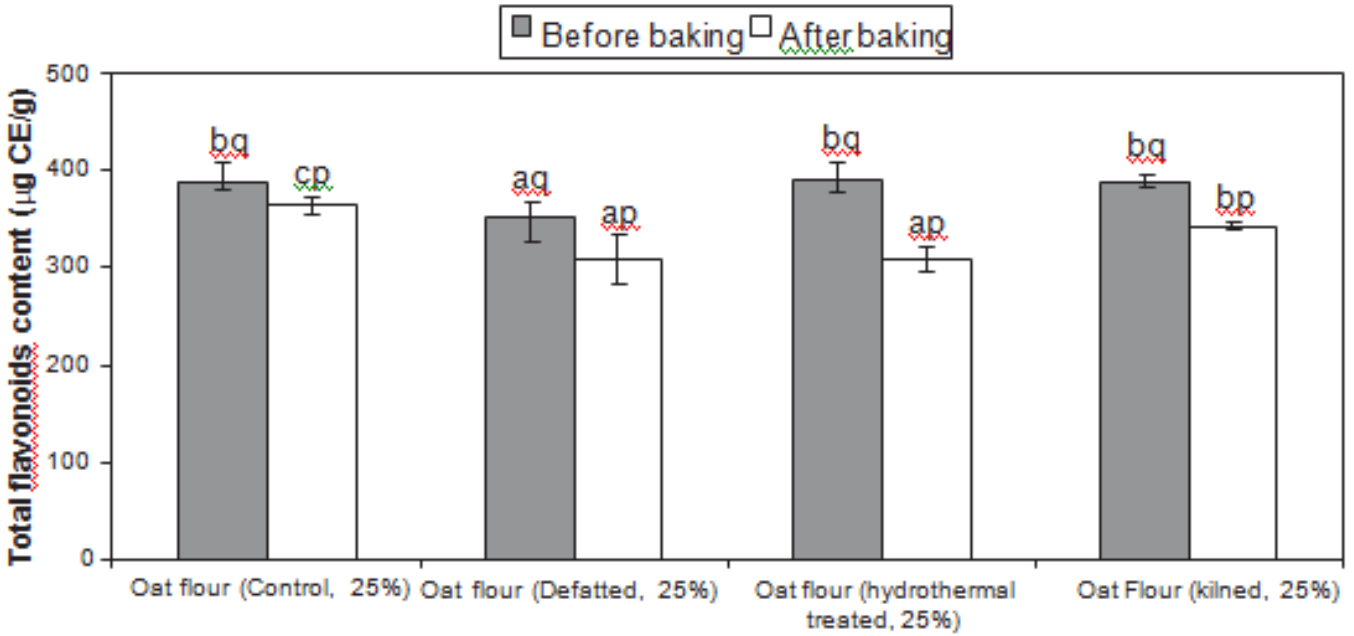


Fig. 5. Effect of baking on total flavonoids content of chapatties containing 25% oat flour in different forms. Superscripts a, b and c show significant difference among the blends chapatti while p and q show significant effect of baking.

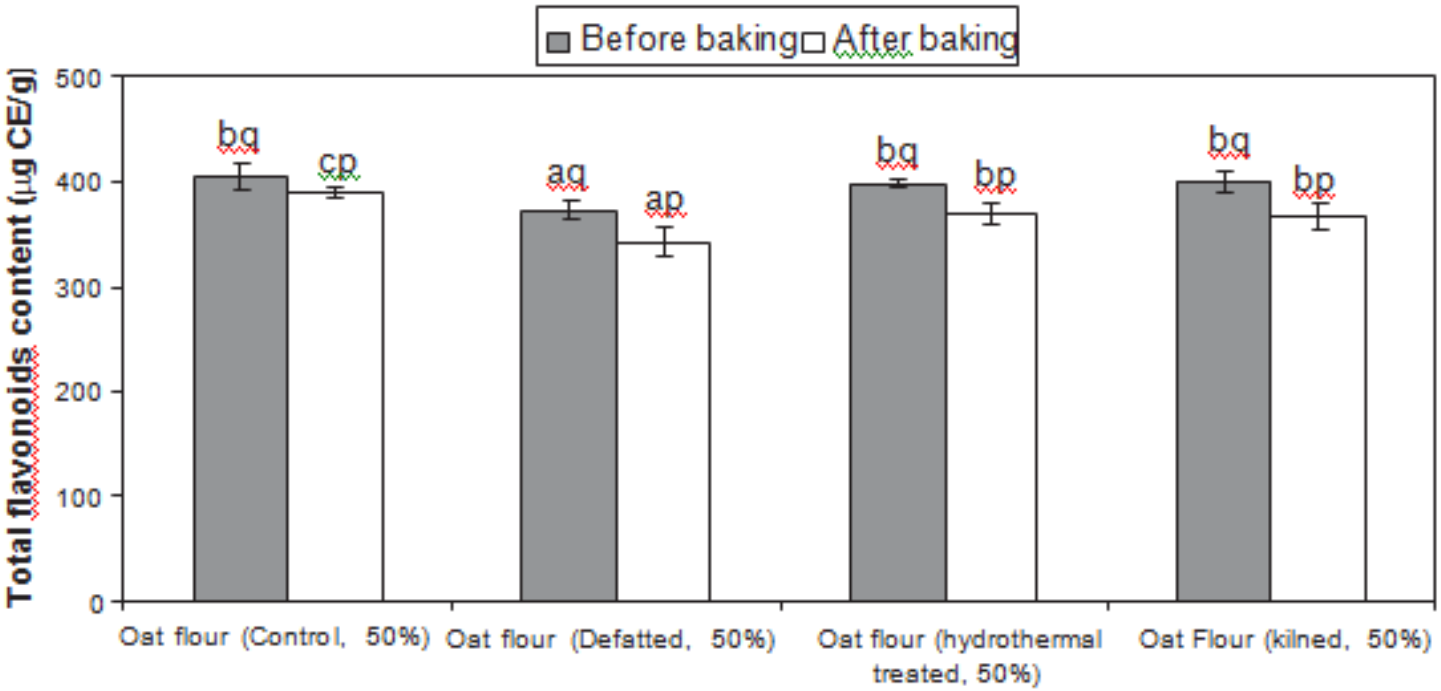


Fig. 6. Effect of baking on total flavonoids content of chapatties containing 50% oat flour in different forms. Superscripts a, b and c show significant difference among the blends and chapatti while p and q show significant effect of baking.

Table 8

Effect of baking of chapatties on non-enzymatic browning index (OD/0.1 g).

| Treatment | 25% incorporation | | 50% incorporation | |
|---|---|---|---|---|
| | Before baking | After baking | Before baking | After baking |
| Oat flour (control) | $0.156^{aq} \pm 0.002$ | $0.186^{aq} \pm 0.001$ | $0.318^{bp} \pm 0.003$ | $0.387^{bq} \pm 0.003$ |
| Oat flour (defatted) | $0.116^{ap} \pm 0.002$ | $0.148^{aq} \pm 0.002$ | $0.160^{ap} \pm 0.002$ | $0.180^{aq} \pm 0.003$ |
| Oat flour (hydrothermal treated) | $0.199^{bp} \pm 0.001$ | $0.239^{bq} \pm 0.001$ | $0.356^{cp} \pm 0.002$ | $0.395^{bq} \pm 0.002$ |
| Oat flour (kilned) | $0.141^{bp} \pm 0.003$ | $0.169^{bq} \pm 0.001$ | $0.398^{dp} \pm 0.003$ | $0.437^{cq} \pm 0.002$ |

Values represent mean ± standard deviation. a, b, c and d superscripts are significantly ($p < 0.05$) different column wise within different blends and p and q superscripts show significant effect of baking within a blend.

**Annexure III**

## Achievements from the project

The research carried out in this project has resulted in 2 publications in high impact international peer reviewed journals.

1. Gujral HS, Sharma P & Rachna (2011). Effect of roasting on beta glucan extractability, physiochemical and antioxidant properties of oats. LWT- Food Science & Technology, 44, 2223-2230.

**2.** Gujral HS, Sharma P, Gill BS and Kaur S.(2013). Effect of incorporating hydrothermal, kilned and defatted oats on antioxidant and chapatti making properties of wheat flour. Food Chemistry, 138(2), 1400-1406.

**Annexure IV**

**Summary of the findings**

Oats were subjected to treatments like defatting, hydrothermal cooking and kilning, milled into flour and then the control and treated flours were incorporated into wheat flour at 25% and 50% levels and chapatti making behaviour and antioxidant properties were studied. The treatments significantly affected the antioxidant properties of oats. Incorporating oat flours to wheat increased total phenolic content but low-ered the antioxidant activity however both were decreased significantly upon baking. The reducing power of the oat blended flour was higher than the wheat flours and ranged from 8.0 to 15.5 lmol AAE/g and was further increased upon baking. The metal chelating activity of flour blends varied from 62.0% to 73.8% and further increased upon baking. After baking the total flavonoid content was lowered and ranged from 308 to 389 lg CE/g. The non-enzymatic browning index significantly increased up to 27.6% upon baking.

The antioxidant properties, damaged starch, beta glucan extractability and physicochemical properties of ten different oat cultivars were studied after sand roasting at 280 °C for 15 s. The groat content within the cultivars varied from 6.59 to 7.76 g/10 g oats. Roasting lowered the length/breadth ratio and bulk density and resulted in puffing of the groats. Color characteristics $a^*$ indicating redness and $b^*$ indicating yel- lowness and nonenzymatic browning index significantly ($p < 0.05$) increased upon roasting. The total phenolic (mg FAE/g) and flavonoid content (mg/g) decreased significantly by 11.4-50.2% and 22.7-49.9%, respectively. An increase in reducing power (mmol AAE/g) ranging from 1.1 to 37.6% and metal chelating activity ranging from 13.2 to 180.2% was observed in the roasted groats. The DPPH radical scavenging activity in the roasted groats increased by 4.6-73.0%. The peak viscosity of the roasted groat flour decreased by 9.1-51.1% while the final viscosity decreased by 15.4-57.5%. The damaged starch content in the groats increased after roasting and the increase ranged from 72 to 82%. Roasting significantly increased the extractable beta glucan content in the groats by 9.8-61.1%. It was concluded that roasting significantly affects the physicochemical and pasting behavior of groats and increases the availability of phytochemicals like beta glucan and the total antioxidant activity.

**Annexure V**

**Contribution to the society**

The study revealed that oats are a healthy option for replacement of wheat as they are high in bioactive compounds mainly soluble fiber and antioxidants.

Sand roasting of oats affected the physicochemical properties of groats as it lead to grain expansion, lowered the length/breadth ratio and bulk density, changed its colour characteristics by increasing its yellowness and redness and also increased the nonenzymatic browning index. The damaged starch content increased due to bursting of starch granules. Roasting significantly affected the pasting behavior of the oat flour. The roasted flour showed an increase in antioxidant activity, reducing power, metal chelating activity while the total phenolic and flavonoid content decreased significantly. The extractable b-glucan significantly increased after roasting.

To take advantage of the bioactive compounds present in oats and increase utilisation of oats in human foods we can incorporate oat flour in wheat flour up to a level of 50% and acceptable chapat- tis can be made. Oats can be subjected to various treatments like defatting, hydrothermal treatment and kilning to improve their oxidative stability and these treatments significantly alter the anti- oxidant properties of the oats with increase being observed in the reducing power and metal chelating activity and a decrease being observed in the total phenolic and flavonoid content and antioxi- dant activity. The antioxidant potential of the wheat and oat flour blends is enhanced as the oats have higher total phenolic and fla- vonoid content and higher reducing power. The baking process also affects the antioxidant behaviour with an increase being ob- served in reducing power, metal chelating activity and non-enzy- matic browning index and decrease being observed in total phenolic and flavonoid content and antioxidant activity. Since cha- pattis form an essential component of the daily Indian diet there- fore part of the wheat flour should be replaced with oats to tap the nutraceutical potential of oats.

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