



Effect of Toasting and Natural Fermentation on the Phytochemical and Functional Properties of Oats Grown in Ethiopia

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Abstract. Toasting and natural fermentation are traditional processing methods commonly practiced in Ethiopia. This study was carried out to examine the influence of these traditional processing methods on the phytochemicals and functional properties of oats. Oat grains were toasted for 3 h at 115 °C and milled into flour, and raw oats flour spontaneously fermented for 24 h and 48 h, while untreated oats flour served as a control. Results show that toasting caused a significant ($P < 0.05$) decrease in the bulk density, water solubility index, foaming capacity, and foaming stability in the range; (9.6–18.7%), (7.1–31.2%), (20–46%), & (14.4–38.5%), respectively, while it significantly ($P < 0.05$) increased the total phenolic contents, DPPH antioxidant activity, water absorption capacity, and oil absorption capacity in the range; (20.7–30.4%), (4.3–33%), (87.3–92.7%), (69.1–76%), respectively. Twenty-four hour and 48h fermentation of oats caused a significant ($P < 0.05$) decrease in the, bulk density, foaming capacity, and foaming stability in the range; (15.5–22.7%), (42.4–68%), & (4–74.2%), respectively, while it significantly ($P < 0.05$) increased the total phenolics, total flavonoids, DPPH scavenging capacity, oil absorption capacity, and water solubility index in the range; (18.6–52.2), (34.8–81.3%), (5.3–43.7%), (8–14.9%), (10.7–55.6%), respectively. Thus, the phytochemicals, and some functional properties of oats were amplified by these low-cost household traditional oat processing methods.

Keywords: Oats · Natural fermentation · Toasting · Functional properties · Total phenolic content · Total flavonoid content

1 Introduction

Oat (*Avena sativa*) is a cereal grain that belongs to the grass family *Poaceae*. Oat grain's nutritional composition makes it a valuable component of the human diet. Proteins, starches, essential fatty acids, vitamins, minerals, phytochemicals, and soluble

dietary fibers are among the many nutrients abundant in oats (Rasane *et al.* 2015; Angelov *et al.* 2018; Jamil *et al.* 2016). Because of its high β -glucan, soluble dietary fiber, and avenathramide, an oats-specific antioxidant, oats have been known as a functional food (Van den Broeck *et al.* 2016).

Literature information indicated processing of oats had an impact on the oat matrix qualitatively and its composition quantitatively (Grundy *et al.* 2018). In the industry, kiln heating, extrusion cooking, microwave heating, superheated steam processing, and controlled fermentation are common methods used for boosting oats' nutrient content and functional properties (Nkhata *et al.* 2018; Franz *et al.* 2014; Freire *et al.* 2015; Marco *et al.* 2017). Processing improves nutrient digestibility and bioavailability by mixing up the food matrix. It can, however, affect food functionality by changing the structure of its components (Grundy *et al.* 2018; Ramashia *et al.* 2019). Finding the right balance between a high amount of food transformation and food processing is one of today's pressing challenges (Grundy *et al.* 2018). A distinction should be made on the degree of processing, which will aid in the acceptance of foods with the highest health importance.

In Ethiopia, oats are traditionally processed at the household level into a variety of foods such as *Injera*, *Kitta*, *Anebabiro*, gruel, porridge, *Enket*, and *tella*. All of these foods are subjected to thermal treatment (toasting), and some are subjected to natural fermentation. Toasting is a quick dry-heat treatment and it is a simple traditional experience that is mostly used to cook or pre-cook oats and is widely practiced in households and rural areas of the country. Natural fermentation has also been used traditionally to prolong the shelf life, improve the taste and flavor, and nutritional properties of oat-based food products. Their effects on these food product functionalities and phytochemical composition, however, have not yet been studied.

Processing changes the nutritional composition of foods in one way or the other before consumption. As a result, understanding the composition and food stability after processing is indispensable. Thus, cultural oat foods should be processed to keep them safe and acceptable for consumption, but not to the point where their nutritional value is compromised. Although some research findings on the impact of modern processing methods on the nutritional composition of oats are available, little is known about the effects of toasting and natural fermentation as practiced at the household level. The current study's goal is thus to investigate the impact of these traditional food processing methods on the phytochemicals and functional properties of two Ethiopian indigenous varieties and one improved variety of oats.

2 Materials and Methods

2.1 Sample Collection

Two Indigenous oat varieties (white and black-colored oats) were collected from the Gozamin district of northwest Ethiopia, and one improved oat variety (Goslin) was obtained from the Adet Agricultural Research Center (Fig. 1).

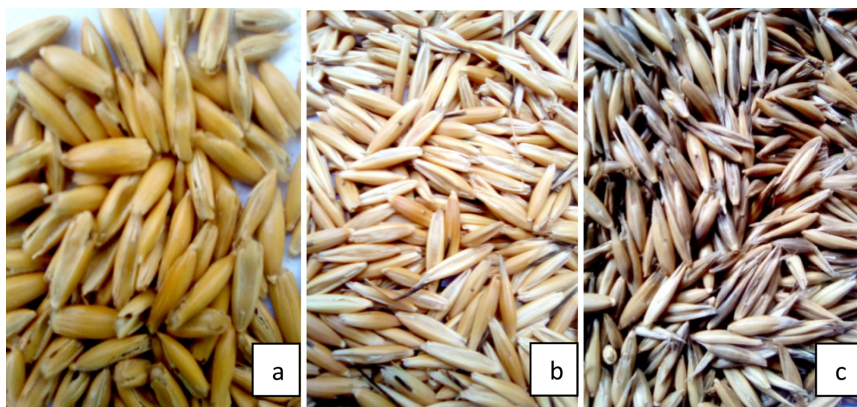


Fig. 1. Improved and local oat varieties (a) Goslin (improved variety) (b) white-oat (local variety) (c) black-oat (local variety)

2.2 Sample Preparation

All oat varieties were dehulled and winnowed to remove husks, ruptured and immature grains, and other unwanted materials. The grains were toasted in an oven (Blast Air Oven, DHG-9240A, China) for 3 h at 115 °C using the method described in (Sandhu *et al.* 2017). The raw and toasted oats grains were pulverized in an electric grinder (RRH-200, Zhejiang, China), and the flour was sieved through a 0.05 mm sieve. Natural fermentation of raw oat flour was conducted using the method described in (Ibrahim *et al.* 2005). Briefly, 250 g of oat flour was combined with 500 ml of deionized water and then fermented for 24 and 48 h at room temperature (22.2 °C). The blended flour sample was then placed on flat glass plates and dehydrated for 20 h in an oven (Blast Air Oven, DHG-9240A, China) at 45 °C, before being pulverized and sieved with a mesh size of 0.425 mm.

2.3 Determination of Phytochemicals

Extraction of Phytochemicals

A 0.5 g flour was shaken with a 10 ml methanol-water 80/20 (v/v) solution for 24 h. It was then centrifuged at 4000 rpm for 10 min before being purified with a filter paper (Whatman No. 1) (Azwanida 2015). This extract was used to determine the sample's DPPH percent inhibition, total phenolic, and total flavonoids.

Determination of Total Phenolic Contents (TPC)

The TPC was measured using the Singleton and Rossi (1999) method. In brief, 0.5 ml of the extract was mixed with 2.5 ml of Folin- Ciocalteu's reagent and 2.5 ml of 7.5% sodium bicarbonate, and then incubated for 30 min in a thermostat set to 45 °C. The color formed during the reaction was measured at 765 nm spectrophotometrically (JASCO V-630, Japan). The standard was gallic acid (0.0, 3.12, 6.25, 12.5, 25, 50, 100,

200 µg/ml, $R^2 = 0.998$). TPC of the sample was then measured in milligrams of gallic acid equivalent (GAE) per gram of dry matter.

Determination of Total Flavonoid Contents (TFC)

TFC was determined using the outlined method of (Xu and Chang 2007). The (+) - catechin was mixed with 0.25 ml of sample extract and 1.25 ml of deionized water before adding 75 µL of 5% sodium nitrite solution. Exactly 150 µL of a ten percent aluminum chloride solution was added after six min and then 0.5 ml of one molar sodium hydroxide solution was also added to the solution mixture after 5 min of standing. Deionized water was used to dilute the mixture to 2.5 ml and the absorbance was recorded immediately at 510 nm using a spectrometer (JASCO V-630, Japan). The obtained sample extract concentration was compared to the (+) - catechin calibration curve (0.0, 7.8, 15.2, 62.5, 125, 250, and 500 g/ml, $R^2 = 0.996$). TFC of the sample were quantified in milligrams of (+) - catechin equivalent (CE) per gram of dry matter.

Determination of DPPH Scavenging Activities

The current study employed DPPH (2, 2-diphenyl-1-picrylhydrazyl) scavenging activity to examine the antioxidant properties of oats. It offers valuable information on the antiradical activity of the sample. Oats extract directly react with and quench free radicals of the DPPH assay. The samples' DPPH percent inhibition was determined using the method outlined by (Kirby and Schmidt 1997). A stock solution of 500 ml DPPH (0.004%) was prepared in methanol. One ml of sample extract was mixed with 4 ml of DPPH solution and incubated for 30 min in the dark. The absorbance of this solution was measured using a spectrometer (JASCO V-630, Japan) at 517 nm. Among the various concentration of the sample extract (2–14 mg/ml), 8 mg/ml was chosen to assess the DPPH percent inhibition. The absorbance of the sample extract was compared to the absorbance of the standard L-ascorbic acids (8 mg/ml) and finally, the DPPH percent inhibition was computed using Eq. (1).

$$\text{Inhibition (\%)} = \frac{(\text{Absorbance of control} - \text{Absorbance of sample extract})}{\text{Absorbance of sample extract}} \times 100 \quad (1)$$

2.4 Determination of Functional Properties

Bulk densities (BD) of the raw and processed (toasted and fermented) oats flour were determined following the described method in (Butt and Rizwana 2010). In a 25 ml measuring cylinder, 10 g of flour was transferred and tapped repeatedly until the constant volume was obtained. The BD was computed using Eq. (2).

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of flour (g)}}{\text{Volume of flour after tapping (ml)}} \quad (2)$$

The Sosulski *et al.* (1976) method was used to assess the water absorption capacity (WAC), oil absorption capacities (OAC), and water solubility indexes (WSI). One g flour and 10 ml oil or deionized water was mixed in a 50 ml bottle. The solution

mixture was shaken for 1 h and then centrifuged (Sigma 2-16KC, UK) at 3500 rpm for 30 min. The oil or water was drained with a pipette and hung on for 25 min (V_2) to finish dropping. The volume difference was considered as absorbed water or oil by the sample. Equation (3) was then used to determine the WAC and OAC of the sample.

$$\text{Water/oil absorption capacity (ml/g)} = \frac{(\text{Initial volume } (V_1) - \text{Decanted volume } (V_2))}{\text{Weight of sample flour}} \quad (3)$$

The supernatant collected from the WAC measurement is used to determine the WSI. This supernatant was heated in an oven (Blast Air Oven, DHG-9240A, China) at 105 °C for 12 h to evaporate the water (Sosulski *et al.* 1976). The soluble matter dried on the surface of the flat glass and then the WSI was calculated using Eq. (4).

$$\text{WSI (\%)} = \frac{\text{Supernatant weight after drying}}{\text{Sample weight}} \times 100 \quad (4)$$

The method described in Narayana and Narasinga Rao (1982) was used to obtain the foaming capacity (FC) and foaming stability (FS) of the sample. In brief, 1.0 g of flour was mixed with 50 ml of deionized water in a glass measuring cylinder. The flour and deionized water were thoroughly shaken for 5 min, and the amount of foam produced was measured just after 30 s. The FC was then calculated using Eq. (5).

$$\text{Foaming capacity (\%)} = \frac{(\text{foam volume AS} - \text{foam volume BS})}{\text{foam volume BS}} \times 100 \quad (5)$$

Where; AS - after shaking, BS - before shaking

The FS was calculated by measuring the amount of foam left after 1 h using Eq. (6).

$$\text{Foaming stability (\%)} = \frac{(\text{foam volume AS} - \text{foam volume after one hour})}{\text{Volume of foam AS}} \times 100 \quad (6)$$

Where; AS - after shaking

2.5 Experimental Design and Statistical Analysis

This study employed a completely randomized design (CRD) with three replicates. The effects of processing were investigated using a one-way analysis of variance (ANOVA) to determine whether there were any significant differences in phytochemicals and functional properties among the three oat varieties. Means significant values were separated by Tukey's test and $p < 0.05$ values are considered statistically significant. Data were analyzed using Minitab®, Version 19.

3 Results and Discussion

3.1 Effect of Toasting and Fermentation on Phytochemicals

The effect of traditional processing methods (toasting and natural fermentation) on the total phenolics, total flavonoid, and total antioxidant content of oats is shown in Table 1. The phytochemicals of oats were significantly ($p < 0.05$) affected by the processing methods.

Phenolic compounds are affected by the temperature used during food processing (Cavalcante *et al.* 2017). The TPC of all oat varieties were significantly ($p < 0.05$) increased by the toasting. It increased by 20.7–30.4%, with Goslin oat having the highest increment. This increment might be linked with the release of phenolic compounds as a result of matrix fragmentation which occurs during heating (Kalam Azad *et al.* 2019). The current study is similar to the findings of Sandhu *et al.* (2017), a significant increment of the TPC of different oats varieties by 11.5–27.1% as a result of toasting. The rise in TPC as a result of heat treatment of cereals and legumes has also been stated by many other studies (Rasane *et al.* 2015; Chandrasekara and Shahidi 2011).

Natural fermentation also improved the TPC significantly ($p < 0.05$), in the range of 18.6–52.2%; the highest value was recorded for 24 h fermented flours. For 48 h fermented flours, increments in the TPC were observed in the first 24 h, and decrements in the second consecutive 24 h. This increase could be attributed to microorganisms degrading cereal grain matrices, resulting, previously attached polyphenols leaked during fermentation (Đorđević *et al.* 2010). For example, *B. subtilis* and *L. plantarum* both have an enzyme called β -glucosidase that breaks the glucoside bonds of polyphenols and reduced sugars, increasing phytoconstituents (Dueñas *et al.* 2005). Nkhata *et al.* (2018) and Martins *et al.* (2011) also reported phenolic compound enhancement could be because of the activity of enzymes like α -amylase, β -glucosidase, and lactase. As a result, natural flour fermentation is a low-cost traditional processing method for increasing phytochemicals and thus protecting the body from the potentially harmful effects of free radicals that may arise during body metabolism. Aside from the level of heat treatment and fermentation, storage conditions such as the amount of oxygen, exposure to sunlight, and the temperature of the room, all have an impact on a food product's phytochemical bioavailability (Cox *et al.* 2012). Toasting and natural fermentation would be commendable cultural food processing experiences for increasing the TPC of oat.

Table 1. Effect of traditional processing methods on TPC (mg GAE/g), TFC (mg CE/g), and DPPH percent inhibition (%) of white-colored, black-colored, and Goslin oat varieties

Oat varieties	Processing methods	TPC	TFC	DPPH percent inhibition
White	Raw (control)	1.75 ± 0.01 ^c	0.69 ± 0.02 ^c	13.4 ± 0.12 ^c
	Toasted	2.17 ± 0.08 ^b	0.60 ± 0.03 ^c	15.2 ± 0.06 ^b
	Fermented – 24 h	2.55 ± 0.04 ^a	1.14 ± 0.04 ^a	16.6 ± 0.16 ^a
	Fermented – 48 h	2.22 ± 0.05 ^b	0.93 ± 0.03 ^b	15.9 ± 0.20 ^b
	CV	14.17	26.77	8.1
Black	Raw (control)	1.88 ± 0.02 ^c	0.75 ± 0.02 ^c	18.16 ± 0.09 ^b
	Toasted	2.27 ± 0.06 ^b	0.71 ± 0.03 ^c	18.94 ± 0.04 ^b
	Fermented – 24 h	2.68 ± 0.07 ^a	1.36 ± 0.01 ^a	19.54 ± 0.05 ^a
	Fermented – 48 h	2.23 ± 0.06 ^b	1.05 ± 0.09 ^b	19.14 ± 0.04 ^a
	CV	13.57	29.2	2.8
Goslin	Raw (control)	1.61 ± 0.05 ^b	0.52 ± 0.02 ^b	11.2 ± 0.16 ^c
	Toasted	2.10 ± 0.18 ^{ab}	0.52 ± 0.08 ^b	14.9 ± 0.08 ^c
	Fermented – 24 h	2.45 ± 0.05 ^a	0.93 ± 0.03 ^a	16.1 ± 0.08 ^a
	Fermented – 48 h	1.98 ± 0.12 ^{ab}	0.82 ± 0.05 ^a	15.3 ± 0.12 ^b
	CV	17.61	29.49	13.7

The values represent the mean ± standard error (SE) of three replicates. Means with a different letter in the same row differ significantly.

In this study, total flavonoid decrement was observed by toasting even though statistically insignificant. According to Sandhu *et al.* (2017), the toasting of different oat cultivars led to a decrease in TFC by 23–40.1%. In buckwheat, toasting at 120 °C for 40 min caused a 33% decrease in flavonoids whereas, toasting at 160 °C for 30 min decreased total flavonoids by 15.9% (Qin *et al.* 2010; Zhang *et al.* 2012). The decrease in TFC after toasting could be attributed to the heat sensitivity of flavonoids compounds (Zhang *et al.* 2019). Most flavonoid compounds are thermally sensitive and may degrade (Mazumder *et al.* 2020). A significant ($p < 0.05$) increment of the total flavonoids was also observed which is in the range; 34.8–81.3% for all oat varieties. TFC increased in 24 h fermented flour, similar to that of TPC. TFC increment was indicated by Wang *et al.* (2014) in their study of fermentation effect on walnut, chestnut, and lotus seeds.

The DPPH percent inhibition of oats was used to determine their ability to quench reactive species. The antioxidant activities of all oat varieties were improved significantly ($p < 0.05$) upon toasting. It increased by 4.2–33%, with Goslin oat showing the highest increment. According to Sandhu *et al.* (2017), the toasting of oats at 115 °C for 3 h, increased the total antioxidant activity by 29.1–53.6% and Xu *et al.* (2009) reported increments of oats total antioxidant activity by 82.2% upon toasting. Maillard reaction products, which may result from the reaction of amino acids and reduced sugars when cereal products are heated, release compounds such as 5-hydroxymethyl-2-furaldehyde, which is known for its high antioxidant properties and could be one of the reasons for the increase in total antioxidant levels after toasting (Dueñas *et al.* 2006). Natural fermentation also improve significantly ($p < 0.05$) the antioxidant activity by

7.6–43.8% and 5.4–36.6% for 24 h and 48 h fermented flours, respectively. The higher DPPH percent inhibition values may be explained by oats' high antioxidant constituents and their cumulative synergistic action. The importance of antioxidants in human health is attributed to their ability to safeguard from oxidative damages such as atherosclerosis, diabetes, arthritis, cancer, and other aging diseases (Nambi *et al.* 2017; Ahn-Jarvis *et al.* 2019). Both raw and processed oats in this study showed a high antioxidant composition and it would further be amplified through the traditional processing methods.

3.2 Effect of Toasting and Fermentation on Functional Properties

Table 2 presents the functional properties of raw, toasted, and fermented oat flours and they exhibited a significant ($p < 0.05$) change upon the processing methods.

The results shown in Table 2 indicated toasting significantly ($p < 0.05$) reduced the bulk density (BD) by 9.6–18.7%, when heated, the link between macronutrients such as starches and proteins breaks, causing the food structure and configuration to deform. As a result, holes were created in its structure, causing it to expand in volume while retaining mass, resulting in a decrease in BD. It is an essential functional property of powders that has an immediate impact on packaging. It also specifies physical properties such as cohesion and porosity, which can have an impact on flow ability and storage stability. Because the BD of the toasted oats was low, they could easily be combined with other food flours to produce a nutritionally improved composite. The current study is in line with Sandhu *et al.* (2017) report, a decrease of BD of oats from 31 to 44% after toasting. For all varieties of oats, natural fermentation reduced the BD significantly ($p < 0.05$). Fermentation for 24 h reduced the BD by 16.4% for the white-colored oat, 20% for the black-colored oat, and 15.5% for the Goslin. Further decrements were shown by 48 h fermentation, 17.8% for the white-colored oat, 22.7% for the black-colored, and 22.5% for the Goslin. As shown in Table 2, the longer the fermentation period, the lesser the BD of the samples become. The current result was comparable to the outcomes of Oladeji *et al.* (2018) and Abd Elmoneim *et al.* (2005), who described a significant reduction in BD upon fermentation of quality protein maize flours and sorghum flour, respectively. Thus, natural fermentation of oats flour can be considered as a beneficial traditional processing method for preparing foods with low BD.

The water absorption capacities (WAC) of toasted oat flours were relatively high when compared to fermented and raw oat flours. WAC decreased 87.3–92.7% up on toasting. According to Sandhu *et al.* (2017), the toasting of oats led to an increase in WAC up to 51.4%. WAC increases due to structure deformity and the formation of holes in the matrix, which allows water to rise via capillary action (Wani *et al.* 2016). According to Abbey and Ibeh (1988), an increase in WAC is also linked to an increase in amylose leaching and a loss of crystalline starch structure. This effect could be caused by the weak interaction of amylose and amylopectin as a result of toasting (Iwe *et al.* 2016). The high WAC of toasted oat flours implies that they can be used to make sausage, dough, processed cheese, and bakery products (Butt and Rizwana 2010). Natural fermentation, on the other hand, reduced water absorption capacity though statistically insignificant ($p > 0.05$). The difference in WAC between raw and

fermented flours could be credited to changes in protein content, the degree to which they interact with water, and their conformational structure induced during fermentation (McWatters *et al.* 2003). WAC is an essential parameter for flours used for the baking purpose (Awuchi *et al.* 2019). Because the added moisture slows the rate of staling, high water absorption is typically needed for baked products (Novie *et al.* 2018). A WAC of 1.25 ml/g or higher is a good indicator of bakery property (Giami and Alu 1994). As a result, all of the raw and processed oat flour analyzed in this study suggests oats could be an excellent functional ingredient in bakery products.

Oil absorption capacity (OAC) differs markedly among processing methods. For all oat varieties, toasted flours showed the highest increase (69.1–76%) in OAC, similar to this study, heating increased the OAC of cowpea flour (Ma *et al.* 2011). The increase in OAC of the toasted sample could be attributed to the denaturation and detachment of protein components, exposing outside the nonpolar side of the protein molecule (Akaerue and Onwuka 2010). Different factors influence OAC, which include starch-protein-lipid bindings, polypeptide sequences, macromolecule conformational features, and the amount of nonpolar amino acids (Chandra and Samsher 2013). However, the main factor influencing OAC is a protein or amino acid that contains both hydrophilic and hydrophobic components. Through hydrophobic interactions, nonpolar amino acid side chains can interact with lipid hydrocarbon chains (Chandra and Samsher 2013). Because oil enhances tastiness, OAC is commonly used to predict product palatability Shah *et al.* (2016) and maintains flavor (Aremu *et al.* 2007). The OAC of raw oat flours was lower than that of toasted and fermented oat flours, which is preferred in the development of food products requiring minimal oil absorption. The higher OAC of processed oat flours would also be beneficial in the preparation of foods that requires high oil holding foods like cookies and bakery products.

After toasting, the water solubility index (WSI) reduced significantly ($p < 0.05$) for the two oat varieties, black-colored oat, and Goslin. It led to a decline of 7.1–31.2%. The WSI is proportional to the extent of soluble solids and is commonly taken as an indicator of starch molecule disintegration and dextrinization (Silva *et al.* 2009). However, natural fermentation significantly amplifies the WSI of the flours for all varieties of oats. It led to an increase by 10.7–48.8% through 24 h fermentation and by 24.7–55.6% via 48 h fermentation. High solubility indicates high leaching and a non-covalent bond between molecules within the flour (Onitilo *et al.* 2007). According to Onweluzo and Nwabugwu (2009), the likely cause of the increase in WSI by natural fermentation is the degradation of high molecular weight carbohydrates and proteins during fermentation to simpler and more soluble constituents.

Table 2. Effect of traditional processing methods on BD (g/ml), WAC (ml/g), OAC (ml/g), WSI (%), FC (%), and FS (%) of white-colored, black-colored and Goslin oat varieties

Oat variety	Processing methods	BD (g/ml)	WAC (ml/g)	OAC (ml/g)	WSI (%)	FC (%)	FS (%)
	Raw (control)	0.73 ± 0.02 ^a	1.66 ± 0.03 ^b	1.72 ± 0.02 ^c	11.35 ± 0.27 ^c	15.71 ± 0.46 ^a	10.82 ± 0.46 ^a
White	Toasted	0.66 ± 0.02 ^{ab}	3.11 ± 0.04 ^a	2.95 ± 0.03 ^a	10.54 ± 0.04 ^c	8.48 ± 0.34 ^b	6.65 ± 0.34 ^b
	Fermented – 24 h	0.61 ± 0.01 ^b	1.62 ± 0.01 ^b	1.86 ± 0.02 ^b	12.56 ± 0.24 ^b	7.30 ± 0.12 ^b	6.38 ± 0.12 ^b
	Fermented – 48 h	0.60 ± 0.03 ^b	1.60 ± 0.03 ^b	1.90 ± 0.01 ^b	15.16 ± 0.14 ^a	5.25 ± 0.02 ^c	2.79 ± 0.02 ^c
	CV	9.3	38.16	24.39	14.9	44.91	44.91
	Raw (control)	0.75 ± 0.01 ^a	1.73 ± 0.01 ^b	1.75 ± 0.04 ^c	12.09 ± 0.28 ^c	14.07 ± 0.10 ^a	11.09 ± 0.25 ^a
Black	Toasted	0.61 ± 0.01 ^b	3.28 ± 0.05 ^a	2.96 ± 0.01 ^a	8.32 ± 0.11 ^d	11.26 ± 0.22 ^b	9.49 ± 0.17 ^b
	Fermented – 24 h	0.60 ± 0.01 ^{bc}	1.56 ± 0.03 ^c	1.89 ± 0.01 ^b	13.60 ± 0.28 ^b	8.11 ± 0.09 ^c	5.68 ± 0.23 ^c
	Fermented – 48 h	0.58 ± 0.00 ^c	1.51 ± 0.01 ^c	1.94 ± 0.02 ^b	15.08 ± 0.08 ^a	5.66 ± 0.23 ^d	5.05 ± 0.10 ^c
	CV	11.23	38.03	23.64	21.55	34.02	34.04
	Raw (control)	0.71 ± 0.01 ^a	1.65 ± 0.01 ^b	1.75 ± 0.04 ^c	10.23 ± 0.21 ^b	14.26 ± 0.21 ^a	9.90 ± 0.07 ^a
Goslin	Toasted	0.60 ± 0.01 ^b	3.18 ± 0.07 ^a	3.08 ± 0.07 ^a	8.94 ± 0.22 ^c	8.11 ± 0.07 ^b	8.09 ± 0.07 ^b
	Fermented – 24 h	0.60 ± 0.01 ^b	1.64 ± 0.03 ^b	1.91 ± 0.02 ^{bc}	15.22 ± 0.23 ^a	5.67 ± 0.21 ^c	5.32 ± 0.06 ^c
	Fermented – 48 h	0.55 ± 0.01 ^b	1.55 ± 0.04 ^b	2.01 ± 0.03 ^b	15.92 ± 0.24 ^a	4.57 ± 0.25 ^d	4.35 ± 0.06 ^d
	CV	10.11	35.57	25.32	25.34	48.24	33.30

The values represent the mean ± standard error (SE) of three replicates. Means with a different letter in the same row differ significantly.

The foaming capacity (FC) of oats flours has been shown in Table 2. It changes significantly ($p < 0.05$) for raw and processed oats. All processing methods used in this study reduced the FC. Toasting decreased by 20–46%, showing an extreme decrease in white-colored oat, and natural fermentation for 24 h decrease 42.4–60.2%, while fermentation for 48 h decreased the FC by 59.8–68%. Because of the soluble proteins on the surface, flours can produce foams (Adebowale and Lawal 2003). FC is primarily reliant on the availability of proteins to form an interfacial film by encapsulating surface tension, which upholds the gas pockets and the decelerating of the combination (Shah *et al.* 2016). The reduction in FC observed after toasting could be then due to the denaturation of the protein molecules during toasting (Jan *et al.* 2019). According to Kouakou *et al.* (2013), the native protein has a greater ability for foaming than the denatured one. Processing methods, pH, protein type, surface tension, and viscosity were the function variables to the FC (Lech 2016). Oat is the only grain with a higher concentration of avenalin (80%) as the primary storage protein (Ahmad *et al.* 2015). Where foaming is desired, i.e. for oat-based food products with a softer texture and lighter mouthfeel, raw oats flour could be a good alternative to toasted and naturally fermented flours.

The foaming stability (FS) of raw and processed oat flours differed significantly ($p < 0.05$). The raw oat flour had the highest foam stability, while the 48 h fermented flours had the lowest foaming stability. Toasting decreased the FS by 14.4–38.5%, while 24 h fermentation decreased FS by 41–48.8%, and 48 h fermentation decreased FS by 54.5–74.2%. A similar decrement in FS by heat processing has been reported by Khalid and Elhardallou (2015) for the cowpea flour. Toasted oats have a lower FS value because denatured proteins have a lower FS value than the native proteins (Kouakou *et al.* 2013). Because FS is dependent on thin-film-encapsulated gas bubbles remaining intact, only highly surface-active solutes can produce stable foams (Cherry and McWatters 2012). High-foaming flours create large air pockets surrounded by a protein film. The ability to create stable foam is essential when making sponge cakes, creamy condiments, and frozen desserts (Adelakun *et al.* 2012). When compared to raw oat flour, roasted and fermented oat flour may not be the best ingredient to use in such formulations. As a result, processed oat flours have a low likelihood of being used in foods that require stable foam formation.

3.3 Correlation Between Phytochemicals and DPPH Antioxidant Activity of Oats

As shown in Table 3, the correlation between DPPH antioxidant activities and phytochemicals contents (TPC and TFC) were evaluated for the raw, toasted, 24 h fermented, and 48 h fermented oats. The correlation coefficient varied from weak to very strong among the processing methods.

Table 3. Correlation coefficient for TPC vs. DPPH antioxidant activity, and TFC vs. DPPH antioxidant activity for the raw and processed oats

Oats	r-values for TPC vs. DPPH antioxidant activity	r-values for TFC vs. DPPH antioxidant activity
Raw	0.91	0.86
Toasted	0.31	0.67
Fermented – 24 h	0.77	0.88
Fermented – 48 h	0.47	0.67

Evans (1996) classified correlation strengths as “very weak,” “weak,” “moderate,” “strong,” and “very strong.” The current study showed a highly significant positive correlation between TPC and DPPH antioxidant activity in raw oats ($r = 0.91$, $p < 0.05$). While the correlations between TPC and DPPH percent inhibition for toasted, 24 h fermented, and 48 h fermented samples were 0.31, 0.77, and 0.47, respectively, these values overlapped on the weak, strong, and moderate ranges of correlation. Sandhu *et al.* (2017) also reported a very strong positive correlation between TPC and DPPH percent inhibition ($r = 0.93$, $p < 0.05$) for all raw oat varieties. Similar outcomes were also found by (Lahouar *et al.* 2014) and (Kerienè *et al.* 2015). Consequently, TPC and DPPH percent inhibition were found to be strongly correlated ($p < 0.01$).

The correlation between TFC and DPPH percent inhibition in raw oats was also significant and very strong ($r = 0.86$, $p < 0.05$). Correlation coefficients for processed oats were also classified as strong and very strong. According to Sandhu *et al.* (2017), TFC and antioxidant capacity of oats were positively correlated with an r -value of 0.71. The highest TPC and TFC were accompanied by the highest DPPH percent inhibition values. Hence, this result proposes the total phenolic and flavonoid compounds are the main sources of their antioxidant activities.

4 Conclusions

Toasting and natural fermentation brought a change in the phytochemicals and functional properties of oats. Toasting showed an increment of total phenolic content and a decrement of total flavonoids. It also modified the functionality of oats, particularly by increasing oil and water absorption capacities and reducing the bulk density and water solubility index. At the same time, natural fermentation enhanced the phytochemicals prominently. Fermented flours were found to have higher antioxidant capacity than unfermented flours. Optimal fermentation and thermal treatment should be established to maximize its nutritional benefits. Characterizations on the nutritional and phytochemical properties of indigenous and underutilized Ethiopian food crops should also be encouraged to diversify the food preference and diet of the community.

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