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Use of extruded finger millet flour to enhance quality characteristics of barley chapatti

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Abstract
In present study, nutritious chapatti was prepared from the barley flour (BF) by incorporating extruded finger millet flour (EF). Different blends of composite flour were prepared by adding EF at a level of 10, 20 and 30g/100g in BF and rheological, textural and sensory quality of composite dough and chapatti were evaluated. Enrichment of BF with EF resulted in improved nutritional, textural, rheological and sensory characteristics of composite as compared to native flour (BF). Composite dough exhibited high extensibility than BF dough. The chapatti prepared by incorporating 20% of EF in BF showed higher puffing along with the high overall sensory score in comparison to control barley chapatti. Barley-extruded finger millet flour composite chapatti has enhanced nutritional value. Utilization of barley in the chapatti is a promising way to add barley in the human diet.

Keywords: Barley, extruded finger millet, chapatti, rheology, sensory properties

Introduction
Barley (*Hordeum vulgare* L.) is known as functional grain as it contains bioactive compounds, B-complex vitamins, tocotrienols, tocopherols and β-glucan (Madhujith *et al*., 2006) [19]. β-glucans that are present in large quantities are soluble dietary fibre with the potential to reduce blood cholesterol level and increase water holding capacity (Mudgil et al., 2016) [24]. Moreover, these β-glucans also prevent or reduce some pathologies such as diverticular and heart disease, colon cancer, and type-2 diabetes, improve lipid metabolism and promote weight loss by increasing a sense of satiety (Baik and Ullrich, 2008; Izydorczyk and Dexter, 2008) [2, 13]. Considering the health benefits, the Food and Drug Administration recommends that daily intake of 3g of β-glucan reduces the risk of coronary heart disease by lowering blood cholesterol (Sharma and Gujral, 2014) [32]. Due to these health benefits, consumption of barley in food should be encouraged. Presently, very little barley is utilised for human consumption because of hulled nature, difficulties in milling and lack of gluten protein.
The physical and chemical properties of the kernel like fibre, colour, texture, hardness etc. present challenges for using barley as food. Barley can be substituted with other cereals either raw or extruded. Finger millet (*Eleusine coracana* L.) is also a nutritious coarse cereal; has high protein, crude fibre, calcium and phenolic content than other cereals like wheat (Chetan and Malleshi, 2007) [6]. High phenolic content has cholesterol-lowering properties and assists in controlling the glucose homeostasis by inhibiting pancreatic amylase and intestinal α-glucosidase activity, thus beneficial in managing type-2 diabetes (Krishnan *et al*., 2011) [17]. The incorporation of extruded finger millet flour effects the technological, textural and sensory properties of bread (Patil *et al*., 2016) [26]. Extrusion cooking is a versatile, cost-effective process that uses high temperature, pressure and shear forces to alter the structure of a material and can be used for the production of various types of breakfast cereals and snacks (Eastman *et al*., 2001) [9]. The extractability of dietary fibres of extruded product is more as compared to raw material (Sharma and Gujral, 2013). Extruded wheat flours is a useful alternative to pregelatinized starch and hydrocolloids that increase the bread output in bakery production (Martinez et al., 2013) [21].
Barley is gaining popularity in utilising as food for human consumption in different baked and extruded products such as cookies, chapattis, bread and extruded snacks etc. (Gujral and Gaur, 2002; Sharma and Gujral, 2013) [11, 33]. Chapattis are a good alternative to make use of barley as they have been a staple food of Indian subcontinent and parts of the Middle East for

hundreds of years (Gujral *et al*., 2008) [12]. Hence, chapatti would be better food to add β-glucan of barley and nutrients of extruded finger millet in the human diet. Moreover, incorporation of extruded finger millet flour could be the best alternative to overcome the problem of raw barley flour. On this backdrop, the present investigation was commenced to evaluate the rheological, textural and sensory properties of composite chapatti prepared from barley and extruded finger millet flour.

Materials and Methods

Materials

Barley and finger millet grains were procured from the local market of New Delhi, India. Grains were cleaned and milled separately in hammer mill and screened through BS 30 mesh sieve to get whole grain flour having a uniform particle size.

Extrusion processing of finger millet flour

Sufficient amount of water was added in the finger millet flour to attain desired moisture content (21.3% wb). The flour was fed into the co-rotating and intermeshing twin-screw extruder (BTPL, Kolkata, India) with L/D ratio 20:1 and die diameter of 3 mm. The feed rate of material and screw speed were set at 8kg/ h and 375 rpm, respectively. Finger millet flour was extruded at 130 °C barrel temperature. The expelled hot extrudates were dried at 60 °C in tray dryer for 2 hours. The dried extrudates were ground in a mill grinder to form a powder and pass through 30 mesh screen.

Preparation of barley-extruded finger millet flour blends

Three different blends of barley-extruded finger millet composite flour were formed by incorporating extruded finger millet flour (EF) at 10, 20 and 30% level of substitution in barley flour. The composite flour containing EF at 10, 20 and 30% levels were labelled as BF (BF10, BF20 and BF30). The corresponding chapatti prepared from composite flour were designated as BC (BC10, BC20 and BC30). Dough and chapatti of barley flour were taken as reference.

Chapatti preparation

Preliminary trials were carried out to determine the quantity of water required to form a non-sticky and consistent dough that could be easily rolled and sheeted to make chapatti. The optimum amount of water required to develop a dough was reported as the water absorption (%). Optimum water absorption of native barley flour was 80g/100g, whereas, flour blends containing EF at 10, 20 and 30g /100g was 84, 85 and 86g /100g, respectively. The flour (30g) was mixed with an optimum quantity of water and kneaded in dough mixture (Philips, India) for about 3 minutes. The dough was rested for half an hour to attain desired structural formation. The dough ball (30g) was rolled into a thin and flat round sheet (12cm diameter) using a chapatti maker (Sunflame, India). This raw chapatti was placed on a preheated flat iron griddle and baked from both the sides until the chapatti puffed. The baking time varied from 70 to 75 sec. The chapatti was allowed to cool at room temperature and then wrapped in aluminium foil for further analysis. The chapattis were analysed for sheetability and puffing (Gujral *et al*., 2008) [12].

Pasting properties of flour

Pasting properties of the composite flour were studied using a Rapid Visco Analyser (RVA) (MCR 52, Anton Paar, Austria) (AACC, 2000). A flour sample of 3.5 g (14% moisture basis) was held in RVA at 50 °C for 1 min and stirred at 960 rpm. Then temperature rises from 50 °C to 95 °C with constant stirring at 160 rpm, holding the sample at 95 °C for 2.5 min followed by cooling to 50 °C @ 12 °C/min, with holding at 50 °C for 2 min. The pasting time (PTI), temperature (PT), peak viscosity (PV), breakdown viscosity (BV), final viscosity (FV), setback trough viscosity (SBT) and setback peak viscosity (SBP) of different composite flours were assessed from the viscogram using Thermocline Version 2.2 software (Newport Scientific, Warriewood, NSW and Australia).

Textural properties of dough

Dough texture was measured in terms of dough strength, extensibility and stickiness by using Texture analyser. The dough strength was assessed as per the AACC international method: 74-10.02 (AACC, 2000) [1]. Texture analyser was equipped with 49N load cell and cylinder probe of 36mm diameter with pre and post-test speed of 1mm/s and 10mm/s, respectively.

The extensibility of dough was measured by Texture analyser (TA-XT2, Stable Micro Systems, Surrey, UK) equipped with modified Keiffer extensibility rig (Keiffer *et al*., 1998) [16] in which the load cell of 49 N was used with pre-test speed of 2mm/s, post-test speed of 10mm/s, a distance of 75mm, trigger force of auto- 0.049N of data rate acquisition of 200 points per sec. Dough stickiness was measured using Chen-Hoseney stickiness rig (Chen and Hoseney, 1995) [5]. Each dough sample was analysed in 15 replications and computations were done using "Texture Expert" software.

Rheology of barley dough composites

Rheological/ viscoelastic properties of dough formulations were evaluated by Anton Paar- CCR 52 Rheometer (Anton Paar, GmbH, Germany), equipped with PP50 (50 mm diameter) parallel plate geometry. The dough samples were carefully placed on the lower plate and the upper plate was allowed to move downward until the distance between plates reached to 1mm. After loading, the sample was rested for 5 mint to remove residual stress. Extra dough was trimmed and a thin layer of paraffin was applied over the exposed edges of dough sample to avoid dehydration during measurement. For measurement of dynamic viscoelastic properties, firstly the linear viscoelastic range of the samples were obtained with a strain sweep (0.01-100%) at a constant frequency of 1Hz followed by an analysis of dynamical oscillatory frequency sweep at 25 °C using the parallel plate geometry (PP50) in controlled- strain mode at a frequency range from 0.01 to 100Hz. The storage modulus (G'), loss modulus (G") and damping factor as a function of frequency were continuously accessed throughout the test. The value of G′ and G″ were used to calculate the complex modulus ($(G^* = G'^2 + G''^2)^{1/2}$) (Sun *et al*., 2020) [38] and loss tangent ($\tan \delta = G''/G'$).

Same rheometer was used to conduct the creep test at 25 °C and constant shear stress was applied for 300s according to linear viscoelastic range. Then the shear was removed swiftly during the recovery phase and the sample was rested for 600s to recover the elasticity (instantaneous and retarded) of the deformation. The creep and creep recovery parameters were calculated by the RheoCompass software of the rheometer. All the experiments were performed in triplicates.

Sensory evaluation of chapatti

The sensory properties (color, taste, texture and overall acceptability) of the composite chapatti were evaluated by using a nine-point hedonic scale. The samples were coded with random three-digit numbers. Twenty semi-trained panellists from Division of Food Science and Post-Harvest Technology, ICAR-Indian Agricultural Research Institute, New Delhi were selected and instructed to evaluate each sample for sensory attributes as per the method of Lu et al. (2010) [18] with minor alterations.

Statistical analysis

Preliminary trials were performed to evaluate the effectiveness of incorporation of EF at different levels in the barley flour. Analysis of variance (ANOVA) was performed by using SAS (9.4) software to investigate the significant difference among treatments. Pair-wise comparison of treatments were examined by Tuckey's HSD test, used at a 5% level of significance. The linear association among response was determined by Pearson's Correlation Analysis.

Results and Discussion

Pasting properties of composite flour

The results of the pasting profile revealed that the barley had a maximum value of pasting properties and the value decreases with the addition of EF (Table 1). The pasting profile of barley was high due to the presence of high β-glucan. Yildiz *et al*. (2013) [42] reported high pasting profile of composite wheat containing a high amount of dietary fibre (oat, pea, lemon and apple). The barley flour transformed into paste at 66.38 °C (in 3.769 min) with PV, FV and HV of 5923.94, 7050.88 and 3206.79 cP, respectively. The value of PTI, PV, FV, HV, BV, SBT and SBP reduced significantly with the incremental addition of EF. Similarly, a decrease in values of pasting properties was observed by Meng *et al*. (2019) [23] in mung-wheat composite flour containing extruded mung flour. The extrusion cooking led to the expansion and breakdown of starch granules. During extrusion cooking, the physicochemical properties of starch changes as a result of morphological changes of the starch granules and the degree of gelatinization (Yeh and Li, 1996) [41].

Table 1: Effect of substitution of extruded finger millet on pasting properties of barley composite flour

Pasting Properties	Composite				
	Control	BF10	BF20	BF30	SE
Pasting time (min.)	3.769^b	3.652^b	3.551^c	3.428^d	0.004
Pasting temperature (^{0}C)	66.38^a	65.67^a	65.09^a	64.38^a	1.048
Peak viscosity (cP)	5923.94^a	4709.81^b	3267.47^c	2475.64^d	63.844
Final viscosity (cP)	7050.88^a	5737.65^b	4311.32^c	3565.95^d	63.656
Hold viscosity (cP)	3206.79^a	2686.29^b	1966.92^c	1632.56^d	27.365
Breakdown viscosity (cP)	2717.15^a	2023.52^b	1300.55^c	843.08^d	41.941
Setback trough viscosity (cP)	3844.09^a	3051.36^b	2344.4^c	1933.39^d	20.242
Setback Peak viscosity (cP)	1126.94^a	1027.84^a	1043.85^a	1090.31^a	67.767

Values within the same row followed by same superscript letters are not significantly different (p > 0.05); Control: 100% barley flour; BF: Extruded Finger millet flour; 10, 20 & 30: Percent level of substitution; SE: Standard error

PT and SBP were not significantly (p>0.05) affected by the addition of EF. Low value of SBT indicated low retrogradation of starch particles as a result of degradation of amylose and/ or the complex formation between amylose and other molecules like lipids (Seetapan *et al*., 2019) [31]. Therefore the use of EF can be beneficial for chapatti or food products in which syneresis or staling is a major quality problem. Similar decrease in pasting properties (peak, final and setback) was observed by Palabiyik *et al*. (2016) [25]. The setback viscosity related to starch staling, thus, lower the value, less is the starch staling (Collar, 2016) [7].

Dilution of starch could be the reason for the decrease in pasting properties. The starch content directly related to pasting properties as the higher the amount of starch present, the higher the pasting properties (Ragee and Abdel-Aal, 2006) [28]. In general, control had higher pasting properties as compared to composites containing EF. The decrease in pasting properties is due to the increase in insoluble fibre content (Yadav *et al*., 2010) [40]. Sandrin *et al*. (2017) [30] reported a decrease in the pasting properties of extruded flour. This decrease in pasting properties due to degradation of starch granules upon extrusion and hence with the incremental addition of extruded flour results in lowering the pasting profile of barley composite flour.

Dough texture

Dough stickiness increased significantly with the addition of EF (Table 2). A high stickiness value could be influenced by the high water absorption of pre-gelatinized EF. There was no difficulty in dough handling with an increase in stickiness value until 20% level of substitution. The composite flour converted into sticky mass after 20% substitution of EF and the dough mass was difficult to handle and roll. Similar increase in stickiness was observed by Patil *et al*. (2016) [26] in composite bread containing extruded finger millet. The stickiness of dough was increased with increasing substitution of flaxseed flour to refined wheat flour (Marpalee *et al*., 2014) [20]. Work of adhesion for control was 0.12g.sec and increased with substitution of EF.

Table 2: Effect of substitution of finger millet flour on uniaxial textural properties of barley composite dough

Textural properties	Composite				
	Control	BF10	BF20	BF30	SE
Stickiness (g)	4.49^c	4.89^c	6.34^b	14.84^a	0.149
Work of Adhesion (g.sec)	0.12^c	0.14^c	0.19^b	0.59^a	0.010
Dough Strength/Cohesiveness (mm)	0.42^b	0.43^b	0.40^b	0.71^a	0.010
Resistance to Extension (g)	40.84^a	17.42^c	22..18^b	21.27^b	1.715
Extensibility (mm)	7.59^a	9.22^a	8.24^a	8.66^a	0.226

Values within the same row followed by same superscript letters are not significantly different (*p*>0.05); Control: 100% barley flour; BF: Extruded Finger millet flour; 10, 20 & 30: Percent level of substitution; SE: Standard error

Analogous trend was observed in dough strength/ cohesiveness, resistance to extension and extensibility. The value of dough strength/ cohesiveness of BF10 (0.43mm) and BF 20 (0.40mm) were not significantly different from control but value for BF30 (0.71mm) was significantly more than control (0.42). Resistance to extension was greatly reduced with incorporation of EF. However, among composite blends, BF20 (22.18g) had higher resistance to extension but the value was decreased by 45.69% as compared to control (40.84g). Dough extensibility is an indicator of viscosity and the desirable dough should have high extensibility value to promote high gas retention. Control dough exhibits lower value of extensibility (7.59) as compared to composite blends. However, BF20 showed a minimum value of extensibility (8.24mm) among composite blends containing different levels of EF.

Rheology of composite dough using small deformation test

Oscillatory measurement provides useful information about the viscoelastic characteristics of dough. The complex modulus (G*), storage modulus (G′), loss modulus (G″) and loss tangent (δ) were used to measure the stiffness and elastic versus viscous behaviour. The values of these parameters of the composites were significantly altered as compared to control (Table 3). Composite dough presented a higher value of G′ than G″, indicating a dominance of elastic behaviour over viscous behaviour.

Table 3: Viscoelastic parameters of corn, pearl millet and barley composite

Dough	Storage Modulus (G′) [Pa]	Loss Modulus (G″) [Pa]	Tan δ [Degree]	Complex modulus [Pa]
Control	2.61E+04^{a}	1.80E+04^{b}	0.825^{a}	3.17E+04^{b}
BF10	2.15E+04^{b}	1.89E+04^{b}	1.207^{b}	2.86E+04^{c}
BF20	2.52E+04^{b}	1.99E+04^{a}	1.009^{b}	3.21E+04^{b}
BF30	2.98E+04^{a}	2.11E+04^{a}	0.856^{a}	3.65E+04^{c}

Values within the same column followed by same superscript letters are not significantly different (p>0.05); Control: 100% barley flour; BF: Extruded Finger millet flour; 10, 20 & 30: Percent level of substitution

The thermomechanical modification of finger millet flour by extrusion cooking leads to a significant change in viscoelastic parameters of the composite. The value of G′, G″ and G* increases and tan δ decreases with incremental substitution of EF. Martinez *et al*. (2014) [22] also observed an increase in G′, G″ and G* and a reduction in tan δ when extruded rice flour was added to the formula. The value of storage modulus for control was 2.61E+04 and increased from 2.15E+04 to 2.98E+04 with addition of EF at a level of 10% to 30%. The reason could be the presence of a high quantity of pregelatinized starch in extruded flour as compared to unextruded flours (Slade and Levine, 1994) [37]. In BF 20, the value of G′ decreased by 3.44% and G″ increased by 10.56% in contrast with control.

Loss tangent (tan δ), the ratio of viscous and elastic response of material indicates the elasticity of the material. Low value of tan δ means the dough is more elastic (Puppo *et al*., 2005) [27]. The composite had a high value of tan δ as compared to control (0.825) and the value declined from 1.207 to 0.856 with an increasing level of EF. Complex modulus (G*) is a good indicator of the stiffness of viscoelastic material. The complex modulus of control was 3.17E+04 and increased by 1.26% and 15.14% with 20% and 30% level of EF substitution, respectively. It shows that BF30 was stiffer than BF20.

Table 4: Effect of substitution of finger millet of composite dough flour on creep and creep recovery

	Sample	Control	BF10	BF20	BF30
Creep Phase	J_{max} (1/Pa)	2.09E-04^{d}	9.23E-04^{a}	4.89E-04^{c}	7.09E-04^{b}
	J_0 (1/Pa)	2.52E-05^{b}	4.00E-05^{a}	4.19E-05^{a}	3.00E-05^{b}
	J_m (1/Pa)	6.41E-05^{c}	1.55E-04^{b}	2.60E-04^{a}	2.37E-04^{a}
	λ (s)	8.4479^{b}	10.971^{a}	10.05^{b}	13.238^{a}
	J_0 (1/Pa)	6.60E-05^{a}	5.56E-05^{b}	4.44E-05^{c}	5.66E-05^{b}
Recovery Phase	J_m (1/Pa)	1.26E-04^{a}	1.27E-04^{a}	4.16E-05^{b}	6.68E-05^{b}
	λ (s)	165.96^{a}	71.209^{d}	132.48^{b}	94.304^{c}
	J_e (1/Pa)	1.92E-04^{a}	1.82E-04^{a}	8.60E-05^{c}	1.23E-04^{b}
	J_v (1/Pa)	1.72E-05^{c}	7.41E-04^{a}	4.03E-04^{b}	5.86E-04^{b}
	J_e/J_{max} (%)	91.74^{a}	19.72^{b}	17.6^{c}	17.4^{c}
	J_v/J_{max} (%)	8.26^{b}	80.28^{a}	82.4^{a}	82.6^{a}

Values within the same column followed by same superscript letters are not significantly different (p>0.05); Control: 100% corn or pearl millet or barley flour; CF, PF, BF: Extruded Finger millet flour; 10, 20 & 30: Percent level of substitution; J_{max}: creep compliance; J_0: instantaneous compliance; J_m: viscoelastic compliance; λ: mean retardation time; J_e: elastic compliance; J_v: viscous compliance; J_e/J_{max}: elastic share of compliance; J_v/J_{max}; viscous share of compliance

Creep recovery test is important for evaluating the behaviour of dough under controlled stress for a prolonged time period. The results of creep and recovery compliance measurements are presented in Table 4. The creep and creep recovery parameters were determined by using Berger's model in terms of creep compliance (J_{max}), instantaneous compliance (J_0), viscoelastic compliance (J_m), mean retardation time (λ), elastic compliance (J_e), viscous compliance, (J_v), elastic share of compliance (J_e/J_{max}), viscous share of compliance (J_v/J_{max}).

The creep compliance (J_{max}) reflects maximum strain at constant stress with time. The maximum creep compliance (J_{max}) and instantaneous creep compliance (J_0) for composites were higher than those for control. The rigidity (firmness) of dough could be characterized by the maximum creep compliance, J_{max} (Wang and Sun, 2002) [39]. It was reported by Wang and Sun (2002) that stronger dough samples which had greater resistance to deformation had smaller creep compliance than softer dough samples. Among composite, BF20 showed smaller creep compliance (4.89E-04), higher instantaneous compliance (4.19E-05) and maximum viscoelastic compliance (2.60E-04). The retardation time (λ) is the time required for the applied stress to decrease to 1/e (approximately 36.5%) of its initial value under constant deformation (Jimenez- Avalos *et al*., 2005) [14]. The mean retardation time of control sample was lower than that of the composite. However, among composite, BF20 showed a lower value of λ (10.05s). In the recovery phase, the parameters reported were elastic compliance (J_e), viscous compliance, (J_v), elastic share of compliance (J_e/J_{max}), viscous share of compliance (J_v/J_{max}). The control had a higher value of J_0 (6.60E-05) and the value decreased significantly with the addition of EF. BF20 had a lower value of J_0. The value of J_m increased with the incorporation of EF. The mean retardation time for BF20 was higher (132.48s) than that of control and other composites. The beneficial effects of EF in the composite dough can be clearly seen by the values of J_e and J_v. Among composites, the value of J_e was higher for BF20 and reserve was observed with respect to J_v The J_e/J_{max} of viscoelastic compliance was 17.6% and J_v/J_{max} of viscoelastic compliance was 82.4% for BF20.

The dough samples substituted with different proportions of EF containing partially gelatinized starch showed different rheological properties. This showed that the starch fraction plays a crucial role in the viscoelastic properties of the dough (Khatkar and Schofield, 2002) [15].

Technology properties of barley composite chapatti

Technological properties of chapatti were evaluated by determining the sheetability and puffing of the chapatti. The results presented in Fig.1. Chapatti from barley flour does not puff as wheat chapatti due to lack of adequate viscoelastic properties of gluten. However, with the incorporation of EF (20%), considerable improvements were noticed as shown in fig.1. Appreciable differences were observed in sheeting and puffing in case of BF20. A significant composite ($p<0.05$) difference was observed with respect to sheetability of composite dough. Inclusion of EF in native flours, significantly ($p<0.05$) improved handling properties and rollability of dough, by providing cohesive properties. The sheetability score of BF20 increased to 65% which was much higher than control (5%). Similarly, puffing score was also increased by three folds as compared to control.

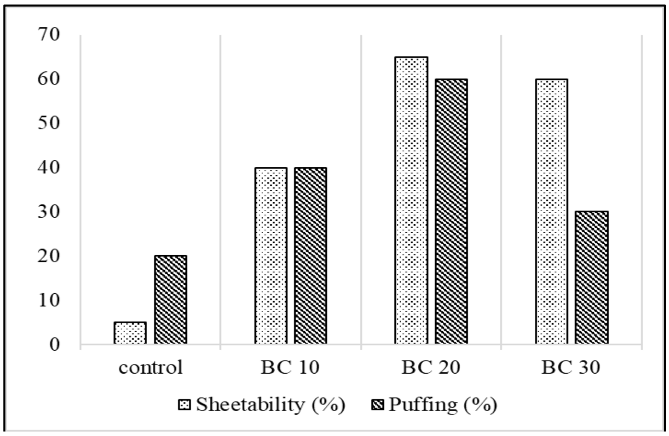

Fig 1: Sheetability and puffing of composite chapattis of barley

Sensory quality of barley composite chapatti

Chapattis from respective composite flours were scored for colour, texture, taste and overall score by nine-point hedonic scale. The results of sensory evaluation of composite chapattis are presented in web diagram (Fig. 2). Colour score was highest for control (9) and BC10 (9) followed by BC20 (8) and BC10 (7). Rehman *et al*. (2007) [29] also observed a similar decrease in colour score of chapatti prepared from composite flour (wheat flour- detoxified Indian vetch). The score for taste and texture was lowest for control (5) and lied in between 6 and 8 for composite chapattis containing EF. However, BF20 showed a higher score for taste and texture along with overall score (8). Higher overall score for composite chapatti with 20% substitution of EF was due to higher preference for taste and texture over the other samples. Bhol and Bosco (2014) [4] found the increase in acceptability score of composite bread substituted with malted finger millet (20g/100g). The composite bread enriched with extruded finger millet flour had high overall acceptability score (Patil *et al*., 2016) [26]. Overall results from sensory studies suggest that EF in the composite can significantly increase the score than corresponding one made from native flour.

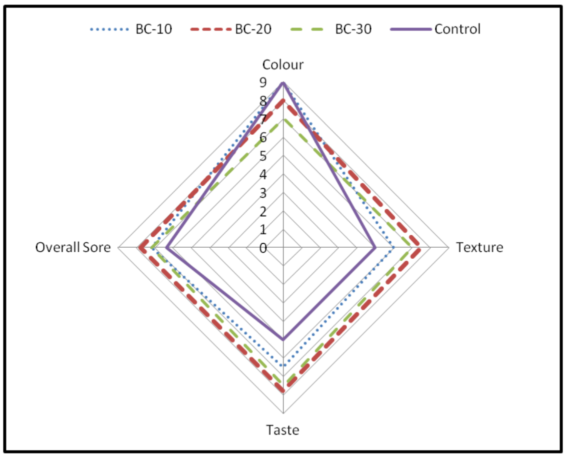

Fig 2: Sensory quality of composite chapattis of barley Control: 100% barley flour; BF: Extruded Finger millet flour; 10, 20 & 30: Percent level of substitution

Table 5: Pearson's correlation coefficients between pasting, technological, textural properties of Barley composite

		Pasting profile of flour							Dough texture							Rheological properties			
		PTI	**PT**	**PV**	**FV**	**HV**	**BV**	**SBT**	**SBP**	**STK**	**WA**	**DS**	**RE**	**E**	**P**	**G′**	**G”**	**G***	**Tan δ**
Pasting profile of flour	PTI	1																	
	PT	0.467^{ns}	1																
	PV	0.984**	0.417^{ns}	1															
	FV	0.987**	0.441^{ns}	0.997**	1														
	HV	0.983**	0.47^{ns}	0.996**	0.996**	1													
	BV	0.980**	0.365^{ns}	0.997**	0.992**	0.987**	1												
	SBT	0.985**	0.412^{ns}	0.991**	0.997**	0.986**	0.990**	1											
Dough texture	SBP	0.136^{ns}	0.362^{ns}	0.062^{ns}	0.139^{ns}	0.096^{ns}	0.032^{ns}	0.174^{ns}	1										
	STK	-0.870**	-0.389^{ns}	-0.806**	-0.793**	-0.800**	-0.806**	-0.782**	0.080^{ns}	1									
	WA	-0.855**	-0.361^{ns}	-0.791**	-0.776**	-0.781**	-0.794**	-0.766**	0.116^{ns}	0.999**	1								
	DS	-0.753**	-0.384^{ns}	-0.648*	-0.642*	-0.644*	-0.647*	-0.636*	0.010^{ns}	0.960**	0.961**	1							
	RE	0.973**	0.406^{ns}	0.989**	0.992**	0.989**	0.983**	0.989**	0.142^{ns}	-0.757**	-0.740**	-0.601*	1						
	E	-0.612*	-0.221^{ns}	-0.646*	-0.666*	-0.642*	-0.646*	-0.682*	-0.324^{ns}	0.418^{ns}	0.394^{ns}	0.241^{ns}	-0.622*	1					
	P	-0.33^{ns}	-0.452^{ns}	-0.420^{ns}	-0.446^{ns}	-0.441^{ns}	-0.400^{ns}	-0.447^{ns}	-0.372^{ns}	-0.131^{ns}	-0.161^{ns}	-0.285^{ns}	-0.447^{ns}	0.471^{ns}	1				
Rheological properties	G′	0.49^{ns}	-0.550^{ns}	-0.516^{ns}	-0.492^{ns}	-0.527^{ns}	-0.506^{ns}	-0.462^{ns}	0.644^{ns}	0.813^{ns}	0.809^{ns}	0.778^{ns}	-0.434^{ns}	0.521^{ns}	-0.341^{ns}	1			
	G”	0.29^{ns}	-0.997**	-0.986*	-0.982*	-0.983*	-0.988*	-0.980*	-0.210^{ns}	0.893^{ns}	0.881^{ns}	0.777^{ns}	-0.971*	0.761^{ns}	0.319^{ns}	0.607^{ns}	1		
	G*	-0.45^{ns}	0.059^{ns}	0.041^{ns}	0.014^{ns}	0.059^{ns}	0.025^{ns}	-0.024^{ns}	-0.915^{ns}	-0.418^{ns}	-0.417^{ns}	-0.423^{ns}	-0.050^{ns}	-0.247^{ns}	0.543^{ns}	-0.861^{ns}	-0.130^{ns}	1	
	Tan δ	0.83^{ns}	-0.701^{ns}	-0.670^{ns}	-0.650^{ns}	-0.678^{ns}	-0.663^{ns}	-0.624^{ns}	0.485^{ns}	0.897^{ns}	0.891^{ns}	0.840^{ns}	-0.598^{ns}	0.616^{ns}	-0.209^{ns}	0.981*	0.750^{ns}	-0.748^{ns}	1

*Significant at p<0.05; ** Significant at p<0.01;ns Non-significant; PT: Pasting temperature; PV: Peak viscosity; FV: Final viscosity; HV: Holding viscosity; BV: Breakdown viscosity; SBT: Setback trough viscosity; SBP: Setback peak viscosity; WA: Work of Adhesion; DS: Dough Strength; RE: Resistance to Extension; E: Extensibility; P: Puffing; PTI: Pasting time; G′: Storage modulus; G”: Loss modulus; G*: Complex modulus; Tan δ: Tangent

Correlation between pasting, textural and rheological properties

The results of the correlation analysis among pasting, textural and rheological properties of barley composites are presented in Table 5. The PTI showed a strong positive correlation with PV (r=0.984, p<0.01), FV (r=0.987, p<0.01), HV (r=0.983, p<0.01), BV (r=0.980, p<0.01), SBT (r=0.985, p<0.01) and negative correlation with STK (r=-0.870, p<0.01), WA (r=-0.855, p<0.01) and DS (r=-0.753, p<0.01). PV exhibited a strong positive correlation with FV, HV, BV, SBT and RE. DS and WA were correlated negatively with PT, PV, FV, HV, BV and SBT. However, DS correlated positively with WA (r=0.961, p<0.01) and STK (r=0.960, p<0.01). G″ exhibit strong negative correlation with pasting properties (PT, PV, FV, HV, BV, and SBT) and dough extensibility. G* was not significant with pasting properties, textural and rheological properties. Tan δ was correlated positively with storage modulus (r=0.981, p<0.05). Results showed that pasting, technological and textural parameters have a vital role in defining dough and chapatti quality.

Conclusion

Barley-finger millet composites were unique as barley provides β-glucan that is beneficial for food texture and prevention of coronary heart disease whereas finger-millet contains a high content of phytochemicals and dietary fibre. Incorporation of barley in the form of chapatti is the best alternative for its utilization in the human diet. The pasting and rheological properties of the composite flour were influenced by the addition of extruded finger millet flour. The water holding capacities, texture and useful viscoelastic qualities of the composites were improved due to incorporation of extruded flour. Extruded finger millet flour at 20% level of substitution enhanced the puffing and softness of chapatti and increasing acceptability for taste and texture. The physical and chemical properties of composites could be valuable for developing new functional foods with improved nutritional value and desirable texture qualities for health concerned consumers.

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