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Effect of different drying methods on physico-chemical and functional properties of flour produced from sprouted whole wheat grain

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The effect of different drying methods on physico-chemical and functional properties of sprouted wheat flour was analyzed in this study. For this research, the controlled germination of wheat was performed at 27-30°C temperature and 85 per cent relative humidity for 30-36 h immediately after soaking for a period 10-12 h. The samples were dried using recirculatory tray drying (TD), vacuum drying (VD) and microwave drying (MD). The results of proximate analysis, amylose content, α-amylase activity and crystallinity of sprouted wheat flour obtained from TD, VD and MD varied significantly ($P<0.05$) and VD sample showed higher α-amylase activity (9.40 units/mg) and crystallinity (22.49%) with low amylose content (20.32%). The VD samples exhibited higher L* (82.89) and b* (18.82) value with reduced a* value (3.38). The functional properties like rheological behaviour (G' and G"), water absorption index and water soluble index also varied significantly ($p<0.05$) among samples with improved nature in VD samples.

Key Words : Sprouting, Drying, Crystallinity, Amylose content, α-amylase activity

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INTRODUCTION

At present, the demand for commercially marketed nutraceutical items has generated a need for healthy functional ingredients which can be shelf-stable as well as simple to use in formulations. The challenge of developing new products with special health-promoting functions needs to be addressed by the food industry. To overcome this challenge, they must enumerate the alternate sources of other natural and nutritionally rich ingredients with suitable functional properties. In this regards, whole grain items have shown an appealing potential towards the food sector and consumer market due to their several health beneficial effects (Poutanen *et al.*, 2014 and Ktenioudaki and Gallagher, 2012). These days, germinated (sprouted) grain products are the most recent advances in whole grain products owing to their improved nutritional, functional and sensory characteristics (Ding *et al.*, 2018). The enzymatic alteration increases the dietary intake and bioavailability of nutrients in the cereal-based diet. During germination, the amylolytic enzymes, specifically α-amylases hydrolyses the α-(1–4) linkages of starch to disintegrate the complex carbohydrate into low molecular weight

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compounds like maltose, glucose, dextrins and oligosaccharides. Moreover, the storage proteins responsible for the formation of gluten network (gliadins and glutenins) are also hydrolyzed by proteolytic enzymes to release free amino acids like α-aminobutyric acid (GABA) and peptide chains (Baranzelli *et al.*, 2018). Simultaneously, germination influences several physiological processes inducing increment in reducing sugar, bioavailability of minerals, antioxidant potential as well as phenolics compound (Ding *et al.*, 2018). Additionally, the formation of soft kernel structure and diminution of anti-nutritional factors such as phytic acid during germination stands out to be the most important aspects for formulation of healthy food (Jan *et al.*, 2017).

In addition to nutritional improvement, the functional properties of flour produced from sprouted whole wheat also play an important role in food formulation. Some researcher have claimed that uncontrolled sprouting or over sprouting adversely affected the functional chacteristics of dough due to enzymatic degradation of complex carbohydrates and proteins (Edwards *et al.*, 1989). However, controlled germination produced flour with enhanced functional properties such as higher loaf volume, improved batter consistency and better liking scores for bread (Shafqat, 2013), increased elasticity and plasticity for pasta (Agrahar-Murugkar and Jha, 2010), further better consumer acceptability for whole-wheat tortillas (Liu *et al.*, 2017). Likewise, Singh *et al.* (2001) revealed that sprouting duration and conditions have a compelling impact on rheological and functional properties *viz.*, enzymatic activity, water absorption index (WAI) and water solubility index (WSI) of whole wheat flour.

The nutritional and functional attributes of plant materials are significantly dependent on numerous physiological factors such as the chemical composition and molecular framework of the biopolymer. On the contrary, the chemical composition and molecular framework of the biopolymer are substantially influenced by different processing operations such as drying, dehydration, extraction, purification and many others (Piwiñska *et al.*, 2016 and Mirhosseini and Amid, 2013).

Drying process is generally a thermal treatment, significantly influenced the physical properties like texture, structure, density, porosity as well as other health-promoting quality of the dried product as a significant amount of moisture removed during drying. Additionally, the type and conditions of drying may produce an entirely different product from the same raw material (Mirhosseini and Amid, 2013). The most widely used drying techniques in food processing operations are oven drying, spray drying, freeze drying, microwave drying, and vacuum drying, each having their own merits and demerits over other (Majid *et al.*, 2018; Abera *et al.*, 2017 and Hayta *et al.*, 2002). Further, the chemical composition of the food materials also greatly influenced by different drying methods causing lowering in moisture content, protein, fat, several amino acids with simultaneous increment in ash and fibre content (Abera *et al.*, 2017). On the other hand, the thermal treatment is an essential processing tool for germinated seeds as it inactivates several anti-nutritional compounds like phytates as well the trypsin inhibitor (TI) content upto 60 per cent, though 80 per cent inactivation is recommended as safe for the consumer (Agrahar-Murugkar and Jha, 2010). In addition, the drying of commodities at an elevated temperature for longer duration may cause a diminution in flavour, colour and nutrients affecting the overall quality of the product (Li *et al.*, 2014). Therefore, an optimal drying condition and method should be selected so as to inactivate the toxic enzymes, microbes and biologically active compounds, at the same time improving the nutritional, physico-chemical and functional properties. Thus, in this study, a comprehensive attempt has been made to evaluate the effects of different drying methods on physico-chemical and functional properties of sprouted wheat flour and appropriateness of suitable method to produce best quality flour.

METHODOLOGY

Materials:

Wheat (*Triticum aestivum* L.) seeds of Sharbati Sonora variety were procured from a local market, West Medinipore, West Bengal, India. The seeds were devoid of any infestation having initial moisture content of 10.24 per cent (db) used for the study. Food grade α-amylase from *Bacillus subtilis*, sodium hydroxide (NaOH) anhydrous, potasium iodide (KI), maltose monohydrate , soluble potato starch, sodium potassium tartrate, 3,5-Dinitrosalicylic acid (DNS), sodium phosphate (monobasic, anhydrous) and sodium chloride (NaCl) of analytical grade (AR) were purchased from Sigma-Aldrich or Merck, India.

Preparation of germinated (sprouted) whole-wheat flour:

The sprouting (germination) of wheat seeds was carried as per method described by (Ding *et al.*, 2018 and Marti *et al.*, 2017) with some modifications. The wheat seeds were initially soaked in distilled water (1:4; seed: water) at 25±2°C for a duration of 12 h so as to initiate the enzymatic activity. Then the seeds were washed with distilled water and placed in germination trays by layering them over a moist muslin cloth of a controlled environmental test chamber (REMI, Maharashtra, India). The controlled conditions for sprouting were maintained at 27±2°C with relative humidity (RH) of 85±2% for duration of 30-36 h. The seeds were sprinkled with splash of water at a regular interval of 3 h to keep seeds moistened. After that the germinated seeds were placed in a refrigerated condition so as to halt the excess enzymatic activity. The germinated seeds were then dried using reciculatory tray dryer (60°C for 8 h), vacuum dryer (600 mm Hg for 12 h) and microwave dryer (30 w for 45 min) to reduced the moisture content of the samples upto 10 per cent (db). Then the samples were cooled to room temperature followed by milling using a local cereal grinder (Centrifugal, Kolkata, India) to produced flour from dried samples. The flour was then passed through a 60-mesh sieve to give a uniform particle size of 300 μm. The flour obtained from the above methods was stored in a cold chamber at -18°C until further analysis.

Physico-chemical composition of sprouted wheat flour:

The moisture, protein, crude fat, crude fibre, ash content, total carbohydrate, energy value of sprouted wheat flour obtained from different drying methods were evaluated as per AOAC (1990) methods. All the values are measured in triplicates. The total protein was calculated by multiplying a protein factor 5.75 to the total nitrogen obtained from Kjeldahl method. Similarly, the crude fat and ash content were measured using soxhlet and direct ashing method, respectively. The total energy was obtained by adding individual energy from fat (9 kCal), protein (4 kCal) and carbohydrate (4 kCal).

Colour change analysis:

The colour attributes of the samples were measured using a spectrophotometer (CM-5d, Konica Minolta Inc., Tokyo, Japan). The instrument expressed the results in CIEL*a*b* framework where 'L*' indicates lightness, 'a*' redness to greenness and 'b*' yellowness to blueness. In order to reduce error in measurement, white calibration was executed with reference standard (L* = 98.45, a* = - 0.10, b* = - 0.13). A glass cell containing the powdered flour was placed above the light source and covered with a white plate and L*, a*, b* values were recorded (Singh *et al.*, 2003). The total colour difference (ΔE) was calculated using the following eq.:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where, $\Delta L^* = L^* - L_0^*$, $\Delta a^* = a^* - a_0^*$, $\Delta b^* = b^* - b_0^*$) and L_0^*, a_0^* and $b_0^*$are the colour of control (normal whole wheat flour) and L*, a* and b* are the colour of dried samples.

Amylose content :

The amylose content of the samples was evaluated using a colorimetry method described by Williams *et al.* (1970) and Gibson *et al*. (1997). The amylose content was measured by comparing against a standard curve and the outcomes were expressed in percentage of amylose.

~-Amylase activity:

Alpha-amylase activity was determined in triplicate according to Bernfeld (1955) using the Sigma quality control test procedure (Sigma-Aldrich, USA) for enzymatic assay of α-amylase (EC 3.2.1.1). In this method, one unit of amylase activity will liberate 1.0 mg of maltose from starch in 3 minutes at pH 6.9 at 20°C. The results are expressed as Units/mg solids.

X-ray diffraction analysis :

A simple and non-destructive method was followed to determine the crystallographic properties of the dried samples (Chen *et al.*, 2015). The samples were placed in a humidity chamber for 24 h at 25°C and 100 per cent relative humidity for equilibration. The flour samples were packed tightly in a circular glass cell and placed in an X-ray diffractometer (D8- Discover, Bruker, Germany) equipped with a copper tub operating at 40 kV and 10 mA with Cu Kα radiation (λ= 0.154 nm). The samples were scanned through the 2θ range of 5-35° with a rate of 2°/min at 25°C. The peak characteristics of XRD pattern was recognized as per theoretical diffractogram

(Xiao *et al.*, 2017). The total relative crystallinity (Xc) of the samples was calculated using the following eq.:

$$\text{Total relative crystallinity, Xc (\%)} = \frac{Ac}{(Ac + Aa)} x100$$

where, Ac is the area of the crystalline peak and Aa is the area of the amorphous peak.

Water absorption index (WAI) and water solubility index (WSI):

WAI and WSI of flours were determined as per method described by Singh *et al.* (2003) with slight modification. An accurately weighed 2.5 g of samples from each treatment was mixed with 30 ml of distilled water. The mixture was cooked in a water bath at 90°C for 15 min constantly stirring with a glass rod. The gel was allowed to cool to room temperature followed by centrifuging at 3000 x g for 15 min. The supernatants were discarded and transferred to a Petridish. WAI and WSI were evaluated as per the formulae:

$$\text{WAI} = \frac{\text{wt of sediment}}{\text{wt of original dry sample}}$$

$$\text{WSI (\%)} = \frac{\text{wt of dry solids in supernatants}}{\text{wt of original dry sample}} x\ 100$$

Dynamic rheological properties:

The dynamic rheological properties of all the dried flour were evaluated using a dynamic controlled stress rheometer (Bohlin, Malvern, UK) installed with a distilled water refrigeration circulation bath (Behera and Srivastav, 2016). The instrument was mounted with a parallel plate system (dia. 40 mm) and a gap of 1 mm between the plate and stage was kept between the plate and stage for measurement. The sample was covered with a serrated plate to avoid slippage as well as silicon oil around the exposed edges to reduce moisture removal during measurement. Initially, the linear viscoelastic region (LVR) of all the samples was identified by amplitude stress sweep test at 1, 10 and 100 Hz. Then, the frequency sweep test was performed keeping stress value 1 Pa for all the measurements where frequency varied from 0.01 to 100 Hz. All the tests were performed at a constant strain rate (0.1%) and temperature (30°C). The storage modulus (G') and loss modulus (G") were evaluated as a function of frequency to characterize the dough quality. Values were recorded as a result of three measurements.

Statistical analysis:

All the results are expressed as mean ± standard deviations with triplicates. The one-way analysis of variance (ANOVA) and Duncan's multiple range test was utilized to perform significance test and calculate the least significant differences between means ($P < 0.05$) using SPSS 20 (SPSS Institute, Chicago, IL, USA).

OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Effect of drying on physicochemical properties:

The chemical composition of sprouted wheat flour produced from different drying methods is shown in Table 1. The moisture content of flour from above methods was within safe limit for storage which provided a desirable shelf-life. The moisture content values were also significantly different ($p<0.05$). The moisture content in microwave dried samples was higher (8.33%) from other two methods; vacuum dried (VD) samples being lowest moisture content (6.61%). The decrease in moisture content in vacuum dried samples may occur due to high α-amylase activity which caused changes in the structural framework of molecules. In contrast, the microwave dried

Table 1: Chemical composition of flour obtained from different treatment (on w.b.)

Parameters	TD	VD	MD
Moisture (%)	7.79 ± 0.11^{b}	6.61 ± 0.14^{a}	8.33 ± 0.19^{c}
Protein (%)	12.75 ± 0.54^{b}	14.37 ± 0.52^{c}	11.41 ± 0.41^{a}
Fat (%)	1.67 ± 0.09^{a}	1.46 ± 0.08^{a}	1.98 ± 0.09^{b}
Crude fibre (%)	$3.41\pm0.0.8^{b}$	4.35 ± 0.09^{c}	3.12 ± 0.08^{a}
Ash (%)	1.87 ± 0.07^{b}	2.54 ± 0.08^{c}	1.48 ± 0.08^{a}
Carbohydrate (%)	72.51 ± 1.17^{b}	70.67 ± 1.94^{a}	73.68 ± 1.52^{b}
Energy (k Cal)	356.07 ± 1.78^{b}	353.30 ± 1.76^{a}	358.18 ± 1.79^{b}

Results are expressed as mean values ± standard deviations (n=3). Means in a row with same superscripts (a,b,c,) are not significantly different ($p<0.05$)

(MD) samples due to less exposure to heat and high internal energy generation elevated the moisture content (Hemis *et al.*, 2012).

The protein content of tray dried, vacuum dried and microwave dried samples varied significantly ($p<0.05$). The protein content in case of vacuum dried showed significant increment ($p<0.05$) from all the samples which was found to be in agreement with the findings of Singkhornart *et al.* (2013). However, the significant decrease ($p<0.05$) of MD samples protein content may be due to structural modification and denaturation of protein (Hayta *et al.*, 2002).

In all the dried samples, the fat content of VD samples significantly decreased ($p<0.05$). This may be due to degradation of starches and lipid molecules upon higher enzymatic activity (Table 1) in case of VD samples. On contrary, there was a considerable increase in crude fibre content in VD samples as sprouting enhances synthesis of several structural carbohydrates *viz.*, cellulose and hemicelluloses (Majid *et al.*, 2018).

On analysis of the total carbohydrate and total energy content, the present study showed that TD and MD samples did not differ significantly ($p<0.05$) except the VD samples demonstrated a reduction in total carbohydrate content and total energy content. This may be due to higher α-amylase activity degrading the complex structure to smaller fractions which caused a reduction in available sugar for energy conversion.

Effect of drying on colour characteristics of samples:

The colour profile such as L*, a*and b* values of all the samples is shown in Table 2. From the Table 2, it was observed that the drying methods significantly ($p<0.05$) affected the colour parameters. A bright yellow colour wheat flour was generally preferred by the consumer (Piwiñska *et al.*, 2016). The results affirmed that all the samples had lightness (L*) value close to 80 and the yellowness indicator, b* values were in positive range. From the values of L* and b*, it was confirmed that all the samples were light yellow in colour. However, the higher value ($p<0.05$) was found for VD samples (82.89) as compared to other methods. In vacuum drying, reduced pressure caused least reduction in brightness than other high-temperature methods. Additionally, some intrinsic factors like non-enzymatic browning during high-temperature drying resulted in decreased brightness (Piwiñska *et al.*, 2016). Drying methods also had a significant effect on redness value of wheat flour. The value of redness indicator (a*) increased with increasing temperature (Piwiñska *et al.*, 2016). The sprouted wheat flour produced from TD and MW exhibited a higher a* value (3.69 and 3.42) as compared to VD samples (3.38). However, all a* values are significantly ($p<0.05$) higher with respect to the control sample. This may be due to the occurrence of Maillard reaction which resulted upon agglomeration of free amino acids with reduced sugars and dextrins aroused largely during germination (Baranzelli *et al.*, 2018 and Piwiñska *et al.*, 2016). Yellowness parameter (b*) of all the samples also considerable differed ($p<0.05$) with an elevated amount from the control sample.The lowest b* value (18.51) was observed for MD samples yet with an elevated amount that of control. Furthermore, high temperature and long duration induced higher intensity of yellow colour as thermal inactivation of lipoxygenase (LOX) occurred at elevated temperature minimizing the pigment's oxidative degradation. Moreover, in the vacuum drying the oxidative degradation of yellow pigment is minimized as moisture removal occurs in absence of oxygen reserving the yellowing characteristics (Piwiñska *et al.*, 2016). This study was similar to the findings of Piwiñska *et al.* (2016). The ΔE^* of all the samples also varied significantly ($p<0.05$). The VD samples showed an extensively lower deviation from the control samples.

Effect of drying on enzymatic activity and amylose content:

Alpha-amylase is the most key enzyme present in

Table 2 : Colour attributes obtained from different drying methods

Samples	L*	a*	b*	ΔE^*
Control	86.43 ± 0.15	2.00 ± 0.07	13.19 ± 0.09	……..…..
TD	80.59 ± 0.17^{b}	3.69 ± 0.08^{b}	18.96 ± 0.08^{c}	9.88 ± 0.09^{c}
VD	82.89 ± 0.17^{c}	3.38 ± 0.08^{a}	$18.82\pm0.09_{b}$	6.79 ± 0.09^{a}
MD	78.48 ± 0.18^{a}	3.42 ± 0.09^{a}	18.51 ± 0.09^{a}	9.67 ± 0.10^{b}

Results are expressed as mean values ± standard deviations (n=3)

Means in a column with same superscripts (a,b,c) are not significantly different ($p<0.05$)

the endosperm of cereal grains causing degradation of starch into smaller fraction like dextrin, maltose and glucose by hydrolyzing the α (1→4) glucosidic linkage. Germination primarily activates α- amylase enzyme resulting in higher enzymatic activity (Table 3). The increased enzymatic activity results in breakage of high molecular polymers (amylopectin and amylose) into smaller fractions like maltose, dextrin etc. (Noda *et al.*, 2004). However, drying methods and the temperature had considerable effects on quality and quantity. The values of both α- amylase activity and amylose content of all the samples varied significantly ($P<0.05$) and also in agreement with the findings of Noda *et al*. (2004) and Ichinose *et al.* (2001). The VD samples showed a higher α- amylase activity (9.41U/mg) with least amylose content (20.32 %) compared to other methods (Table 3). Recently, baking industries incorporate commercial enzymes, specifically α- amylase in baked products to reduce stalling rate as stalling occurs due to heat reversible accumulation (retrogradation) of both the amylopectin and amylose (Giannone *et al.*, 2016). Thus, higher enzymatic activity reduced both the amylopectin and amylose content aiding higher shelf-life with reduced stalling rate. The enzymatic activity in-case of MD samples was least due to high temperature causing inactivation of enzymes (Hemis *et al.*, 2012). In contrast, the reduced pressure in vacuum drying caused less inactivation of enzymes with less degradation of amylopectin in absence of oxygen.

Effect of drying on X-ray crystallography:

X-ray crystallography furnishes an insight knowledge about the degree of crystallinity and material characteristics whether crystalline or amorphous nature. The X-ray diffraction patterns received for TD and VD samples exhibited a typical A-type X-ray diffraction curve with peaks of 2θ at 14.89°, 17.71° and 22.87°, respectively. Mean while, the MD samples showed an indistinct B-type X-ray diffraction curves which depicted poor crystalline nature of the samples (Fig. 1). The B-type X-ray diffraction patterns of MD samples were formed due to the poor interaction of amylose fraction with naturally occurring fatty acids and phospholipids of wheat starch at high temperature. These studies were well consistent with the research outcomes of the previous studies carried out for wholegrain wheat, germinated wheat, potato starch and buckwheat (Xiao *et al.*, 2017; Jan *et al.*, 2017; Chen *et al.*, 2015 and Hizukuri, 1961).

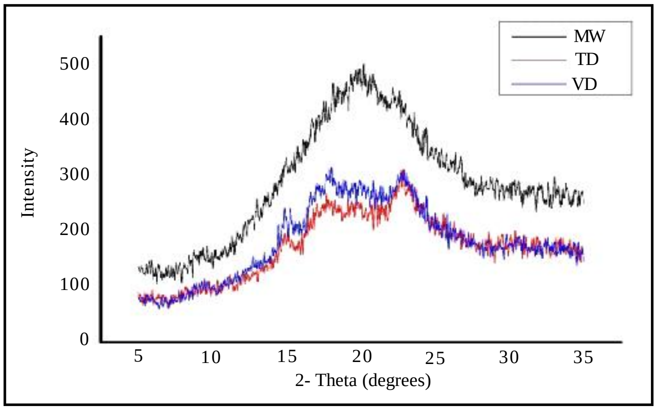


Fig. 1 : X-ray diffraction patterns of microwave (MD), vacuum (VD) and tray dried (TD) sample

The relative crystallinity (Table 3) of all the samples varied significantly ($p<0.05$) and degree of crystallinity increased from MD samples (14.61%) to VD samples (22.49 %). The alternation in crystallinity levels mainly depends on the orientation of amylose and amylopectin molecules as well as their interaction among themselves (Jan *et al.*, 2017). In these aspects, drying methods and heating temperature significantly influenced the crystalline characteristics of all the dried samples. The thermal treatment was responsible for destruction as well as rearrangement of molecules simultaneously causing structural changes inside the matrix. It was predicted that the double helical chains within the starch crystals may be displaced resulting in recrystallization and reason for the formation of small crystalline regimes of starch granules on cooling (Chen *et al.*, 2015). This could be the possible cause for an elevation in relative crystallinity of VD and TD samples. On contrary, the generation of high temperature in microwave drying destroyed the crystalline matrix as well short duration heating results in

Table 3 : Effect of drying on enzymatic, amylose and crystallinity values

Drying method	Amylose content (%)	α- Amylase activity (units/mg)	Crystallinity (%)
TD	21.47 ± 0.02^{b}	8.24 ± 0.02^{b}	20.08 ± 0.09^{b}
VD	20.32 ± 0.03^{a}	9.41 ± 0.10^{c}	22.49 ± 0.05^{c}
MD	23.42 ± 0.13^{c}	7.85 ± 0.12^{a}	14.61 ± 0.05^{a}

Results are expressed as mean values ± standard deviations (n=3), Means in a column with same superscripts (a,b,c) are not significantly different ($p<0.05$)

partial gelatinization and movement of double helical chains which disrupted the crystallite orientation in the matrix (Chen *et al.*, 2015). This may result in decreased crystallinity level of TD samples.

Effect of drying on WAI and WSI :

Water absorption index and water solubility index are the most two important functional parameters and have a great impact on dough properties such as viscosity, elasticity etc. In addition, they also affect the swelling and dough consistency which has greater implication in baking process (Niba *et al.*, 2001). The WAI and WSI of all the samples showed significant variation among all the treatments ($p<0.05$). Among all the samples, the VD samples showed the lowest WAI and the highest WSI whereas the MD samples exhibited highest WAI and lowest WSI (Fig. 2). The WAI and WSI may be attributed to an increase in amylolytic and proteolytic activity upon germation (Singh *et al.*, 2001). The decrease in WAI in VD samples may occur due to the reduction in structural carbohydrates, specifically amylose content during sprouting. This can be visualized from correlation-regression analysis among amylose content and WAI and WSI (r = 0.94). This inference was quite similar to the findings of Singh *et al.* (2001). On the other hand, WSI measures the quantity of low molecular weight fractions derived from starch degradation became easily soluble due to disruption of structural matrix (Singkhornart *et al.*, 2013). In this investigation, the increased temperature as well reduced enzymatic activity in MD produced less low molecular weight compounds causing a reduction in WSI of MD samples. Additionally, the poor interaction among amylose and amylopectin also reduced the WSI of MD samples. Conversely, the higher enzymatic activity and reduced pressure application in vacuum drying increased the smaller fraction compounds from complex starch resulting in a rise in WSI of VD samples. These findings were in well agreement with the research outcomes of Majid *et al.* (2018).

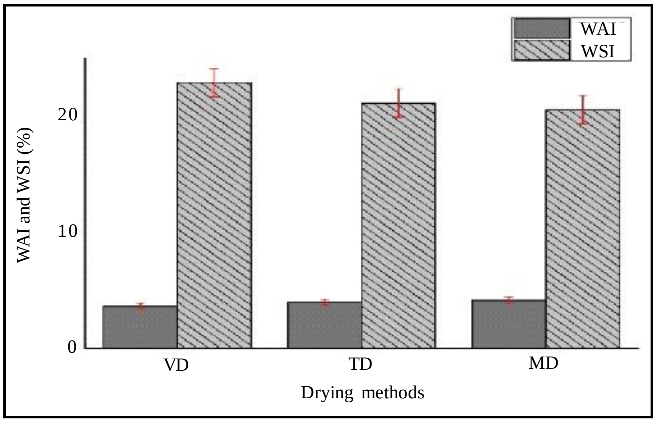
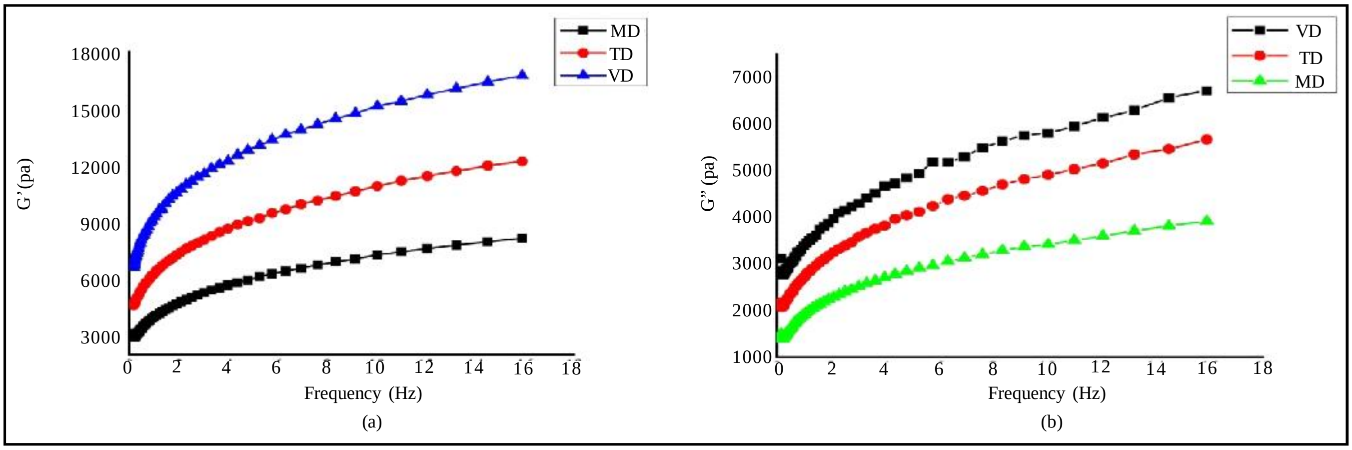


Fig. 2 : Change in WAI and WSI of microwave (MD), Vacuum (VD) and tray dried (TD) sample

Effect of drying on rheological characteristics:

The effect of drying techniques on dynamic rheological properties of TD, VD and MD flour was investigated. The storage modulus (G') and loss modulus (G") of all the samples from different treatment increased with increasing frequency (Fig. 3a and b). Similar results have been documented for sprouted wheat flour and onion powders (Majid *et al.*, 2018 and Singh *et al.*, 2001). The flour from vacuum drying showed a considerable increase in both G' and G" value compared to the samples of other two methods. The low temperature and reduced pressure



(a)

(b)

Fig. 3 : Variation in G' and G" of microwave (MD), vacuum (VD) and tray dried (TD) samples

in vacuum drying caused less degradation of larger molecules. Additionally, the interaction of the protein with lipids, amylose and amylopectin did not disrupt significantly in vacuum drying as VD samples had higher protein compared to others (Table 1). On contrary, the microwave drying generated high temperature which destroyed the gluten network exhibiting lower elasticity (G') and viscosity (G"). Also, due to high WAI, the MD sample lost its elasticity and consistency. This result may be true in the present study because of reduced protein content in MD samples (Hadnaðev *et al.*, 2011).

Conclusion:

Drying characteristics have a significant impact on processing and preservation of food material. The present work revealed the effect of three drying methods like recirculatory tray drying (TD), vacuum drying (VD) and microwave drying (MW) on physico-chemical, crystalline and functional properties of sprouted whole wheat flour. The VD samples exhibits improved nutritional, functional and rheological properties in comparison to other two drying methods. The results from above study showed that VD samples had enhanced enzymatic activity which could be beneficial in reducing stalling rate in baked products. Vacuum dried samples also produced bright yellow colour flour contrasted to other drying methods. Additionally, the increased crystallinity in VD samples may provide higher dietary fibre intake in the diet. On the hand, the MD samples due to high-temperature generation caused significant degradation of granular and structural molecules. The results of MD samples proved its poor functionality as well as rheological properties. Therefore, the recent study recommends and suggests the utilization and commercialization of vacuum drying method to produce flour from sprouted wheat.

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