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# CHARACTERISTICS OF BREAD DOUGH MADE WITH THE USE OF VARIOUS MILLET FLOURS

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**Abstract.** Millets are gaining attention due to their many advantages in cultivation and overall nutritional benefits. Research has been carried out to explore the nutritional properties of various millets. However, the use of millets in today's food processing is minimal as compared to wheat. Three minor millets, namely foxtail, proso, and pearl millets grown in Iran were used in this study. The water absorption characteristics and hardness of these millets have been investigated. The effect that millet flours incorporated in dough have on its rheology has been studied and compared with the effect of wheat on dough rheology. The moisture content of millets increased with an increase in the water temperature, and a regular increase in the water absorption capacity, too, was observed as the temperature rose. The hardness of the millet decreased with an increase in the moisture content of the grains. Pearl millet has been found to have the lowest hardness irrespective of the steeping time and temperature. Incorporation of millet in the dough adversely affected the dough rheology in terms of workability and baking quality. Proso millet highly negatively affected the dough rheology in terms of dough hardness, stability, and dynamic rheological properties. This research highlights the possibility to predict the water absorption characteristics of millet grains to be used to optimise the conditions under which millets are steeped in various bioprocessing operations. It is supposed that on performing proper baking trials to compare the properties of composite flours made from these millets, the results of the rheological studies will prove beneficial and the rheological properties and behaviour will be accurately correlated when the food is applied practically.

**Keywords:** millets, dough rheology, water absorption, dough stability, dynamic rheology.

## Introduction. Formulation of the problem

Millets and sorghum are the oldest cereals used since ancient times. The origins of millets are not precisely known, but millets have been consumed as food since prehistoric times. Some believe that it is the first crop ever cultivated [1]. Millets encompass a number of small-grained annual cereal grasses, including several different species [2] not considered in the western world to have significant importance. However, for centuries, millets have been viewed as a staple food worldwide [3], especially in African and Asian people's diets [4].

## Analysis of recent research and publications

Millets provide a wide range of health benefits and are a good source of energy, proteins, minerals, and vitamins. Millet proteins are a good source of essential amino acids except lysine and threonine, but contain higher amounts of methionine. Millets are rich in phytochemicals and micronutrients, and due to these nutritional benefits, are termed "nutria-cereals" [3]. Millets are well known for their dietary benefits. There are many research evidences of millets' health benefits: their ability to prevent cardiovascular diseases, cancer, lower the blood pressure, reduce the risk of tumour incidence, heart disease, improve the cholesterol level and fat absorption, and postpone gastric emptying [5,6]. Foods based on plants are traditionally considered helpful in preventing many diseases such as cardiovascular disorders, cancer, diabetes, metabolic disorder, and Parkinson's disease [7,8]. Recent research suggests that bioactive compounds abundant in millets such as resistant starch, oligosaccharides, lipids, phenolic acids, flavonoids, lignans, phytosterols, phytic acid, and tannins also have a positive effect on human health [9].

Coeliac disease is one of the common disorders present worldwide. It is mainly caused by enteropathy triggered by ingestion of gluten. Those who are affected by coeliac disease should consume gluten-free foods such as rice, maize, sorghum, millet, amaranth, buckwheat, quinoa, wild rice, and oats [10]. Since millets are gluten-free, millet-based diets are suitable for people who wish to avoid gluten [11].

Nowadays, bakery products account for a major part of the processed food market. This industry is rapidly changing with advancements in developing nutraceuticals and other new products [12]. The primary ingredient for the baking industry is refined wheat flour, which is an excellent source of energy and basic nutrients, but lacks micronutrients, complex carbohydrates, and fibre. The protein quality of wheat is inferior to that of other cereals, and this is primarily attributed to the lower lysine, methionine, and threonine content of wheat proteins [13]. This significantly tells on people's health, especially in those with diabetes and gastrointestinal and colorectal problems [14]. Therefore, it is necessary to find alternative ingredients the baking industry could use to solve this problem.

Biscuits were made with a blend of barnyard millet flour and refined wheat flour by the method of Chakraborty *et al*., [15]. They found that larger amounts of millet flour increased the hardness of the biscuits. Finger millet flour and wheat flour were used to produce biscuits by Saha *et al*.'s method [16]. The dough characteristics and biscuit qualities were evaluated. It was found that the hardness and expansion of the biscuits was higher at higher combinations. In terms of biscuit quality, the composite flour of lower combinations was found to be the better ratio [16]. The effect that replacing wheat flour with finger millet flour had on the batter microscopy, rheology, and quality characteristics of muffins was studied by Rajiv *et al.* The amylograph peak viscosity, breakdown and setback values decreased with an increase in finger millet flour. Combinations of additives improved the quality characteristics of muffins as well as their volume [17]. Extruded breakfast snack was made from millet flour, amaranth, and buckwheat by Brennan *et al*. [18]. The research [19,20] was carried out to study the potential use of millets in beer production. It was found that beer could be brewed from millet, which would be an excellent replacement for barley in beer production.

Even though gluten formation is a unique property of protein in wheat flour, it is possible to replace the wheat flour in bakery products to a certain degree by using other cereal grains. For example, researchers produced bakery products using other grains such as soya bean, rye, etc., as well as gluten-free wheat flour substitutes [21].

However, studies carried out to use millets in bakery products are very limited. The main objective of replacing wheat flour with millets in bakery products is to add more functional and nutritional value to them. Adding such substitutes will affect the baking quality and, in turn, the overall consumer acceptance. Establishing the right proportion of such replacement products in the baking industry has always been a major challenge. Finding the best combination of millet and wheat in a mixture for various bakery products is impossible without multiple research studies. There is, nonetheless, an obvious relationship between flour constituents and the final baked product quality [22]. However, scientists and researchers have not found accurate correlations to determine the quantity and composition of millet to be successfully used in bakery products. Hence it is imperative to better understand, explore, and analyse millets' physicochemical properties in combination with wheat and thus facilitate incorporation of millets in the bakery industry as a wheat substitute. To produce good quality baked products, one must understand the behaviour of dough, since its rheology has a direct impact on the quality of baked products. To successfully incorporate minor millet flours into bakery products, one should understand the effect of millet flours on dough rheology.

Millet dough behavious have not been extensively studied before.

**The purpose** of this research was to study whether three millet flours (i.e. *Pennisetum typhoides*, *Setaria italic*, and *Panicum miliaceum*) are suitable to replace wheat flour in the production of bakery products, based on understanding the rheological behaviour and physicochemical properties of wheat-millet composite flours. The **objectives** of the study:

1. Characteristics of bread dough made from various millet flours.
2. Dynamic rheological properties of dough.
3. Physical properties of dough.

## Research materials and methods

*Sample preparation*

The three types of millet grain, namely pearl millet (*Pennisetum typhoides*), foxtail millet (*Setaria italica*), and proso millet (*Panicum miliaceum*) were obtained from Gonabad City (Khorasan Province, Iran). Prior to each test, these grain types were cleaned manually to remove dirt and other impurities such as stones, mud, etc. to avoid interferences due to these impurities. Also, the samples were hand-selected to remove broken, cracked, and damaged grains.

*Determination of the water absorption of millet*

Cleaned millets were used in the experiment. Each trial involved 100g of the millet grains. The millets were kept in a 1 litre container with a certain quantity of distilled water (i.e. 900ml). The container was kept in a thermostatically controlled water bath to maintain the temperature (±1°C) as long as the steeping lasted. Throughout the steeping period, the steeping water temperature was continuously monitored [23]. Water was used in the experiment with three different temperatures, namely, 30°C, 40°C, and 50°C. Three steeping periods of different duration were considered in the experiment, namely 4, 8, and 12 hours. The container was covered to avoid evaporation during moisture uptake. According to the pre-set durations of steeping periods, the millets were removed from the container, and the water remaining in the container was measured with a graduated cylinder. The excess water which clung to the surface of the millet grains was removed by blotting with tissue paper. Then the grains were weighed, and the increase in the weight was taken as the amount of water absorbed. All experiments were conducted in triplicate, and the average result was expressed on dry basis (% d.b.).

*Hardness of millets*

The rupture stress (hardness) of the millet grains was measured after each steeping period at different temperatures using an Instron texture analyser (M 4502, Instron Corp., Canton, MA) equipped with a cylindrical probe with a diameter of 25mm attached to a 50N load cell. The crosshead speed in this experiment was 2.5mm/min. The hardness of the millets was determined by the compression test method. The study was performed in quintuplicate, and the average values have been reported [23].

*Millet and wheat flour preparation*

After cleaning, the millets were ground to produce flour using a home-scale grinder. The flours were sieved to obtain the same-size particles, then tightly packed and stored in polyethylene bags to avoid changes in the moisture content. Unbleached wheat flour was purchased from a local shop and used in the experiment.

*Composite flour preparation*

Composite flour was prepared by using different proportions of wheat and millet flour. Wheat and millet flours were used in the ratios 1:0, 7:3, 1:1, 3:7, 0:1 to prepare the composite flour. The flours were put in the mixing bowl of a home-scale mixer and mixed for 30min to produce homogeneous composite flours. After mixing, the composite flour was stored in airtight containers to prevent changes in the moisture content.

*Preparation of dough*

Composite flours were prepared by using wheat flour and millet flour. Dough samples were made by mixing 50 g of composite flour with different proportions of water (70% and 80%). The room temperature of the water was maintained (i.e. 22°C). This prevented the water temperature from interfering with the dough rheology. The dough samples were thoroughly mixed and kneaded by using a lab scale dough mixer with a constant kneading speed and kneading direction. The duration of dough mixing and dough resting also remained unchanged throughout the experiment. After mixing, the dough samples were allowed to rest for 30 min in covered bowls [24].

*Dynamic rheological measurements of dough*

A Dynamic Rheometer (AR2000, TA Instruments, Texas, USA) was used for dynamic rheological measurements of the dough. All the tests were conducted using a 40mm parallel plate-plate geometry, and the instrument gap was set at 2mm. The dough samples were transferred between the parallel plates. To prevent moisture loss during testing, a thin layer of low-viscosity (<0.1% of the test material viscosity) silicone lubricant was applied to the exposed dough, and a physical solvent trap cover (located over the geometry but not touching the sample or geometry) was also used during the testing to prevent dehydration. The dough samples were loaded in between the plates, and the samples were rested for 5 min to attain equilibrium conditions and release the stress from the dough induced during mixing and sample handling. All the dynamic rheological tests were performed in triplicate at 25°C, and their averaged results have been reported in this study. The results were analysed on the TA rheology advantage data analysis software [25].

*Dough hardness*

The hardness (N) of the prepared dough samples was measured using an Instron Universal Testing Machine (M 4502, Instron Corp., Canton, MA). The dough was compressed with a plunger with the diameter 4.5cm to produce a 1cm thick sheet. For this, a dough ball was prepared and sheeted by compressing it between two parallel plates made of acrylic and separated by spacers to obtain a sheet 1.0cm thick [26]. When testing the hardness, the dough was compressed with the plunger, and the resistance sensed by the plunger was recorded.

*Physical measurement of the dough*

The water absorption capacity and the stability of dough were measured. A portion of composite flour with a certain mass (i.e. 75g) was put in the bowl and mixed with an adequate amount of water. The amount of water required to achieve the dough consistency was recorded as the water absorption of the composite flour. The mass of the composite flour was kept unchanged for all the samples during the testing. The composite flour dough was kept at 30°C till the dough achieved the stage of its maximum development [26].

*Statistical analysis*

The results reported are the averages of the replicates for all samples. The Statistical Analysis System SAS9.4 (SAS Institute Inc., Cary, NC) was used for statistical analysis. Analysis of variance (ANOVA) with the confidence level of 95% ($P \leq 0.05$) and the Duncan's multiple range test were used to determine the significant effect.

## Results of the research and their discussion

*Water absorption of millet*

The moisture content of the millets was determined after each steeping, and the increase in the moisture content was calculated and compared with the control. The moisture content of the tested millets, as a function of the temperature and steeping time, is presented in Fig. 1-3.

The moisture content of millets increased with the increase in the water temperature. A regular increase in the water absorption was observed as the temperature increased from 30 to 50°C. This confirms that the water absorption is directly proportional to the temperature. The highest moisture content of the millets was found at the highest temperature i.e. 50°C. This behaviour of water absorption is determined mainly by the increased water diffusion rate at higher temperatures. Similar results were observed by Maskan in wheat (2002) [27]. The study considered the relation between the increase in the temperature of steeping and the increase in water absorption, and similar results were observed by many researchers [28,29].

Fig. 1-3 indicate that the initial water absorption rate of millets was rapid (i.e. when compared with the later stages) and became minimal as equilibrium moisture content was achieved. This behaviour is mainly due to the reduction of water transfer driving force during the hydration process as the system nears the equilibrium condition. It was found that the behaviour of the water absorption of millets was similar to that of other cereal grains. There are reports about similar trends in water absorption observed in rice and lupin [30,31].

The initial rapid absorption of water is a common phenomenon in most cereal grains, and it is attributed mainly to the structure and compactness of grains. Besides, it is due to the initial filling of the capillaries on the surface of the seed coats and the hilum [32]. The initial moisture content and physicochemical properties of the grain also influence the water absorption characteristics. The impact of these properties was studied by many researchers [32,33]. The effect of the chemical composition of food materials on the absorption capacity is still unclear, and the dependence is no doubt complex [34]. The proso millet reached the moisture content 40.85% (db) at 30°C after 4 hours of steeping. The pearl millet and foxtail millet only reached the 26.58% (db) moisture content at the same temperature and duration. Also, the highest moisture content, 61.29% (db), was that of the proso millet. It was reached at 50°C after 12 hours of steeping, while the pearl millet and foxtail millet at the same temperature and steeping duration only reached 42.85% (db) and 44.92% (db). The proso millet exhibited different water absorption characteristics when compared with the foxtail millet and pearl millet. It absorbed more water and resulted in a higher moisture content at any steeping duration and temperature compared with the two other millets. At this point, it is not clear what causes this difference in the water absorption of proso millet, so further investigation is required to understand its behaviour.

The hardness of the millets was tested after each trial, the change in the hardness was measured using an Instron texture analyser, and the findings have been reported in Fig. 4. The hardness of the millets decreased with the increase in the moisture content: the highest moisture content of millets resulted in the lowest hardness. The pearl millet was found to have the lowest hardness irrespective of the steeping time and temperature, as compared with the foxtail millet and proso millet. The highest hardness (45.19N) was found in the proso millet samples steeped for 4 hours at the temperature of 30°C. All three millets exhibited highest hardness at 30°C after 4 hours of steeping.

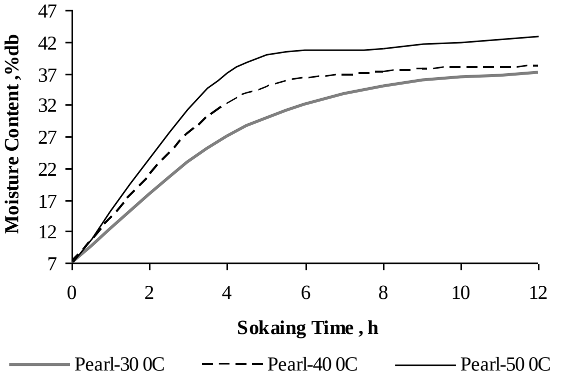


**Fig. 1. Water absorption of pearl millet during hydration, with steeping periods of different duration**

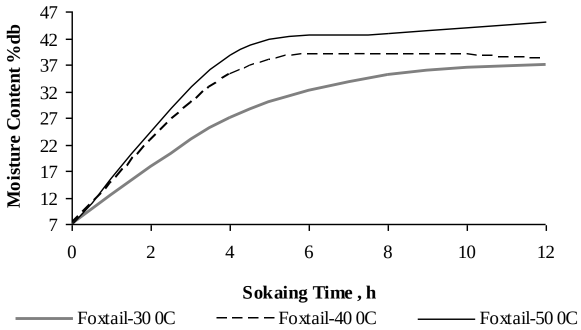


**Fig. 2. Water absorption of foxtail millet during hydration, with steeping periods of different duration**

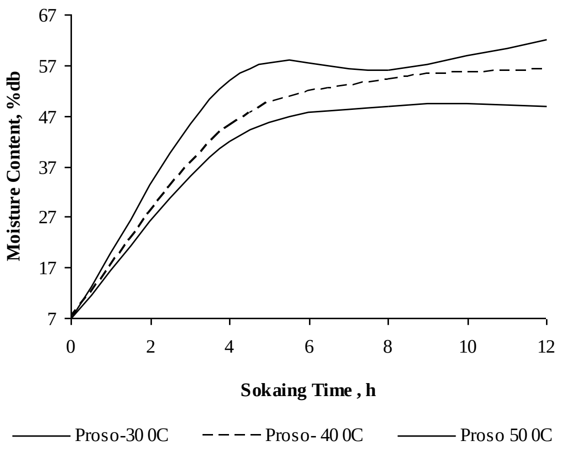


**Fig. 3. Water absorption of proso millet during hydration, with steeping periods of different duration**

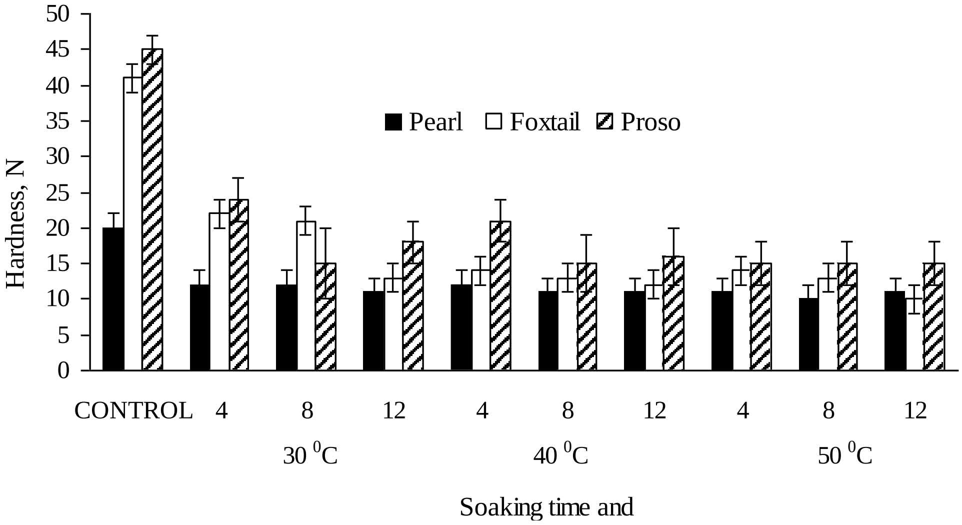


**Fig. 4. Hardness of millets, with different steeping times and temperatures**

The dynamics of hardness in the proso millet differed from that in the pearl millet and foxtail millet. This might be due to the different water absorption of proso millet (Fig. 3). Besides, the stronger outer shell of a proso millet grain resulted in its higher hardness while grains of the other two millets have softer outer shells. For example, the hardness of the proso millet was 16.42N, with the steeping duration 4 hours and the temperature 50°C. Increasing the steeping duration to 8 and 12 hours at the same temperature decreased the hardness but slightly: to 16.19N and 16.23N respectively. This means that the proso millet hardness was not significantly affected by an increase in the steeping duration at 50°C. Generally, the millet hardness decreased with the increase in the moisture content.

Similar results were obtained by Ituen *et al.* (1986). They found that the rupture stress of grains like sorghum and pearl millet decreased with an increase in the moisture content. They also established that more force was needed to rupture larger grains than those of smaller sizes, one should apply more force to rupture a larger area of the grains [33]. The proso millet was found to have a larger grain surface area as compared with the foxtail millet and pearl millet. This accounts for the higher hardness exhibited by the proso millet.

*Water absorption of the dough*

The water absorption of millet flours differs significantly ($P<0.05$) as compared with wheat flour (Fig. 5). Both the type of millet and its concentration were found to be statistically significant. Thus, incorporation of millet flours changed the absorption characteristics of the composite flours. The foxtail millet flour showed the lowest water absorption (52.4%), and the water absorption of the proso millet was the highest (60.55%). Generally, the water absorption of the dough decreased with an increase in the millet flour concentration in the dough. However, incorporation of the proso millet, due to its high water absorption capacity, resulted in quite different water absorption dynamics. The water absorption slightly increased with the increase of proso millet flour concentration in the proso millet composite flour.

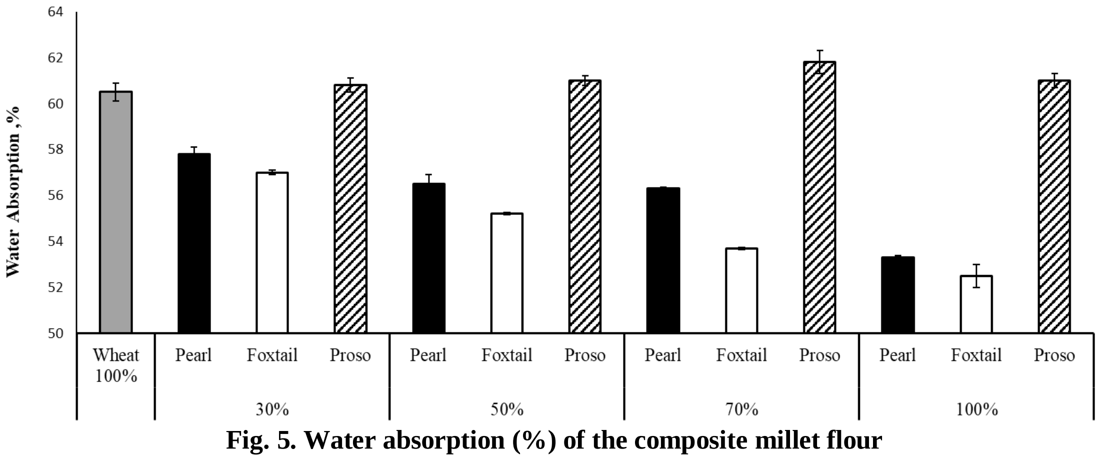


**Fig. 5. Water absorption (%) of the composite millet flour**

The reason for this behaviour lies in the fact that proso millet flour has almost the same water absorption as wheat flour (i.e. about 60%). No significant difference was found between the pearl millet and foxtail millet; however, the proso millet was found to differ significantly from the other two millets. Incorporation of the foxtail millet considerably affected the water absorption. The water absorption decreased with an increase in the pearl millet concentration in the dough. Also, the foxtail millet and the pearl millet in the concentration 30% had almost the same water absorption, and beyond this point, an increase in the millet concentration significantly affected both millet doughs. Of these two millets, the pearl millet showed better water absorption at higher concentrations. Any flours used in the baking process should have as good water absorption as possible since it may lead to greater dough flexibility, thus allowing a baker to produce baked products of good quality.

A similar change in the water absorption was observed by Sivaramakrishnan *et al.* (2004) and Saha *et al.* (2011) [35,16]. However, the changes in the water absorption did not follow any particular pattern in these studies. Saha *et al.* conducted a similar study of finger millet flour (2011) [16]. The dough resistance increased with an increase of wheat flour in the dough, but in terms of resistance to extension, only a small difference was observed. Sivaramakrishnan *et al.* (2004) studied the rheological properties of rice dough for producing rice bread and also found that incorporation of rice in wheat flour decreased the water absorption in the composite flour [35].

*Dough stability*

Stability of dough mainly depends on the proteins present in wheat flour. These proteins play a vital role in dough and in manufacture of bakery products. Wheat proteins can be categorised based on their functionality: gluten proteins, which generally account for 80–85% of total wheat protein, and non-gluten proteins, which constitute about 15–20% of total wheat protein [36]. Besides, wheat proteins can also be classified according to their solubility, first of all it relates to albumins, globulins, gliadins, and glutenins. Non-gluten proteins play a minimal role in dough development [22] and in the baking process. Wheat enzymes such as proteases [37] and endoxylanases [38] and enzyme inhibitors such as protease inhibitors and xylanase inhibitors [39] all have an effect on the bread making performance [40]. Dough stability is an important function and quality determinant of the dough. It determines its rheological behaviour and baking quality. Requirements to dough mixing and sensitivity to over-mixing depend on the quantity and quality of the proteins present in the flour, which also determines the rheological behaviour as well as gas the retention properties during fermentation [41]. Adding millet flour into wheat flour reduces gluten proteins, because millet flours lack gluten-forming protein fractions, which adversely effects on the dough stability. Indeed, the dough stability was affected significantly ($P<0.05$) by adding millet flours (Fig. 6). At any given composite flour concentration, the foxtail millet and the proso millet had a smaller effect on the dough stability than the pearl millet did. For example, all the millet flours exhibited lower dough stability compared with 100% wheat flour, which showed stability exceeding 11.5 minutes. Interestingly, the proso millet flour had a dough stability pattern different from that of the two other millet flours. With the proso millet proportion 3:7, the composite flour exhibited the highest dough stability in 12.5 minutes. However, an increase in the proso millet concentration in the composite flour decreased the dough stability as it was with the pearl millet and foxtail millet. The lowest dough stability (1.5 minutes) was observed with 100% of the pearl millet and foxtail millet flour, which is because of the inability to withstand the mixing process. The ability to withstand processes like mixing is mainly due to gluten-forming proteins in the flour. Thus, lack of gluten in the millets is a drawback when using millet flour in baking.

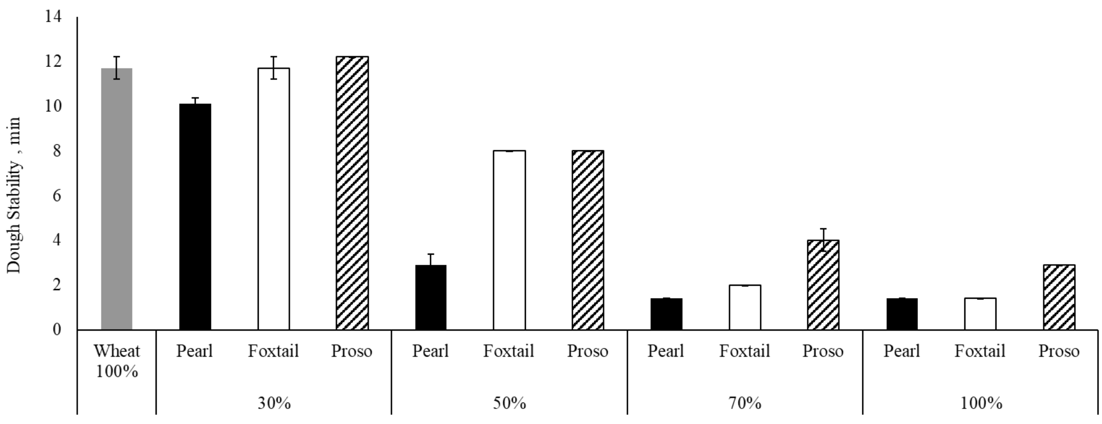


**Fig. 6. Dough stability (min) of the composite millet flour**

*Dough hardness*

The strength of the dough directly affects the baked product quality, and measuring the rheological properties provides crucial information about the dough strength and its potential to be processed into high quality baked products. Dough that is too strong does not allow proper development of the bubbles for dough rising and results in the formation of dense, unpalatable loaves of small volume. On the other hand, too weak dough cannot retain the bubbles and results in large holes in the loaf or in its collapsing. It is well known that in order to optimise the bread quality, mixing must be stopped after an appropriate level of mechanical input. The dough hardness was tested at various moisture levels and at different millet concentrations (Fig. 7). Incorporation of millet flour significantly affected the dough hardness ($P<0.05$). It increased with an increase in the millet flour content in the composite flour. The highest dough hardness was observed in 100% proso millet and the least was observed in 50% pearl millet composite flour. The proso millet was found to be significantly different ($P<0.05$) from the foxtail millet and the pearl millet. However, no statistically significant difference was found between the foxtail and the pearl millet dough. The dough hardness decreased with an increase in the water level in the dough. However, for all moisture levels, the proso millet showed higher hardness than the other two millet composite flours. For example, the 50 % proso millet composite flour dough resulted in 31.577N at the 80% moisture level, and the pearl millet composite flour dough at the same concentration and moisture level had the dough hardness 9.5N.

Dough hardness mainly depends on the gluten strength in the dough, and the gluten strength is basically derived from the presence of the gluten proteins' fractions and ratios. Also, the dough hardness depends on the carbohydrate composition of the flour. The interactions between the millet flour and the wheat flour components (such as protein-lipid interactions and protein-carbohydrate interactions) might be responsible for the higher dough hardness in the composite flour.

*Dynamic rheological properties of the dough*

Dynamic oscillation measurements are a fundamental methodology helping to study and understand the dough rheology. Usually, in oscillatory tests, samples undergo a harmonically varying stress or strain, which allows studying the viscoelastic behaviour. These findings are very delicate and sensitive to changes in the chemical composition and physical structure of the flour and dough [42]. Nowadays, dynamic rheological testing has become a powerful and ideal tool for examining the structure and understanding the fundamental properties and behaviour of wheat flour doughs [43]. The dynamic rheological properties of dough made from wheat flour are strongly influenced by the water and wheat protein content. An increased water content decreases the elastic and viscous modulus [44,45], but an increase in the protein content has been shown to decrease the sensitivity of the storage modulus (G′) and loss modulus (G″) to the water content [46]. Higher moduli were observed at higher protein levels [47], and the protein quality had a significant effect on dough properties [46].

Dynamic oscillation measurements of pearl millet, foxtail millet and proso millet composite flours are shown in Fig. 8-13. The protein and water contents have significantly influenced the dynamic rheological parameters of the dough. Addition of millet flour to wheat flour changed the protein content and water absorption characteristics. Besides the protein content, the protein quality, which is generally measured as the gliadin-to-glutenin ratio and the quantity of glutenin subunits (high and low molecular weight), also has an effect on the rheological properties of the dough [48]. However, little information is available on the specific effect the protein quality has on the dynamic oscillation properties of wheat flour dough. The storage modulus and loss modulus both increased with an increase in the frequency for 100% wheat flour dough as well as for all composite flour doughs tested.

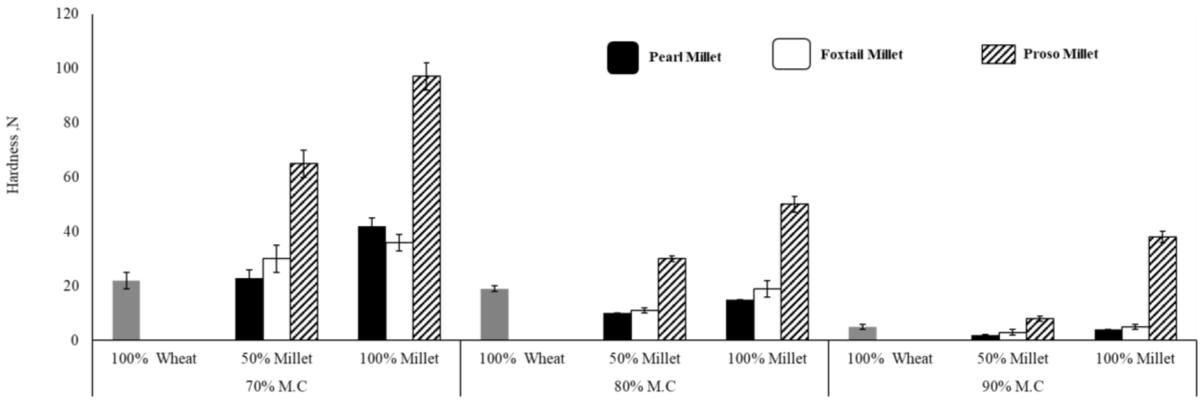


**Fig. 7. Changes in the hardness (N) of millet-incorporating dough depending on the millet concentration & the moisture content of the dough**

The moduli for composite flour doughs have been found to be higher than those of 100% wheat flour dough. The increased moduli might be due to the difference between the interactions of starch and gluten fractions in the composite flour. The higher modulus is probably a result of the strong bonds in the composite flour from the starch granules in the dough: the starch granules act as a filler material which reinforces the gluten matrix and produces stronger bonds. The moduli found in the pure millet dough were higher than in the pure wheat dough. Also, in the 100% millet dough, the values of the moduli changed significantly with changes in the frequency. All the wheat flour and composite flour doughs have shown the values of G′ higher than those of G″, which proved that the dough was rather elastic than viscous. Addition of millet flour into the wheat flour significantly (P<0.05) increased the storage modulus and loss modulus. All the millet flours (Fig. 8-13) exhibited similar tendencies in the values of G´ and G´´. However, the pearl millet produced a less pronounced effect on the dough than the other two millets did. For example, the value of G´ for the 10% pearl millet composite flour was around 605Pa, and the G´´ value was 317Pa. The other two millets, i.e. the doughs from foxtail millet and proso millet composite flours, had higher moduli even at lower concentrations of the millet incorporated. For example, the G´ and G´´ values of the 10% foxtail millet composite flour were around 1610Pa and 678Pa respectively. There was no significant difference between the wheat dough and the pearl millet dough in terms of G´. This means that the pearl millet flour is more suitable to replace wheat in the dough than the foxtail millet or the proso millet is. The loss modulus (G´´) values have been found to be significant (P<0.05) for all millets and all concentrations, and the pearl millet least affected the loss modulus values. These values (G´´) are much higher than those of 100% wheat dough moduli. This proves that even a minor quantity of millet flour can potentially change and influence notably the rheological properties of dough, especially its elasticity and viscosity.

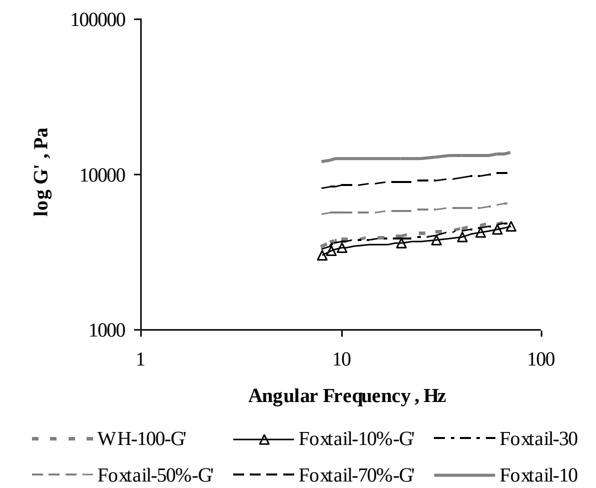


**Fig. 8. Storage modulus (G´) of foxtail millet-incorporating dough**

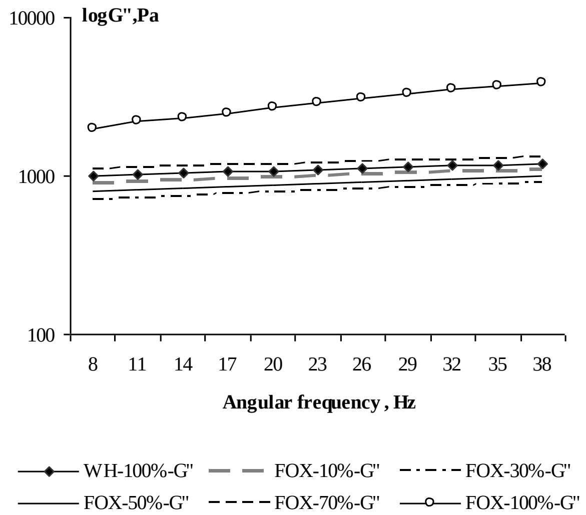


**Fig. 9. Loss modulus (G´´) of foxtail millet-incorporating dough**

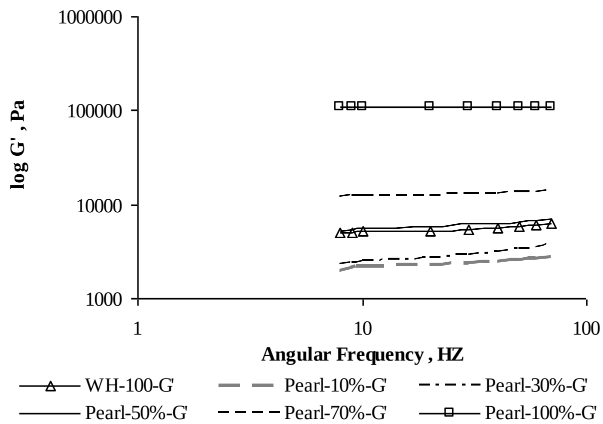


**Fig. 10. Storage modulus (G´) of pearl millet-incorporating dough**

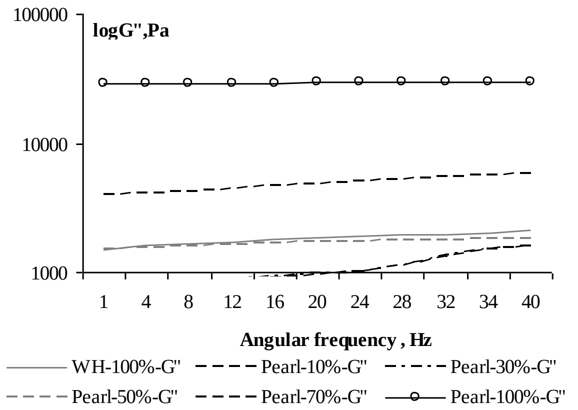


**Fig. 11. Loss modulus (G´´) of pearl millet-incorporating dough**

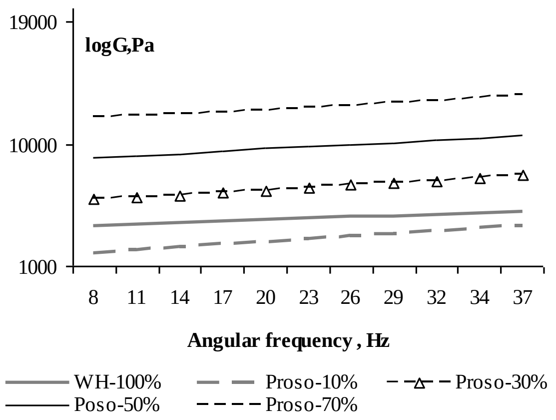


**Fig. 12. Storage modulus (G´) of proso millet-incorporating dough**

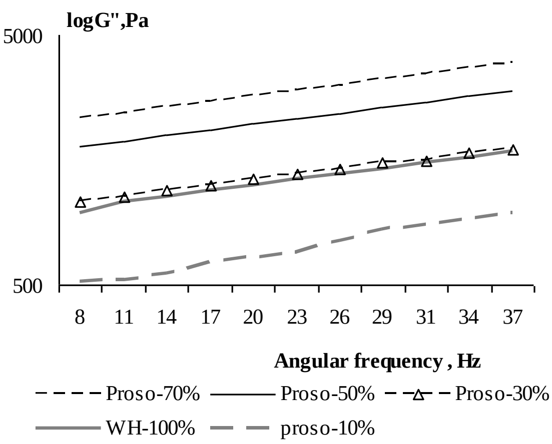


**Fig. 13. Loss modulus (G´´) of proso millet-incorporating dough**

## Conclusion

Millets are gaining attention due to their many advantages in cultivation and overall nutritional benefits. The primary raw materials of these processed products undergo various unit operations which involve incorporation or removal of water. Understanding the water absorption characteristics of millets is an important and first step in the promotion of millets in bakery products since the water absorption of dough largely depends upon the flour properties. This study highlights the possibility to predict the water absorption characteristics of millet grains, which could be used to optimise the steeping conditions of millets in various bioprocessing operations: fermentation, germination, malting, etc. The hardness of millets decreased with an increase in their moisture content. These data will be useful for designing post-harvest processing equipment intended for dehulling or milling. The effect of three minor millet flours in dough has been studied to understand their properties and behaviour better. All three millets affected the dynamic rheological properties of the dough. Among the three millets, proso millet flour highly affected the rheology of the dough. Proso millet flour significantly increased the hardness of the dough as compared to the pearl millet and the foxtail millet. The dough stability has also been found to be affected by all three millets flours. It has been established that the pearl millet has the smallest effect on the dough rheology. Dough hardness and dough stability were least affected in the dough from pearl millet composite flour. It is supposed that on performing proper baking trials to compare the properties of composite flours made from these millets, the results of the rheological studies will prove beneficial and the rheological properties and behaviour will be accurately correlated when the food is applied practically.

**References:**


1. Anderson E, Martin J. World production and consumption of millet and sorghum. Econ Bot. 1949;3(3):265-288. https://doi.org/10.1007/BF02859097
2. Gomez MI, Gupta SC, Millets C. Encyclopedia of Food Sciences and Nutrition. 2nd ed. Oxford: Benjamin Academic Press; 2003.
3. Singh KP, Mishra A, Mishra HN. Fuzzy analysis of sensory attributes of bread prepared from millet-based composite flours. LWT-Food Sci Technol. 2012;48(2):276-282. https://doi.org/10.1016/j.lwt.2012.03.026
4. Casey P, Lorenz K. Millet: functional and nutritional properties. Bakers Digest. 1977;51:45-51.
5. Gupta N, Srivastava AK, Pandey VN. Biodiversity and nutraceutical quality of some Indian millets. Biol Sci. 2012;82(2):265-273. https://doi.org/10.1007/s40011-012-0035-z
6. Truswell AS. Cereal grains and coronary heart disease. Eur J Clin Nutr. 2002;56(1):1-14. https://doi.org/10.1038/sj.ejcn.1601283
7. Chandrasekara A, Shahidi F. Bio accessibility and antioxidant potential of millet grain phenolics as affected by simulated in vitro digestion and microbial fermentation. J Funct Foods. 2012;4(1):226-237. https://doi.org/10.1016/j.jff.2011.11.001
8. Manach C, Mazur A, Scalbert A. Polyphenols and prevention of cardiovascular diseases. Curr Opin lipidol. 2005; 16(1): 77-84.
9. Spiller GA, editor. Handbook of Dietary fiber in human nutrition. 3rd ed. Boca Raton FL: CRC Press; 2001. Chapter 6.1. Miller G. Whole grain, fiber and antioxidants. *P.* 453-460.
10. Gallagher E, editor. Gluten-free Food Science and Technology. John Wiley & Sons, Ltd; 2009. Chapter 4. Thompson T. The nutritional quality of gluten-free foods. P. 42-51. https://doi.org/10.1002/9781444316209.ch4
11. Arendt EK, Bello FD, editiors. Gluten-Free Cereal Products and Beverages. Elsevier, Academic Press; 2008. Chapter 6. Taylor J, Emmambux M. Gluten-free foods and beverages from millets.; 119-148. https://doi.org/10.1016/B978-012373739-7.50008-3
12. Kotsianis IS, Giannou V, Tzia C. Production and packaging of bakery products using MAP technology. Trends Food Sci Technol. 2002;13(9-10):319-324. https://doi.org/10.1016/S0924-2244(02)00162-0
13. Chavan JK, Kadam SS, Reddy NR. Nutritional enrichment of bakery products by supplementation with nonwheat flours. Crit Rev Food Sci Nutr. 1993;33(3):189-226. https://doi.org/10.1080/10408399309527620
14. Afkhami F, Ouyang W, Chen H, Lawuyi B, Lim T, Prakash S. Impact of Orally Administered Microcapsules on Gastrointestinal Microbial Flora: In Vitro Investigation Using Computer Controlled Dynamic Human Gastrointestinal Model. Artif Cells, Blood Sub Biotechnol. 2007;35(4):359-375. https://doi.org/10.1080/10731190701460226

15. Chakraborty S, Kumbhar B, Chakraborty S, Yadav P. Influence of processing parameters on textural characteristics and overall acceptability of millet enriched biscuits using response surface methodology. J Food Sci Technol. 2011;48(2):167-174. https://doi.org/10.1007/s13197-010-0164-4
16. Saha S, Gupta A, Singh SRK, Bharti N, Singh KP, Mahajan V, et al. Compositional and varietal influence of finger millet flour on rheological properties of dough and quality of biscuit. LWT - Food Sci Technol. 2011;44(3):616-621. https://doi.org/10.1016/j.lwt.2010.08.009
17. Rajiv J, Soumya C, Indrani D, Venkateswara Rao G. Effect of replacement of wheat flour with finger millet flour (Eleusine corcana) on the batter microscopy, rheology and quality characteristics of muffins. J Texture Stud. 2011;42(6):478-489. https://doi.org/10.1111/j.1745-4603.2011.00309.x
18. Brennan MA, Menard C, Roudaut G, Brennan CS. Amaranth, millet and buckwheat flours affect the physical properties of extruded breakfast cereals and modulates their potential glycaemic impact. Starch - Stärke. 2012;64(5):392-398. https://doi.org/10.1002/star.201100150
19. Agu RC. Comparative study of experimental beers brewed from millet, sorghum and barley malts. Process Biochem. 1995;30(4):311-315. https://doi.org/10.1016/0032-9592(95)87039-3
20. Zarnkow M, Keßler M, Back W, Arendt EK, Gastl M. Optimisation of the Mashing Procedure for 100% Malted Proso Millet (Panicum miliaceum L.) as a Raw Material for Gluten-free Beverages and Beers. J Inst Brew. 2010;116(2):141-150. https://doi.org/10.1002/j.2050-0416.2010.tb00410.x
21. Jideani VA. Optimisation of wheat-sprouted soybean flour bread using response surface methodology. Afr J Biotechnol. 2009;8(22):6364-6373. https://doi.org/10.5897/AJB09.707
22. Goesaert H, Brijs K, Veraverbeke WS, Courtin CM, Gebruers K, Delcour JA Wheat flour constituents: how they impact bread quality, and how to impact their functionality. Trends Food Sci & Technol. 2005;16(1-3):12-30. https://doi.org/10.1016/j.tifs.2004.02.011
23. Niba LL, Bokonga MM, Jackson EL, Schlimme DS, Li BW. Physicochemical properties and starch granular characteristics of flour from various Manihot esculenta (cassava) genotypes. J Food Sci. 2002;67(5):1701-1705. https://doi.org/10.1111/j.1365-2621.2002.tb08709.x
24. Huang S, Miskelly D. Steamed Breads: Ingredients, Process and Quality. Oxford: Wood head publishing; 2016.
25. Julianti E, Rusmarilin H, Yusraini E. Functional and rheological properties of composite flour from sweet potato, maize, soybean and xanthan gum. Journal of the Saudi Society of Agricultural Sciences. 2017;16(2):171-177. https://doi.org/10.1016/j.jssas.2015.05.005
26. Sang S, Xu D, Ma Y, Jin Y, Wu F, Xu X. Effect of egg yolk on the properties of wheat dough and bread. Food Biosci. 2020;37:100689. https://doi.org/10.1016/j.fbio.2020.100689
27. Maskan M. Effect of processing on hydration kinetics of three wheat products of the same variety. J Food Eng. 2002;52(4):337-341. https://doi.org/10.1016/S0260-8774(01)00124-8
28. Kaptso KG, Njintang YN, Komnek AE, Hounhouigan J, Scher J, Mbofung CMF. Physical properties and rehydration kinetics of two varieties of cowpea (*Vigna unguiculata*) and Bambara groundnuts (*Voandzeia subterranea*) seeds. J Food Eng. 2008;86(1):91-99. https://doi.org/10.1016/j.jfoodeng.2007.09.014
29. Moreira R, Chenlo F, Chaguri L, Fernandes C. Water absorption, texture, and color kinetics of air-dried chestnuts during rehydration. J Food Eng. 2008;86(4):584-594. https://doi.org/10.1016/j.jfoodeng.2007.11.012
30. Bello M, Tolaba MP, Suarez C. Factor's affecting water uptake of rice grain during soaking. LWT-Food Sci Technol. 2004;37(8):811-816. https://doi.org/10.1016/j.lwt.2004.02.014
31. Solomon WK. Hydration kinetics of lupin (*Lupinus albus*) seeds. J Food Process Eng. 2007;30(1):119-130. https://doi.org/10.1111/j.1745-4530.2007.00098.x
32. Hsu KH. Effect of temperature on water diffusion in soybean. J Food Sci. 1983;48(4):1364-1365. https://doi.org/10.1111/j.1365-2621.1983.tb09236.x
33. Ituen EUU, Mittal JP, Adeoti JS. Water absorption in cereal grains and its effect on their rupture stress. J Food Process Eng. 1986;8(3):147-158. https://doi.org/10.1111/j.1745-4530.1986.tb00108.x
34. Sopade PA, Ajisegiri ES, Badau MH. The use of Peleg's equation to model water absorption in some cereal grains during soaking. J Food Eng. 1992;15(4):269-283. https://doi.org/10.1016/0260-8774(92)90010-4
35. Sivaramakrishnan HP, Senge B, Chattopadhyay PK. Rheological properties of rice dough for making rice bread. J Food Eng. 2004;62(1):37-45. https://doi.org/10.1016/S0260-8774(03)00169-9
36. Veraverbeke WS, Delcour JA. Wheat protein composition and properties of wheat glutenin in relation to breadmaking functionality. Crit Rev Food Sci. Nutr. 2002;42(3):179-208. https://doi.org/10.1080/10408690290825510
37. Bleukx W, Brijs K, Torrekens S, Van Leuven F, Delcour JA. Specificity of a wheat gluten aspartic proteinase. Biochimica et Biophysica Acta (BBA) – Protein Structure and Molecular Enzymology. 1998;1387(1-2):317-324. https://doi.org/10.1016/S0167-4838(98)00146-0
38. Cleemput G, Hessing M, van Oort M, Deconynck M, Delcour JA. Purification and Characterization of a β-D-Xylosidase and an Endo-Xylanase from Wheat Flour. Plant Physiol. 1997;113(2):377-386. https://doi.org/10.1104/pp.113.2.377
39. Debyser W, Derdelinckx G, Delcour J. Arabinoxylan solubilization and inhibition of the barley malt xylanolytic system by wheat during mashing with wheat wholemeal adjunct: evidence for a new class of enzyme inhibitors in wheat. J Am Soc Brew Chem. 1997;55(4):153-156. https://doi.org/10.1094/ASBCJ-55-0153
40. Eliasson AC, Larsson K, editors. Cereals in breadmaking: a molecular colloidal approach. New York: Marcel Dekker; 1993.
41. Gan Z, Ellis PR, Schofield JD. Gas Cell Stabilisation and Gas Retention in Wheat Bread Dough. J. Cereal Sci. 1995;21(3):215-230. https://doi.org/10.1006/jcrs.1995.0025
42. Steffe JF. Rheological methods in food process engineering. East Lansing: Freeman press; 1996.
43. Song Y, Zheng Q. Dynamic rheological properties of wheat flour dough and proteins. Trends Food Sci Technol. 2007;18(3):132-138. https://doi.org/10.1016/j.tifs.2006.11.003
44. Létang C, Piau M, Verdier C. Characterization of wheat flour–water doughs. Part I: Rheometry and microstructure. J Food Eng. 1999;41(2):121-132. https://doi.org/10.1016/S0260-8774(99)00082-5
45. Masi P, Cavella S, Sepe M. Characterization of Dynamic Viscoelastic Behavior of Wheat Flour Doughs at Different Moisture Contents. Cereal Chem J. 1998;75(4):428-432. https://doi.org/10.1094/CCHEM.1998.75.4.428
46. Smith TL, Tschoegl NW. Rheological properties of wheat flour doughs. V. Creep and creep recovery in simple tension. Rheologica Acta. 1970;9(3):339-344.
47. Navickis LL, Anderson RA, Bagley EB, Jasberg BK. Viscoelastic properties of wheat flour doughs: variation of dynamic moduli with water and protein content1. J Texture Stud. 1982;13(2):249-264. https://doi.org/10.1111/j.1745-4603.1982.tb01399.x
48. Uthayakumaran S, Stoddard FL, Gras PW, Bekes F. Effects of incorporated glutenins on functional properties of wheat dough. Cereal Chem. 2000;77(6):737-743. https://doi.org/10.1094/CCHEM.2000.77.6.737