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EFFECTS OF RHEOLOGICAL BEHAVIOR ON CEREAL LEGUMES BLENDED FLOURS

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ABSTRACT

The farinograph and mixograph are the most commonly used empirical instruments to determine three parameters: 1) characterize dough rheology; 2) evaluate dough performance during processing; 3) and quality control. Maize, chickpea, and soybean flours ranging from 10% to 50% (in 10% increments) were blended with wheat flour to prepare composite flours for rheological studies. Mixographic results indicated that as flour percentages increased among treatments, peak times and mixing tolerance indices increased. Farinographic results indicated that as flour percentages increased, an increase in water absorption with a concurrent decrease in development and dough stability times due to less gluten content occurred.

Keywords: : Rheology, Mixograph, Farinograph, Cereals, Legumes

INTRODUCTION

Rheology is the study of materials' flow and disfigurement. Generally, it is measured after a controlled, well-defined stress has been applied to a material over a given time, and the resulting force response is measured to give an indication of different material parameters such as stiffness, modulus, viscosity, hardness, strength, and/or toughness. It can also be related to product functionality (**Dobraszczyk and Morgenstern, 2003**). Food rheology focuses on the flow properties of single food components (which might display a complex rheological response function), the flow of a composite food matrix, and the effect of processing on a food's structure and properties. For processed food, the composition and addition of ingredients to obtain a certain food quality and product performance requires deep rheological understanding of single ingredients, their relation to food processing, and the ability to discern different qualities (**Fischer and Erich, 2011**).
Dough rheological techniques are frequently used for the analysis of wheat flour baking value (**Hruskova *et al*., 2006**). A dough's distinctive rheological features can help to predict its expected behavior under various processing conditions that in turn may help select suitable raw materials and their proportions in addition to appropriate processing equipment. As a result of these choices, the quality of the finished product, including texture, and hence, consumer acceptability, will be affected. The role of water content in the final product quality plays an important role as it acts as a plasticizer that significantly affects rheological behavior (**Bhattacharya *et al*., 2006**). Rheological properties of materials depend on the structure and also on the arrangement of ingredients and the forces between them (**Singh *et al*., 2002**). A dough's rheological properties depend on aggregate structure and the tendency to interact with each other (**Bushuk, 1985**). A dough's rheological characteristics are important, as these characteristics affect both the dough's machinability and the quality of the end product. Among the cereal flours, only wheat flour can form a three-dimensional viscoelastic dough when mixed with water. Characterization of a dough's rheological properties is oppressive in predicting the processing behavior and in controlling the quality of food products (**Song and Qiang, 2007**). A flour's water absorption capacity often defines its quality and tendency to form viscoelastic dough. Flour hydration is crucial in the food industry, because it affects its functional properties and the quality of cooking products (**Berton *et al*., 2002**).

Mixing is a critical operation in food processing in which the structure of the food is often formed after it is mixed. Most studies about dough have concentrated on the relationships between mixing, rheology, and baking performance because rheological changes occur in the gluten viscoelastic network during mixing and are very important for product quality. The nature of the mixing action develops the viscoelastic properties of the gluten and also incorporates air, which has a major effect on a dough's rheology and texture (**Dobraszczyk and Morgenstern, 2003**). Mixing results in the hydration of flour particles leading to the development of the gluten matrix. Air is also incorporated into the system during mixing (**Singh *et al*., 2002**). In the case of wheat dough, rheological analysis has been successfully applied as an indicator of the molecular structure of gluten and starch and as a predictor of their functionality in baking performance (**Collar and Bollain, 2005; Bollain *et al*., 2006**). Since gluten free matrices are structurally different than gluten dough, rheological assessment of the gluten free matrices might give an indication of their functionality. The cohesiveness of wheat dough was significantly affected only by soybean protein content (Marco and Cristina, 2008). Soybean proteins shows higher emulsifying activity and emulsion stability than wheat gluten (**Tomoskozi et al., 2001**). Soybean is used in food technology for adding desirable functional properties such as emulsification, fat absorption, moisture holding capacity, thickening, and foaming (**Wolf, 1970**). The addition of 20% soy flour to wheat produced a significant positive effect on the emulsifying activity of the samples (**Ahn and Kim, 2005**).

MATERIAL AND METHODS

Procurement of raw materials

Wheat (Triticum aestivum L.), maize/corn (Zea mays L.), soybean (Glycine max L.), and chickpea (Cicer arietinum L.) were purchased from the local market (Faisalabad, Pakistan) to make cereal-legume blended flours.

Preparation of raw materials

The raw materials were cleaned manually to remove dirt, dust, damaged seeds, seeds of other crops, and foreign matter. Wheat, maize, soybean, and chickpea particles were reduced to fine flour with experimental mills.

Preparation of flour blends

Maize, chickpea, and soybean flours were blended with wheat flour in different combinations to prepare composite flours (Table 1). Each treatment of composite flour was thoroughly mixed and sieved in order to achieve uniform mixing of legume flours with wheat flour.

Table 1 Treatments used to prepare composite flours.

Treatments	Wheat Flour (%)	Maize Flour (%)	Chickpea Flour (%)	Soybean Flour (%)
T_1	100	-	-	-
T_2	90	10	-	-
T_3	80	20	-	-
T_4	70	30	-	-
T_5	60	40	-	-
T_6	50	50	-	-
T_7	90	-	10	-
T_8	80	-	20	-
T_9	70	-	30	-
T_{10}	60	-	40	-
T_{11}	50	-	50	-
T_{12}	90	-	-	10
T_{13}	80	-	-	20
T_{14}	70	-	-	30
T_{15}	60	-	-	40
T_{16}	50	-	-	50
T_{17}	90	3.33	3.33	3.33
T_{18}	80	6.66	6.66	6.66
T_{19}	70	10	10	10
T_{20}	60	13.33	13.33	13.33
T_{21}	50	16.66	16.66	16.66

Rheological studies

Mixograph

Rheological behavior of different flour samples was determined with a mixograph (Model: National Mfg. Co., Lincoln, Nebraska) using the method described in AACC Method No. 54-40A (AACC, 2000). A 10 g flour sample was added to the mixing bowl of the mixograph. After dry mixing for 1 min, 6 mL water was added and mixing was continued for 10 min. Peak time and mixing tolerance were analyzed with the mixograph.

Farinograph

The rheological behavior of composite flour samples was evaluated by using a Brabender farinograph (Model: Brabender DUISBURG 380, Germany) according to method described in AACC Method No. 54-21 (AACC, 2000). A 50 g flour sample was added to the farinograph bowl. Dry mixing was continued for 1 min. Water was added until the farinograph reached the 500 BU line. The farinograph ran for 20 min at 30°C. Dough properties such as water absorption, arrival and departure times, dough stability, dough development time, and tolerance index were measured by the farinograph.

Statistical analysis

The data obtained for each parameter was subject to statistical analysis to determine the significance level (analysis of variance) in a completely randomized design as described by Steel et al. (1997). Means were further compared through Duncan's Multiple Range Test to determine significance differences.

RESULTS AND DISCUSSIONS

Different wheat varieties found in Pakistan contained varied rheological characteristics. Results showed 55.20%–62.13% water absorption, 3.33–16.42 min dough stability time, and 3.58–9.92 min dough development time for different Pakistani wheat varieties (**Huma, 2004**). Water absorption of different wheat varieties ranged from 58.1%–66.4%, and the dough development time had an average value of 6 min (**Hruskova *et al.*, 2006**). In another study, wheat had 53.6% water absorption and 1.53 and 1.40 min for dough development and dough stability times, respectively (**Paraskevopoulou *et al.*, 2010**). Studies showed that Irish, Greek, and Canadian wheat varieties had water absorption, dough development and dough stability times ranging from 50.7%–65.5%, 1.5–6 min, and 1–5 min, respectively **(Ktenioudaki *et al.*, 2010**). An increase in the water absorption and both dough development and dough stability times as the concentration of chickpea increased was reported (**Shahzadi *et al.*, 2005**). As the proportion of soy flour increased, a slight increase in water absorption and decrease in dough stability occurred (**Senthil *et al.*, 2002**).

Mixographic studies

A mixograph is the best predictor for chewiness and firmness. Because the mixograph test is simple, it requires relatively small sample sizes, and the results correlate significantly with sensory data. It is the most useful test to predict the end use quality (**Kovacs *et al*., 1997**). The rheological behavior of individual flour blend samples in our study was evaluated by using a mixograph. Mean squares for peak times and mixing tolerance indices of flour blends showed significant differences due to different flour combinations (Table 2).

Table 2 Mean squares for peak time and mixing tolerance index of different composite flour samples.

SOV	df	Peak Time	Mixing Tolerence
Treatment	20	36.788**	33.094**
Error	42	0.416	0.821

**Highly significant (P<0.01)

Means for the peak time in different composite flour samples in Table 3 showed that the maximum peak time obtained by T_{19} was 7.33 min followed by T_{18} (6.63 min) while the minimum attained by T_{21} was 1.10 min followed by T_{11} (1.25 min) and T_{16} (1.38 min). The peak mixograph times for different flour blends varied from 1.10– 7.33 min. An increasing trend in maximum peak time was observed in wheat-maize flour blends followed by wheat-chickpea and wheat-soybean flour blends. Means comparison for mixing tolerance indices indicated that the highest value was shown by T_{18} (11.63 min) followed by T_6 (11.50 min) and T_{19} (11.17 min), while the lowest was observed in T_{16} (6.38 min) followed by T_{11} (6.25 min) and T_{21} (6.13 min). These treatments were found to be no significantly different with respect to each other (Table 3). The mixing tolerance index ranged from 6.13–11.63 min within different treatments. It is obvious from the results that as the percentage of flour increased, peak times and mixing tolerance indices also increased. From the mixograph, the mixing time varied from 2.3–7.9 min and peak dough resistance from 52.3–65.2 AU. The values for both dough development and dough stability times decreased with reduced protein content, but the value of the mixing tolerance index increased (**Roa *et al.*, 2000**). Figure 1 depicts the results related to all 21 treatments.

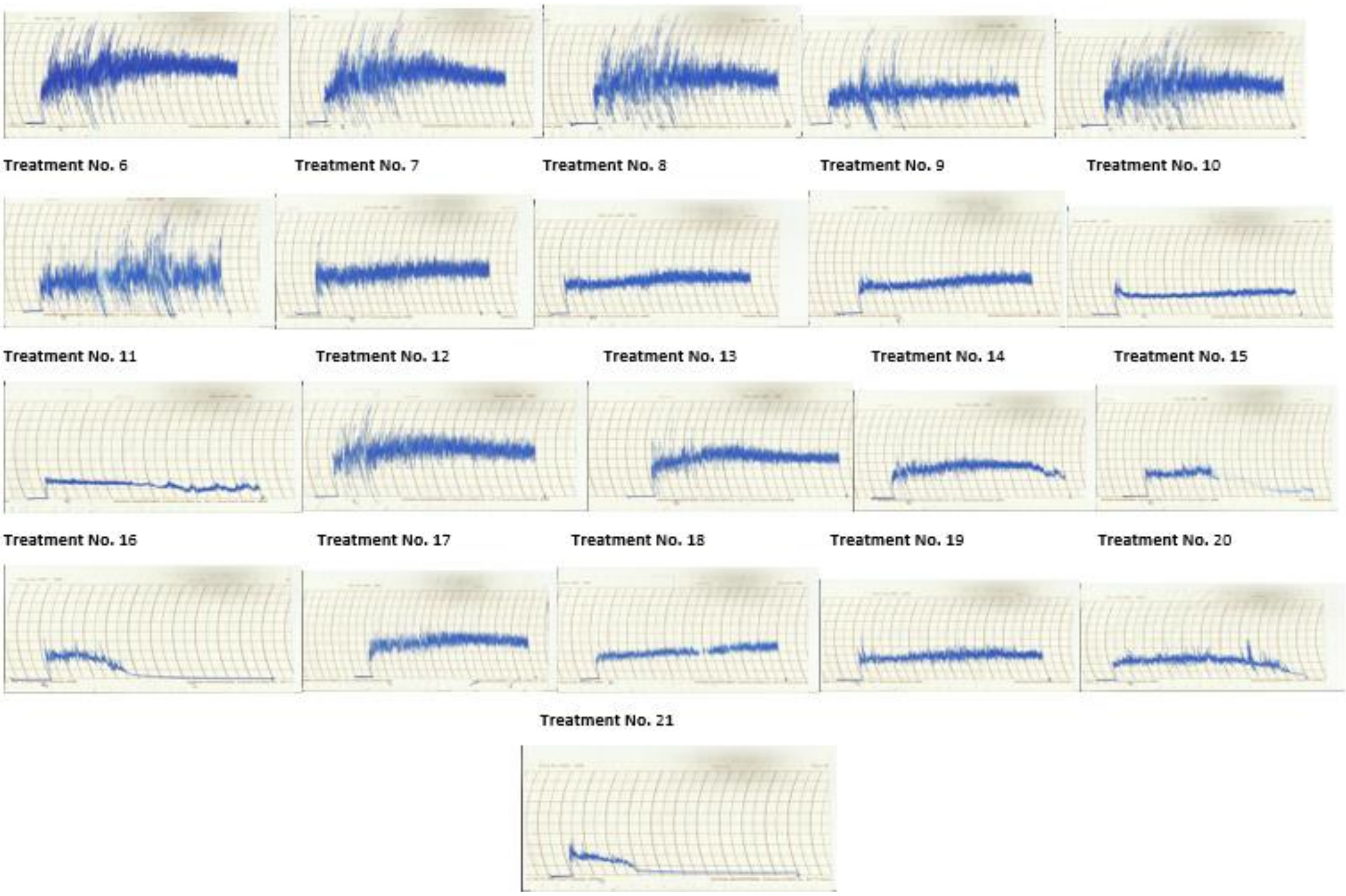

Figure 1 Mixographic results related to all treatments

Table 3 Comparison of means for peak time (minute) and mixing tolerance index of different composite flour samples by mixograph.

Treatments	Peak Time	Mixing Tolerance
1	4.00 ^{fgh}	9.00 ^{ghi}
2	3.88 ^{gh}	8.88 ^{ghi}
3	3.88 ^{gh}	8.88 ^{ghi}
4	4.50 ^{f}	9.50 ^{fg}
5	5.50 ^{de}	10.49 ^{cde}
6	6.50 ^{bc}	11.50 ^{ab}
7	5.25 ^{e}	10.25 ^{def}
8	5.25 ^{e}	10.13 ^{ef}
9	5.75 ^{de}	10.75 ^{be}
10	6.00 ^{cd}	11.00 ^{ad}
11	1.25 ^{k}	6.25 ^{k}
12	3.25 ^{ij}	8.25 ^{ij}
13	3.50 ^{hi}	8.50 ^{hij}
14	4.13 ^{fg}	9.13 ^{gh}
15	2.88 ^{j}	7.75 ^{j}
16	1.38 ^{k}	6.38 ^{k}
17	3.75 ^{ghi}	8.75 ^{ghi}
18	6.63 ^{b}	11.63 ^{a}
19	7.33 ^{a}	11.17 ^{abc}
20	3.29 ^{ij}	8.38 ^{hij}
21	1.10 ^{k}	6.13 ^{k}

Means sharing similar letter in a column are statistically non-significant (P>0.05).

Farinographic studies

A farinograph characteristic is dough development time, which is the time from water addition to the flour until the dough reaches the point of greatest torque. During this phase of mixing, the water hydrates the flour components, and the dough starts to develop. Dough stability is defined as the time difference between the point in which the top of the curve first intercepts the 500 BU line and the point where the top of the curve leaves the 500 BU line or difference between arrival and departure time (**Fulei *et al.*, 2008**). The rheological characteristics of different flour blends were evaluated with a Brabender farinograph. Mean squares for water absorption and peak and dough stability times indicated that non-significant variations prevailed among different composite flours (Table 4). Farinographic characteristics of flour blends showed that as the level of flour blends in composite dough increased, farinographic absorption and mixing tolerance index increased, but mixing and dough stability times decreased (**Doxastakisa *et al.*, 2002**).

Table 4 Mean squares for water absorption, peak time and dough development time for different composite flour samples.

SOV	df	Water Absorption	Peak Time	Dough Stability
Treatment	20	65.138**	149.940**	207.721**
Error	42	0.179	0.398	0.408

**Highly significant (P<0.01)

Means for water absorption of different flour samples indicated the water absorption ranged from 54.25% to 64.20% in different flour compositions (Table 5). The highest value was noted in T_{17} (64.20%) followed by T_{16} (63.38%) and T_{18} (63.30%), while the lowest water absorption was found in T_{19} (59.62%) followed by T_4 (59.42%). Treatments T_{16}, T_{18}, and T_{19}, T_4 were found to be non-significant with respect to each other. Results from different composite flour samples showed that water absorption increased as the quantity of legume flour increased (**Sharif, 2009**). In this study, an increase in chickpea flour quantity also led to an increase in water absorption requirements. In T_6 to T_{11}, which contained different percentages of chickpea flour, a gradual increase in water absorption was observed. Similarly, water absorption in T_{12} to T_{16} increased as the percentage of soybean flour increased (**Senthil *et al.*, 2002**). Results indicate that as corn flour percentages increased, water absorption decreased. Similarly, in all flour blends containing corn, chickpea, and soybean flours, an increase in flour quantity resulted in a decrease in water absorption. Higher water absorption was noted in soybean flour followed by chickpea flour, while the lowest was observed with corn flours. In T_1 (100% wheat), 62.20% water absorption was noted. That result matched the findings of **Hruskova et al. (2006)** who reported that water absorption of different wheat varieties ranged from 58.1% to 66.4%.

Means of peak stability times for different composite flours indicated that variations existed in peak times among treatments (Table 5). In the present study, the highest peak time (20.37 min) was observed in T_6 (50% corn), T_5 (40% corn) and T_4 (30% corn) had peak stability times of 16 and 13.63 min, respectively. Composite flour samples containing corn showed higher peak stability times. Peak stability times of different flour combinations ranged from 6 to 20.37 min. As the percentage of corn flour increased in wheat-corn combinations, a decrease in peak stability time was noted. Similarly, in all flour blends (T_{17}-T_{21}), the same pattern was noted. With the addition of chickpea and soybean from 10% to 50% levels, peak stability times decreased in accordance with the results of **Dobraszczkisa and Morgenstern (2003)**, who reported that as the level of flour blends increased, peak stability time decreased. This decreasing trend might be due to a decrease in gluten content. In wheat flour, the peak stability time was recorded as 5.50 min and was similar to that described by **Ktenioudaki et al. (2010)** in which peak stability times ranged between 1.5–6 min in different wheat varieties. Dough stability mean times for different flour samples are shown in Table 5. Dough stability time ranged from 4.25 to 17.25 min for different flour combinations. The highest dough stability was recorded in T_{17} (17.25 min) followed by T_7 (16.13 min), while the lowest was found in T_{16} (4.25 min). High stability time was found in wheat-maize flour blends followed by wheat-chickpea and wheat-soybean flour blends. The decreasing trend in wheat-maize flour combinations ranged from 15.50–11.38 min. In wheat-chickpea flour combinations it ranged from 16.13 to 12.88 min, and in wheat-soybean flour blends it ranged from 15.13 to 4.25 min. In all flour blends it ranged from 17.25 to 5.88 min. It is obvious from the results that dough stability times decreased within treatments and appear to be associated with reduced protein content. Figure 2 depicts all results related to farinograph of 21 treatments.

Table 5 Comparison of means for water absorption (%), peak time (min) and dough stability (min) of different composite flour samples by farinograph.

Treatments	Water Absorption	Peak Time	Dough Stability
1	61.65^{g}	6.75^{k}	11.25^{i}
2	61.15^{h}	8.75^{de}	15.50^{cd}
3	60.92^{h}	9.13^{d}	15.00^{de}
4	59.42^{j}	13.63^{c}	13.50^{f}
5	57.38^{k}	16.00^{b}	11.38^{i}
6	54.25^{l}	20.37^{a}	12.25^{h}
7	61.92^{fg}	8.25^{ef}	16.13^{b}
8	62.20^{f}	9.00^{d}	15.75^{bc}
9	62.78^{de}	8.00^{fg}	15.13^{de}
10	62.88^{cde}	8.25^{ef}	13.88^{f}
11	63.22^{bc}	7.00^{ijk}	12.88^{g}
12	62.70^{e}	7.50^{ghi}	15.13^{de}
13	62.65_{e}	6.00^{l}	7.88^{j}
14	62.88^{cde}	6.63^{k}	5.13^{m}
15	63.10^{bcd}	7.00^{ijk}	5.13^{m}
16	63.38^{b}	7.00^{ijk}	4.25^{n}
17	64.20^{a}	8.75^{de}	17.25^{a}
18	63.30^{b}	7.75^{fgh}	14.88^{e}
19	59.62^{j}	7.38^{hij}	12.38^{gh}
20	61.20^{h}	6.63^{k}	7.25^{k}
21	60.03^{i}	6.88^{jk}	5.88^{l}

Means sharing similar letter in a column are statistically non-significant ($P>0.05$).

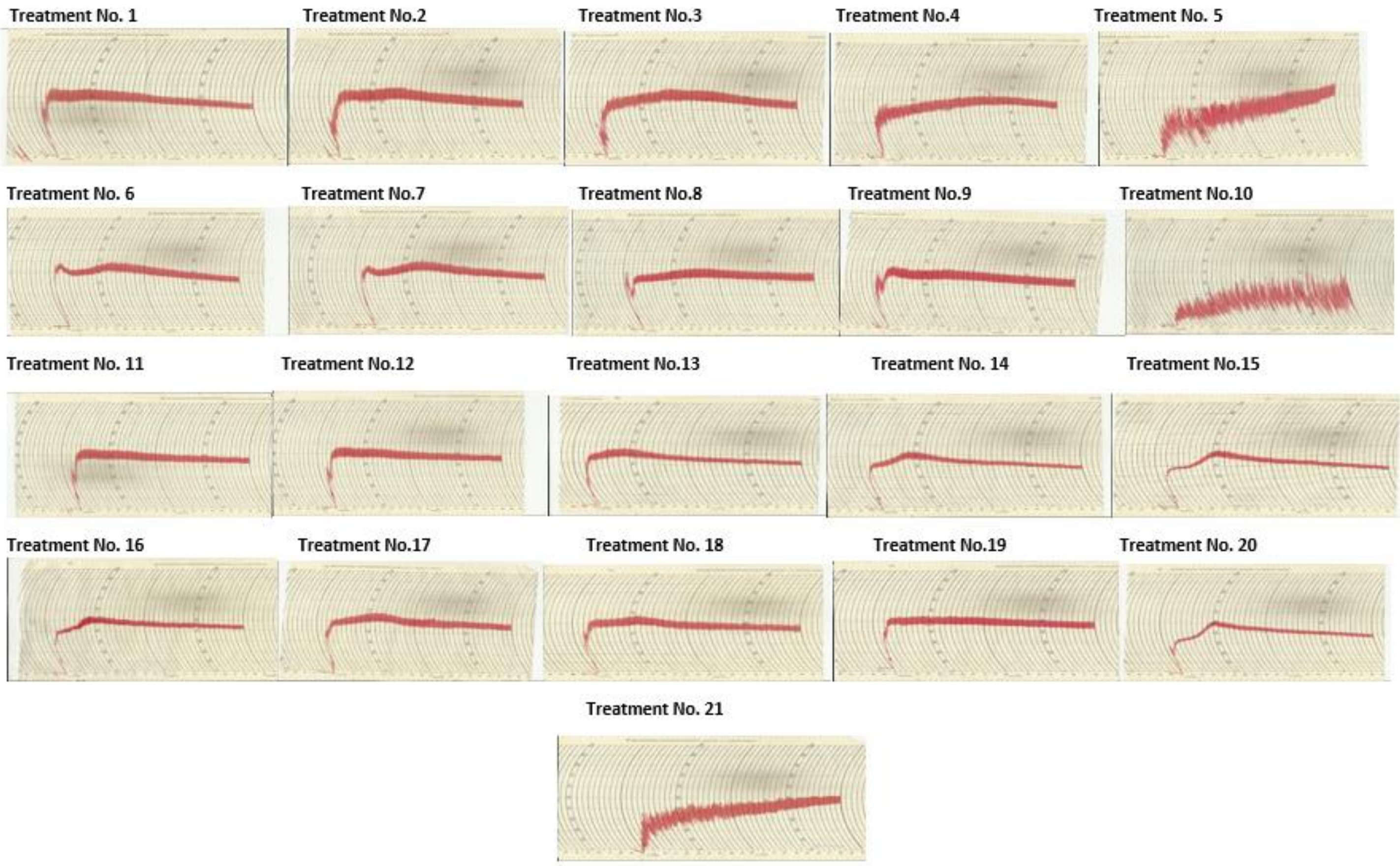

Figure 2 farinograph results related to 21 treatmens

CONCLUSION

From the results of the study, it can be concluded that rheological characteristics of composite flour within treatments differ significantly. Mixographic studies showed that increasing different flour combinations among treatments produced an increase in peak stability times and mixing tolerance indices. Farinographic studies indicated that the amount of water required for making dough increased, and the strength of the dough decreased with increasing legume levels due to the lack of gluten. As the concentration of flour levels increased within treatments, there was a decrease in both development and dough stability times. Less gluten content and more requirements for water will not necessarily

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