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Wheat flour solvent retention capacity, pasting and gel texture

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RESEARCH ARTICLE

Abstract

The effects of chickpea (CP), Turkish beans (TB), and black cumin (BC) meals on the solvent retention (SRC), pasting, gel texture, and gluten acid method values of wheat flour were determined. Wheat flour was replaced by meals at 5, 10, and 15%. The pasting and textural properties of the flour-gel were determined using a rapid viscoanalyser and a texture analyser. The average SRC water absorption (WSRC), sodium bicarbonate (SBSRC), lactic acid (LASRC), and sugar solution (SUSRC) values for the control were 67, 69, 106 and 113%, respectively. The highest average values of the 10% TB meal replacement for WSRC, SBSRC, LASRC, and SUSRC were 74, 75, 105 and 115%, respectively. BC blends exhibited SRC and pasting properties values lower than TB and CP indicating a large influence of BC on the functional properties of the flour. Except for springiness, all other gel texture parameters were lower for BC blends. The gluten acid test results showed evidence for a BC/glutenin interaction. Overall, BC had more influence on the control flour with respect to water absorption or WSRC.

Keywords: wheat, chickpea, RVA, black cumin, Turkish beans

1. Introduction

The relationship between wheat flour quality and dough rheology measured by mechanical dough property testing instruments, such as Farinograph, Mixograph, and Extensograph, is used to determine the suitability of the flour for specific baked products (e.g. bread, cookies, and cakes). The ratio of glutenin to gliadin defines the quality of the flour because it is directly related to viscoelasticity or strength of the dough (Khatkar *et al.*, 1995). Farinograph and Mixograph are typically used to obtain information on wheat flour's water-absorption capacity and gluten strength (Shogren, 1990; Shuey, 1984). Dynamic oscillatory measurements involving small deformation is a fundamental approach and is being preferred for evaluating wheat flour quality (Singh, 2011). A correlation was established between dynamic moduli of wheat flour dough measured by dynamic rheometer and the rheological properties measured by empirical methods, such as the Farinograph (Singh and Singh, 2013). The rheological properties of wheat flour dough are critically influenced by water absorption, gluten elastic properties and salt (Ren *et al.*, 2008). In general, flours suitable for cookie making require low water absorption, weak gluten, and arabinoxylans (Kweon *et al.*, 2011).

Solvent retention capacity (SRC) is a solvation test for flours that is based on the excessive swelling behaviour of polymer networks in particular specific solvents. SRC is a solvent-compatibility measure for the three main functional polymeric components of wheat flour: gluten, damaged starch, and pentosan. This in turn, facilitates the prediction of the functional role of each of these components to overall flour functionality. Four diagnostic SRC solvents, i.e. water, diluted aqueous lactic acid, diluted aqueous sodium carbonate, and concentrated aqueous sucrose solutions, are used for determining the SRC value. It is critical to use a SRC pattern of values rather than any single individual SRC solvent value for determining successful end-use applications for the tested flour. SRC is adopted by the AACC as method number 56-11, 2000 (AACCI, 2000). In this test, four different solutions: lactic acid, sucrose, water and sodium carbonate are used to provide information on chemical and physical aspects of wheat samples. In general, lactic acid SRC (LASRC) values are associated with glutenin characteristics, sodium carbonate SRC with starch damage, sucrose SRC with pentosan content plus gliadin properties and water SRC (WSRC) with all four constituents (Guttieri, 2001). Duyvejonck *et al.* (2011) reported water retention capacity, sodium carbonate retention capacity, sugar retention capacity, and lactic acid retention capacity of different types of wheat ranged from 56 to 66%, 74 to 88%, 90 to 102% and 106 to 147%, respectively. Xiao *et al.* (2006) reported significant correlation between LASRC and straight dough loaf volume of hard winter wheat and the sedimentation test.

Since SRC was shown to predict the characteristics of wheat flour regardless of the application (hard wheat for bread or soft wheat for cakes), the objectives of this work were to use SRC, flour pasting properties, and gel textural properties to determine how black cumin (BC), Turkish bean (TB) and chickpea (CP) meals affect the properties of wheat flour.

2. Materials and methods

Materials

Hard red spring wheat flour, Turkish bean, black cumin and chickpea grains were procured from local market.

Preparation of defatted meals

BC, CP and TB meals were defatted using 3:1 hexane:meal (v/w). Samples were stirred in hexane for 4 h after which hexane was decanted and replaced with fresh solvent three times. Protein and moisture content of wheat flour were determined according to AACC methods (39-11) and (39-06), respectively, whereas Farinograph was done according to method 54-21 (AACCI, 2000). Hard red spring wheat flour was replaced at 5, 10 and 15% by defatted meals of Turkish bean, black cumin and chickpea. 100% wheat flour was used as control. All the blends were stored in air tight containers at 4 °C until further used.

Rapid viscoanalyser measurements

Pasting properties of wheat flour-meals (BC, CP and TB) blends were determined using a Rapid Visco Analyser (Newport Scientific, Sydney, Australia). Flour blends (3.5 g at 14% moisture basis) were directly weighed into aluminium rapid viscoanalyser (RVA) canisters and the total weight was brought to 28 g by distilled water. The obtained slurry was heated to 50 °C for 50 s, raised to 95 °C in 3.42 min (at 13.15 °C/ min), and held at 95 °C for 3.30 min. It was then cooled to 50 °C in 3.48 min (at 12.93 °C/min) and maintained at 50 °C for 2 min. The speed of the paddle was 960 rpm for the first 10 s and dropped to 160 rpm throughout the remainder of the experiment. All measurements were replicated three times and the Thermocline for Windows software was used to process the data (TCW, Newport Scientific).

Textural studies on cooked gels

Gel texture parameters were determined on RVA-prepared gel. The gels (35 mm high) were transferred into 25 ml beakers with an 30 mm internal diameter and stored overnight at room temperature. Gels were compressed using Brookfield CT3 Texture Analyzer (Brookfield Engineering Laboratories, Inc., Middleboro, MA, USA) in two penetration cycles at a speed of 0.5 mm/s to a distance of 10 mm into the gel using a 12.7 mm wide and 35 mm high cylindrical probe. Gel hardness, springiness, cohesiveness and adhesiveness were recorded, whereas the gumminess was calculated as a product of hardness and cohesiveness, and chewiness as a product of gumminess and springiness.

Solvent retention capacity

The SRC of the blends was determined according to AACCI method no. 56-11 (AACCI, 2000). Four different types of solvents were used: double distilled water, sucrose (50%, v/v), sodium bicarbonate (5%, v/v) and lactic acid (5%, v/v). 25 ml of solvent was added to 5 g flour or blend in 30 ml centrifuge tubes. Samples were vortexed vigorously for 5 s to allow contact between the solvent and the sample. Samples were vortexed 4 times for 5 min with one min intervals to allow for swelling. The tubes were centrifuged at 3,000 rpm (1,239×*g*) g for 15 min. After decanting the separated liquid, the weight of the swollen sample (pellet) was recorded and the SRC values (%) for each solvent were calculated as:

$$\%SRC = [\frac{\text{gel weight}}{\text{flour weight}} \times \left(\frac{86}{100 - \%\ \text{flour}}\right) - 1] \times 100$$

Wheat gluten acid method

The wheat gluten acid method was performed with a RVA (Perten Instruments, Hägersten, Sweden) (Perten, 2014). 15 g flour sample (12% moisture) and 22.5 ml distilled water or BC water-extract were placed in a RVA canister, shaken for 10 s after which 2.5 ml of 1.0 M lactic acid was added. Samples were stirred by the RVA peddle at 1000 rpm at 25 °C, then reduced to 160 rpm and heated to 50 °C in 2 min and held for 7 min. Peak viscosity, final viscosity (FV), and break down (BD) were measured. BD is calculated according to the following formula:

$$BD = 100 \times \frac{FV - V3}{FV3}$$

where V3 is the viscosity at 3 min.

Statistical analysis

All measurements were done in triplicate. Data was subjected to one-way analysis of variance and Duncan's Multiple Range test at $P \leq 0.05$ was used to compare means.

The PASW® Statistics 18 software (Quarry Bay, Hong Kong, China P.R.) was used for analysis.

3. Results and discussion

Wheat flour (control) proximate analysis showed 12.3% moisture and 11.8% protein content, whereas Farinograph water absorption was 57.9%. CP-flour blend exhibited 61.8, 62.3 and 63.1% Farinograph water absorption for the 5, 10, and 15% blends, respectively, whereas TB showed 62.1, 63.1 and 63.9% for the 5, 10, and 15% blends, respectively. In addition, BC blends exhibited 57.9, 58.1 and 58.3% Farinograph water absorption. The WSRC, which is associated with all wheat flour components, was generally lower than the control (Table 1). In the case of BC- and CP-containing samples, it was significantly lower than the control, but TB exhibited a significant increase in water absorption at high TB percentage. Higher levels of meal don't appear to have a significant effect on the WSRC, especially between 5 and 10% blends.

A similar observation was noted for the Farinograph of the blends, where TB>CP>BC, whereas WSRC of the blends was TB>CP>BC as well. For both methods, the difference between blends was significant ($P \leq 0.05$) (Table 2). The WSRC data identify the overall change on the flour components due to the addition of the meals, which might also predict the final quality of the flour. Water absorption is a very important parameter for wheat flour quality because it is critical for gluten development during mixing.

Therefore, water absorption is essential for determining the effect of any additive to wheat flour that might change the dynamics of water in the dough system. Different types of European wheat were reported to have a WSRC between 52 and 66% depending on the supplier (Duyvejonck, 2011). A low WSRC value is evident of dough with less viscoelastic properties which could lead to low loaf volume.

While WSRC has been correlated with the overall water holding capacity of all flour components, sodium bicarbonate (SBSRC) has been associated with starch damage. High SCSRC values are commonly reported for hard wheat and much less for soft wheat. For CP blends there was no significant change in SCSRC except for the 10% (Table 1). Significantly high SCSRC for the TB blends as a function of higher meal percentage could indicate high starch damage, whereas the increase in SCSRC by BC could not be attributed to starch damage because BC doesn't contain starch. The increase in SCSRC values were

Table. 2. Farinograph water absorption and solvent retention capacity (SRC) water for the 10% chickpea, Turkish beans and black cumin / wheat flour blends.[1]

10% blends	Farinograph water absorption	SRC water
Chickpea blend	61.8b	66.3b
Turkish beans blend	63.1a	74.1a
Black cumin blend	58.1c	63.8c

[1] Means carrying different letters in columns for a specific meal samples are significantly different.

Table 1. Effect of chickpea, Turkish beans and black cumin extracts on the solvent retention capacity of soft wheat.[1]

Meal level (%)	H_2O (%)	$NaHCO_3$ (%)	Lactic acid (%)	Sucrose (%)
Chickpea meal + wheat flour				
0	67.05±0.46ab	69.22±0.45ab	106.38±1.09a	112.65±1.13a
5	67.83±0.03a	68.45±0.32b	92.58±1.38b	110.47±1.01ab
10	66.36±1.62ab	69.88±0.64a	85.64±0.79c	109.00±1.34b
15	65.95±0.42b	68.38±0.58b	84.06±0.27c	103.64±1.49c
Turkish bean meal + wheat flour				
0	67.05±0.46d	69.22±0.45c	106.38±1.09b	112.65±1.13c
5	70.57±0.70c	74.32±0.39b	109.80±1.10a	112.85±0.82c
10	74.04±0.62c	75.56±1.03b	105.93±1.86b	115.23±1.10b
15	78.89±0.86a	79.49±0.79±a	102.52±2.02c	117.47±1.55a
Black cumin meal + wheat flour				
0	67.05±0.46a	69.22±0.45b	106.38±1.09a	112.65±1.13a
5	63.61±0.48c	66.58±0.28c	88.36±0.09b	77.45±0.32b
10	63.82±0.12c	69.73±0.11b	81.20±0.66c	74.04±0.66c
15	65.13±0.13b	73.82±0.63a	78.42±0.25d	68.54±1.09d

[1] Means carrying different letters in columns for a specific meal samples are significantly different.

comparable with WSRC, which might indicate that the high pH of SBSRC increased the water absorption due to the ionisation of hydroxyl groups of the blends including starch which allows for hydrogen bonding. In other words, the higher degree of starch swelling is considered to be due to the high pH and not to starch damage (Gains, 2000). Another possible explanation could be the solubilisation of BC protein (21-25%) at the high pH which interacted with water thereby increasing SCSRC. Ram Sewa *et al.* (2005) reported that the very high correlation between WSRC and SCSRC indicates direct implication of starch damage in wheat flour water absorption. This could be true for CP or TB, but not for BC because of the lack of starch.

LASRC were lower for all three blends compared to the control except for the 5% TB (Table 1), but the percentage drop was not the same for all blends. The largest reduction on LASRC was noted for BC blend (27%), whereas the least was for TB (0.5%). A lower LASRC showed lower glutenin swelling which indicates direct reduction on gluten quality due to meal interaction with gluten. A positive correlation between LASRC and glutenin content was reported by Colombo *et al.* (2008). Glutenin was commonly used to determine wheat quality where the ratio of glutenin to gliadin is a good predictor of flour quality. The low LASRC values for BC could be attributed to BC protein interaction with gluten components that reduce glutenin contact with water, which leads to reduction in glutenin swelling. Low glutenin swelling is negatively correlated with wheat quality. The low glutenin swelling can be corroborated with the low Farinograph water absorption and the longer dough development time (7.0 min) compared to the control (1.7 min). When compared to CP and TB, BC blends exhibited significantly lower LASRC at all levels of replacement (Table 1). This could be accredited to high protein content as well as the lack of starch compared to CP and TB. The protein content of wheat flour didn't correlate with LASRC as reported in the literature, but glutenin content was reported to positively correlate with LASRC (Colombo *et al.*, 2008; Guttieri, 2001; Kiszonas, 2013). Duyvejonck *et al.* (2011) reported a LASRC range from 106.4 to 147.1% for wheat samples with a protein content ranging from 10.7 to 14.6%, whereas the control of this work exhibited 106.4% for LASRC and 78.4 to 109.8% for the blends depending on blend type and level of replacement (Table 1). It is clear that the presence of meals reduces LASRC values, indicating interference of the meal components with gluten swelling and thus with the overall performance. The effect of BC on gluten viscosity was tested using RVA, where defatted BC meal was water extracted at room temperature and the water-extract used instead of water in the RVA of wheat flour. Data showed significant drop in peak viscosity by 26% (from 1,011±55.86 to 753±42.43), and final viscosity by 25.5% (from 789±73.54 to 588±2.12) (Figure 1). The reduction on viscosity parameters of wheat flour gluten indicates that BC water-extract contains components that interfere with gluten development. This can explain the different behaviour of BC relative to the other meals used in this study. The BC water-extract data was compared to the Farinograph data where dough stability of the BC blend (6.7 min) was much higher than the control (3.3 min). This suggests that BC extracts strengthen the dough, i.e. improved gluten functionality, whereas the water-extract reduced peak viscosity of the flour in the RVA test indicating a hindering effect of the extract. The inconsistency of BC activity on wheat flour can be attributed to the difference in the solid content of the Farinograph and the Perten

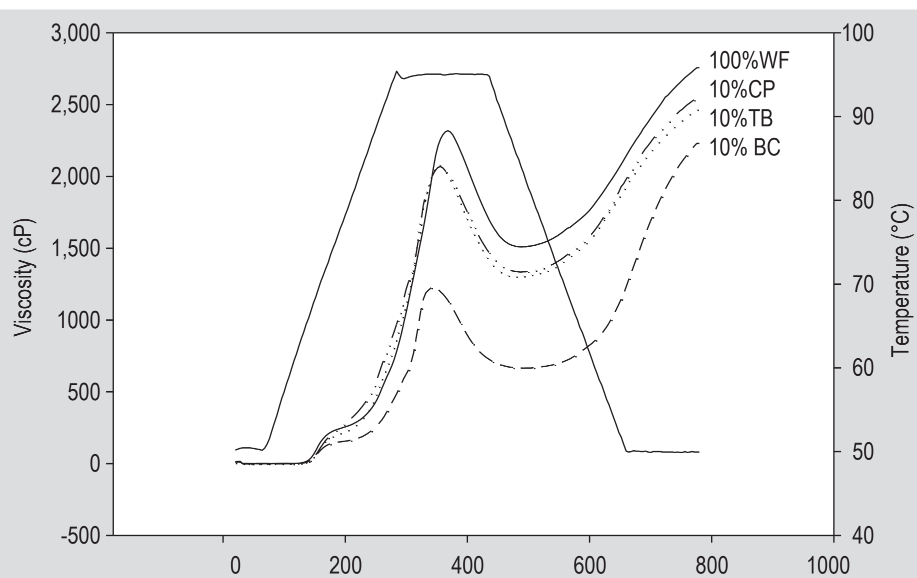

Figure 1. Effect of different meals on pasting properties of wheat flour (WF). BC = black cumin; CP = chickpea; TB = Turkish beans.

RVA 20.02 method, as well as the difference in mixing type between RVA and Farinograph.

Sugar solution SRC (SUSRC) was associated with gliadin characteristics and water soluble pentosan (Gains, 2000). The same author reported that, unlike LASRC, a significant correlation between SUSRC and dry gluten was established, which indicates a contribution of gliadin to dry gluten. Most of the data in the literature reported SUSRC values less than 100%, whereas here TB and CP samples showed SUSRC >100% and BC showed <100%. Once more, BC performed differently by preventing gliadin and pentosan extraction due to interaction, like the case with low glutenin swelling represented by low LASRC. Ram Sewa *et al.* (2005) have developed an equation to predict Farinograph water absorption using SRC values, where each SRC parameter is multiplied by a factor.

All blends exhibited lower RVA peak viscosity, where 10 and 15% appeared to show no significant difference when compared to each other except for the BC extract samples (Table 3). The peak viscosity of BC blend continued to show lower peak viscosity at all three levels (Figure 1). The final viscosity of CP and TB followed the same trend as peak viscosity, but BC showed significant drop on the final viscosity for both 5 and 10% blends and slight increase for the 15%.

Therefore, the peak viscosity and final viscosity of wheat flour blends were significantly lower than the control. The setback data in Table 3 showed significantly higher setback for BC blends compared to other bends or the control. Although, CP and TB contain starch with fairly high amylose content (45% for CP and 52% TB) it was expected for those two blends to show higher setback (Alamri, 2013). The higher setback due to BC could be attributed to the low water absorption of the BC blends, as shown by the low water absorption in the Farinograph, producing a stiffer gel which reduces amylose molecular mobility and facilitates for faster retrogradation resulting in a higher setback. A different interpretation could be based on BC/glutenin interaction instigating a network that traps water and produces a stiffer gel. Conversely, CP and TB with more available water due to less fibre content allows higher mobility of amylose molecules and thus lower retrogradation. In the presence of CP and TB, the peak temperature was significantly higher at 15% blends. Once more, BC blends exhibited higher peak temperature which indicates delayed starch gelatinisation due to low water absorption which reduces water availability. The amount of the available water is known to be critical for starch gelatinisation temperature. BC samples were not significantly different from CP or TB at 5 or 10% blends, but at 15% significantly higher peak temperature was recorded.

Samples containing CP, TB, or BC exhibited significantly ($P \leq 0.05$) softer gels compared to the control. The gel hardness of BC blends was significantly lower than TB, but CP showed no significant difference on gel hardness at all three levels (Table 4). After storage for one day at room temperature, starch gels were mechanically tested for the texture profile (hardness, cohesiveness, springiness, adhesiveness, and gumminess). Most of the testing parameters, except cohesiveness and springiness, decreased after storage time compared to the control (Table 4). Among the tested blends, BC displayed the lowest values for gel

Table 3. Effect of chickpea, Turkish beans and black cumin extracts on the rapid viscoanalyser pasting properties of soft wheat flour.[1]

Meal level (%)	Peak viscosity (mPa·s)	Final viscosity (mPa·s)	Setback (mPa·s)	Peak temperature (°C)
Chickpea meal + wheat flour				
0	2,350.33±28.36a	2,781.33±18.88a	1,230.33±24.01a	66.53±0.55b
5	2,171.33±13.86b	2,619.00±56.96b	1,214.00±68.41a	66.83±0.88ab
10	2,067.00±16.52c	2,494.67±62.13c	1,153.00±57.24a	67.63±0.06ab
15	1,985.00±29.51c	2,492.67±46.09c	1,187.67±56.08a	68.25±0.99a
Turkish bean meal + wheat flour				
0	2,350.33±28.36a	2,781.33±18.88a	1,230.33±24.01a	66.53±0.55b
5	2,147.67±79.43b	2,560.00±88.88b	1,216.33±57.54ab	66.85±0.77b
10	2,019.00±60.80c	2,418.33±42.57c	1,135.33±37.42b	68.23±0.46a
15	1,940.33±69.90c	2,383.33±65.26c	1,134.33±57.47b	67.71±0.91ab
Black cumin meal + wheat flour				
0	2,350.33±28.36a	2,781.33±18.88a	1,230.33±24.01d	66.53±0.55c
5	1,690.00±2.64b	2,288.33±43.25c	1,344.00±46.87c	67.78±0.08b
10	1,275.00±45.57c	2,296.67±68.57c	1,603.67±37.55b	67.72±0.08b
15	1,039.33±24.58d	2,431.67±88.52b	1,884.33±73.66a	88.07±0.12a

[1] Means carrying different letters in columns for a specific meal sample are significantly different.

hardness or chewiness, and regardless of level, springiness, cohesiveness, hardness and chewiness were not significantly different ($P<0.05$) for CP and TB and only springiness for samples with BC was not significantly different. It is interesting to see that BC samples were significantly lower than the control but not among the different levels of BC in the blend, except for cohesiveness where the values increased at higher BC content in the blend (Table 4). Within the same percent and across blends, BC seems to exhibit the lowest value for each percent. Springiness showed no significant difference for all blends at all levels, whereas cohesiveness showed mixed values at 10 and 15% blends.

The wheat acid gluten method showed that the RVA peak viscosity at 3 min and the final viscosity of the flour in water (1,011±55 cP) dropped by 26% both in water and in BC extract (789±73 cP) (Figure 2). This is another evidence for the strong interaction between BC and wheat components that causes significant changes on the functional properties

Table 4. Effect of chickpea, Turkish beans and black cumin extracts on the textural properties of soft wheat flour-gel.[1]

Meal level (%)	Hardness (g)	Cohesiveness	Springiness (mm)	Adhesiveness (mJ)	Chewiness (g)
Chickpea meal + wheat flour					
0	97.67±4.51a	0.47±0.04a	9.43±0.70a	1.20±0.00a	432.65±44.83a
5	98.00±7.81a	0.47±0.36a	9.70±0.26a	0.77±0.21b	420.76±25.41a
10	93.33±9.61a	0.44±0.02a	9.73±0.21a	0.70±0.10b	414.34±73.35a
15	88.67±4.51a	0.46±0.45a	9.33±0.21a	0.63±0.32b	376.94±26.89a
Turkish bean meal + wheat flour					
0	97.67±4.51a	0.47±0.04a	9.43±0.70a	1.20±0.00a	432.65±44.83a
5	87.33±5.03ab	0.47±0.03a	9.70±0.35a	0.97±0.15ab	400.42±27.95a
10	88.67±4.16ab	0.49±0.03a	9.53±0.45a	1.13±0.21a	410.91±34.23a
15	79.67±11.50b	0.49±0.04a	9.63±0.35a	0.77±0.06b	371.98±46.22a
Black cumin meal + wheat flour					
0	97.67±4.51a	0.47±0.04c	9.43±0.70a	1.20±0.00a	432.65±44.83a
5	28.67±2.08b	0.50±0.0c	9.53±0.25a	0.63±0.15b	140.23±18.71b
10	24.00±3.61b	0.54±0.03b	9.07±0.71a	0.53±0.06b	123.24±23.86b
15	14.00±3.00c	0.66±0.09a	9.47±0.52a	0.47±0.11b	86.16±29.55b

[1] Means carrying different letters in columns for a specific meal sample are significantly different.

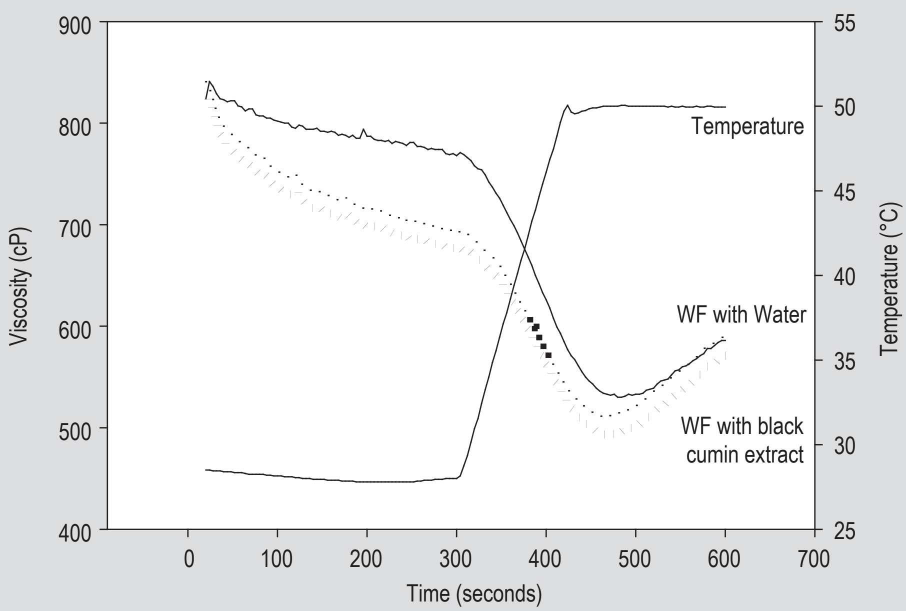

Figure 2. RVA soft wheat gluten index properties of wheat flour (WF) cooked with distilled water and black cumin extract.

of the flour. Therefore, these data can be used as proof for BC interaction with glutenin that results in inhibition of gluten development despite proper mixing and ample water. Since the test was done at 50 °C, the effect of BC extract is mostly limited to gluten and not to starch because starch gelatinisation starts at a higher temperature. Therefore, the interaction of BC extract with glutenin is strong possibility, but more work is needed to directly determine the nature of the interaction. Finally, BC-containing blends influenced nearly all the tested parameters of flour more than CP or TB.

4. Conclusions

Wheat flour-BC blend exhibited lower Farinograph water absorption compared to CP and TB, but it was closer to the control. The water SRC of the blends was generally lower than the control. In the case of BC- and CP-containing samples, it was significantly lower than the control, but TB exhibited significantly higher water absorption at higher percentage TB. Additional meal did not appear to have significant effect on the WSRC, especially between 5 and 10% blends. Similar observations were made for the Farinograph of the blends, where TB>CP>BC, the same as for WSRC. Low WSRC indicates a low dough viscoelasticity which is associated with low loaf volume. The viscous properties of the flour were negatively affected as shown by the lower peak viscosity and setback. It was expected that CP and TB blends would show a higher setback due to the higher amylose content, however BC exhibited the highest setback which could be attributed to the low water absorption of the BC blends.

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