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EFFECT OF GROOVE DEPTH ON WHEAT SIZING REDUCTION AT THE FIRST BREAK ROLLERS

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Abstract: This research looked at how depth of grooves in the first set of break rolls affected sizing process for wheat. These rolls have a modified Dawson-type surface corrugation profile, with groove depths of 0.981 and 1.069 mm. The First break rolls were set up with following operational parameters: fast roll speed of 500 rpm, roll gap of 0.6 mm, and roll differential of 2.5:1. Coarse fraction increased, however sizing, large middlings, fine fraction, and first break flour all reduced as groove depth increased. Since cv. Gerek-79 is structurally more malleable than the other cultivars, it suffered more during the size reduction process. Although it was noticed that starch damage in the first break flour of all cultivars decreased with increasing groove depth, the least amount of starch damage was obtained with cv. Gerek-79 during the size reduction procedure. First break flours from all three varieties did not differ in their Zeleny sedimentation levels based on groove depth. During the first broken rolls' size reduction procedure, the power and energy consumptions of the two groove kinds were nearly identical. Therefore, optimizing groove geometry is crucial for achieving a balance between targeted flour quality, grain structure, and energy consumption. This directly contributes to improving yield and quality control strategies in industrial-scale milling.

Keywords: wheat milling, groove profiling, size reduction, first break rolls, particle size distribution

1. Introduction

Milling process is performed not only to separate the endosperm from bran and germ, but it also involves reduction of the endosperm to flour. This process is accomplished by a sequence of breaking, reducing, and separating operations. The breaking of wheat is accomplished in a break system having rolls which act as the most effective component. These break rolls undertake the most vital functions such as cutting, shearing and scraping. To do these actions, the surface of break rollers is grooved.

There are several break and reduction rollers utilized in today's flour mills, but most of the research has concentrated on the first break rollers (Hesieh et al. 1980; Guritno & Haque 1994; Fang et al. 1997;

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Fang et al. 1998; Pasikatan 2001; Campbell & Webb 2001; Fang & Campbell 2002; Danciu & Danciu 2010a, 2010b; Danciu & Danciu 2011). One possible explanation for this trend is that first-break rollers are typically laden with entire wheat grains. Fang & Campbell (2002) and Hsieh et al. (1980) reported that the first break occurs at a pivotal point in the process of size reduction. Gentle experimentation with various configurations and operating conditions of the first break rollers is required for optimal size reduction, which in turn affects further processing. In the size reduction process, the first break rollers are supposed to break open the wheat grains and get a granulation distribution with the most large middlings and the least amount of flour and fine fraction (Posner & Hibbs, 2011).

The first break rollers have been the subject of much research into their design and operational factors. Roller diameter and roller speed are two of the characteristics that have already been extensively researched (Niernberger & Farrel 1970), roller spiral (Creason 1975, McCorkle 1973), roller gap and corrugation type (Cleve & Will 1966), number of corrugation, roller differential, and feed rate (Schumacher 1967), roller differential and moisture content (Kalkan et al. 2014), grinding action (Gehle 1965, Heide 1956), and grinding pressure (Schumacher 1967, Ward & Shellenberger 1951).

However, the influence of groove depth on the breaking patterns of wheat grains and the subsequent particle size distribution produced by the first break roller milling has not been examined. This has revealed a significant research gap in understanding the role of groove depth on size reduction dynamics and particle distribution. Groove depth is a crucial factor in the design of the first break rollers because it determines the size reduction zone at the nip point. Posner & Hibbs (2011) have reported that particle size distrubution of the materials being milled is matched to the groove depth. If the corrugation is too deep or too shallow, the first break rollers won't be able to open the wheat grains as they should, and the size reduction process won't be able to get a good distribution of particle sizes during the first break rollers. However, optimizing groove depth in mills contributes to the careful balancing of the interactions between mechanical load, grain morphology, energy consumption, and the desired particle size distribution. Therefore, systematically examining the groove depth is going to provide a scientifically critical contribution to the optimization of the grinding mechanism and the increase of process efficiency. This study fills a knowledge gap by examining how groove depth influences the particle size distribution of wheat during the first break rollers, which is an important step in the milling process.

2. Materials and Methods

2.1. Wheat preparation and determination of some physical properties

Wheat cultivars used in this study were supplied from different regions of Turkey: cv. Gerek-79 from Konya (center of part of Turkey), cv. Tosunbey from Ankara (center of part of Turkey), and cv. Fırat-93 from Diyarbakır (south-eastern of Turkey). Mechanical (selector) and manual procedures were used to clean the wheat grains, removing debris, dirt, stones, and damaged grains.

Drying the cultivars in an oven set to 105 degrees Celsius for 24 hours revealed their initial moisture contents (Suthar & Das, 1996). Wheat cultivars' grain hardness was measured using near infrared reflectance spectroscopy (NIR-Percon Inframatic 8620) at initial moisture content. Protein contents of

the cultivars were tested using the Kjeldahl procedure (N x 5.7) by AACC method 46-10 (AACC, 2000). The values for starting moisture content, NIR hardness, and protein content are listed in Table 1.

Table 1 also lists some of the untempered wheat's physical characteristics. One hundred randomly chosen grains were measured for their axial dimensions, or length (L), width (W), and thickness (T), using a digital caliper that reads to a precision of 0.01 mm in order to estimate the average dimensions of the grains. Using Equation 1, the geometric mean diameter of the grains (Dg) was computed (Mohsenin, 1986). One hundred grains were counted, weighed using an electronic scale, and then multiplied by 10 to get the thousand grain mass (Amin et al. 2004)]. Using a mass per hectoliter tester calibrated in kg m-3, bulk density was determined (Desphande et al., 1993).

$$D_g = (LWT)^{1/3} \quad (1)$$

D_g : Geometric mean diameter of wheat grains (mm)
L : Length of wheat grains (mm)
W : Width of wheat grains (mm)
T : Thickness of wheat grains (mm)

Prior to the size reduction procedure, the amount of water needed to temper the wheat grains was estimated based on the level of hardness of the wheat and the initial moisture content. (Özkaya & Özkaya, 2005). It was lightly blended after being sprayed onto the sample within the polythene drum. Table 1 lists the moisture content and tempering times for the size reduction process.

Table 1. Some properties of wheat cultivars

Physical properties	Wheat cultivar		
	Gerek-79	Tosunbey	Fırat-93
Initial moisture content, % d.b.	9.40	9.21	8.80
NIR hardness index	46	64	69
Protein content, % d.b.	9.3	13.6	13.8
Length, mm	5.73	5.84	6.45
Width, mm	2.57	2.66	2.79
Thickness, mm	2.37	2.46	2.46
Geometric mean diameter, mm	3.27	3.36	3.54
Thousand grain mass, g	32.80	34.03	39.07
Tempered moisture content, % d.b.	16.47	17.43	17.65
Tempering time, h	12	21	23

2.2. First break roller mill and power measurement system

At the Cereal Milling Research Laboratory, an experimental first break roller mill with a data acquisition system was developed to be utilized in size reduction processes and power assessments (Fig.1). Two rollers make up the first break roller mill, which also has a hopper, feeders, electric motors, power transmission gear, and speed controllers. The rollers were chosen with a diameter of 250 mm, typical of those used in flour mills, and a length of 400 mm. The rollers had a modified Dawson type surface corrugation profile, with groove depths of 0.981 and 1.069 mm and a helical inclination of 6%. Figure 2 depicts the location of a single grain within a corrugation profile with two varying groove depths. Roller specifications are shown in Table 2. Gear belts and pulleys transmitted power from individual 3-phase asynchronous AC motors (GAMAK) to each roller. There were two speed controllers used to set the optimum speed for each roller individually (Schneider, ATV71HU30N4, 3 kW, 480 V, variable-frequency). Power and energy consumption for the motors controlling each roller were determined by collecting data on current and voltage throughout the first break milling process using a software tool (SoMove Lite-V1.5.2.2) and recording it on two PCs (Anon., 2012a). For a roller differential of 2.5, the fast rotating roller was set to 500 rpm and the slow rotating roller was set at 200 rpm. For setting the feed rate and roller gap an adjustment mechanism was installed in the mill. Roller gap at nip point was 0.6 mm. The roller disposition was set dull to dull for cv. Gerek-79 and cv. Tosunbey and sharp to sharp for cv. Fırat-93 (Hsieh et al. 1980; Hareland, 1998; Fang & Campbell, 2002). The wheat material was distributed uniformly along the rollers using two feeders. A 1.9 kg of tempered wheat were applied for each test of the size reduction process. Duplicate of the experiments were performed. All the experiments were carried out at the Cereal Milling Research Laboratory in the Agricultural Machinery Department of Atatürk University, Erzurum, Turkey.

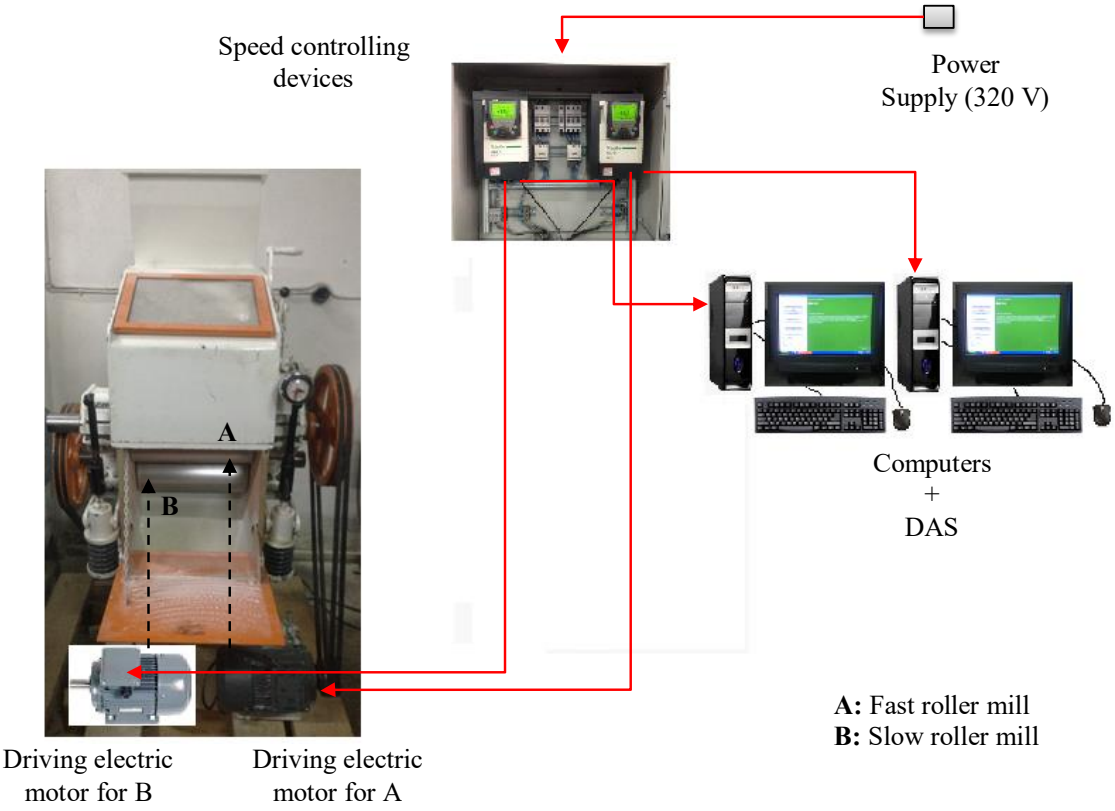


Figure 1. First break roller mill and data acquisition system

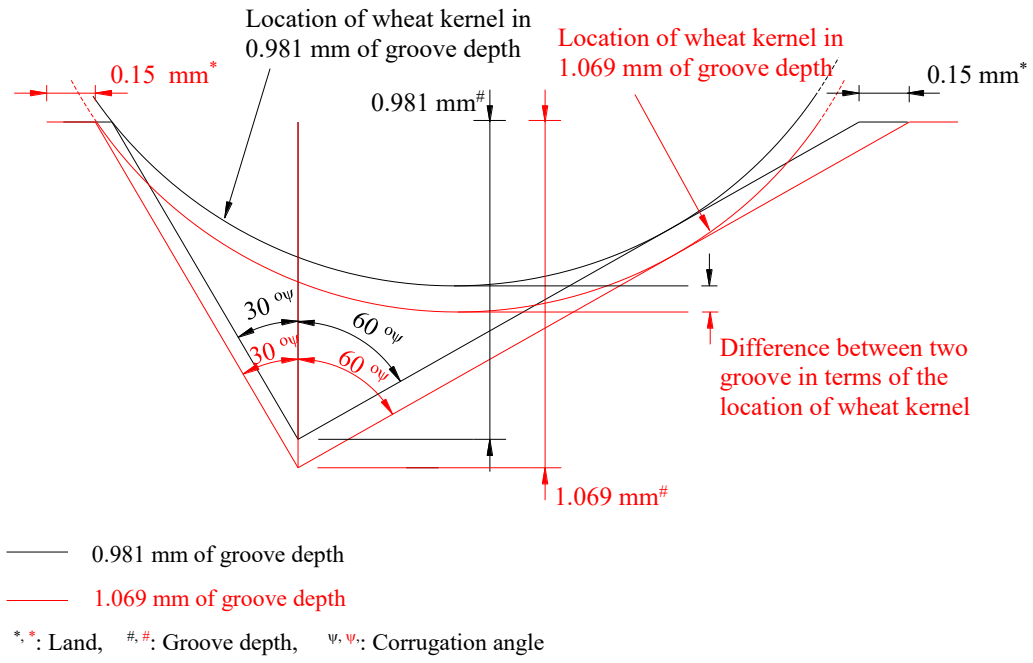


Figure 2. The position of a single wheat grain within corrugation profile with two different groove depths.

Table 2. Roller specifications

Specifications	Groove depth 1	Groove depth 2
Groove depth, mm	0.981	1.069
Flute number per cm	4.1	3.9
Corrugation angle, (°)	30/60	30/60
Roller length, mm	400	400
Roller diameter, mm	250	250
Helical inclination, %	6	6
Land, mm	0.15	0.15

2.3. Evaluation of material reduced in size

Depending on the hardness of the wheat, the material from each experiment was reduced in size and collected, then sifted using a four-sieve unit at an adjustable frequency and shaking time of 10 minutes (cv. Tosunbey and cv. Fırat-93) and 20 minutes (cv. Gerek-79). Each sieve frame measures 300 mm in diameter and 100 mm in depth. Materials were sieved through wire mesh to create the following five fractions: coarse fraction (CF; over 1180 m), sizing (S; through 1180 m and over 530 m), large middlings (LM; through 530 m and over 250 m), fine fraction (FF; through 250 m and over 150 m), and the first break flour (FL; through 150 m). Weighing the residue on each sieve and in the fine collector after the process was completed required a balance accurate to 0.01 g. A starch damage assay kit was used to test the first break flour for starch damage in accordance with AACC 76-31 (Megazyme International-Ireland Ltd., Wicklow, Ireland) (AACC, 1999). The first break flour was subjected to zeleny sedimentation tests using the ICC 116/1 protocol (ICC, 1995).

2.4. Experimental design and statistical analysis

This study, conducted according to a fully randomized factorial experimental design, included 3 wheat varieties, 2 groove depths, 1 roller speed, 1 roller gap, 1 roller differential, and 2 replications. The obtained data were subjected to variance analysis using the SPSS, and the Duncan multiple comparison test was applied to the data belonging to the significant means (Anonymous 2012b).

3. Results and Discussion

3.1. Effect of groove depth on wheat size reduction process

Wheat particle size reduction as a function of groove depth is seen in Fig. 3. Test results showed that for cv. Gerek-79, as groove depth increased from 0.981 mm to 1.069 mm, the amounts of coarse fraction and sizing increased from 85.74% to 87.21% ($p<0.05$) and from 7.05% to 7.10%, respectively, while the amounts of large middlings, fine fraction, and the first break flour decreased from 4.17% to 3.48% ($p<0.01$), from 1.29% to 0.98% ($p<0.05$), and For cv. Tosunbey, the amount of coarse fraction increased from 90.22% to 93.53% ($p<0.01$), the amounts of sizing, large middlings, fine fraction, and the first break flour decreased from 5.61% to 3.83% ($p<0.01$), from 2.51% to 1.68% ($p<0.01$), from 0.77% to 0.50% ($p<0.01$), and from 0.91% to 0.53% ($p<0.01$), respectively, as the groove depth increased from 0.981 mm to 1.069 mm. Similarly, for cv. Fırat-93, the amount of coarse fraction increased from 88.62% to 91.63% ($p<0.05$), the amounts of sizing, large middlings, fine fraction, and the first break flour decreased from 7.66% to 5.71% ($p<0.05$), from 2.53% to1.81% ($p<0.01$), from 0.69% to 0.49 ($p<0.01$), and from 0.55% to 0.37% ($p<0.01$), respectively, as the groove depth increased from 0.981 mm to 1.069 mm. Since the goal of the first break rollers is to get a maximum of large middlings and a minimum of fine fractions and flour, the results of this analysis are relevant to the size reduction process at these rollers (Posner & Hibbs, 2011).

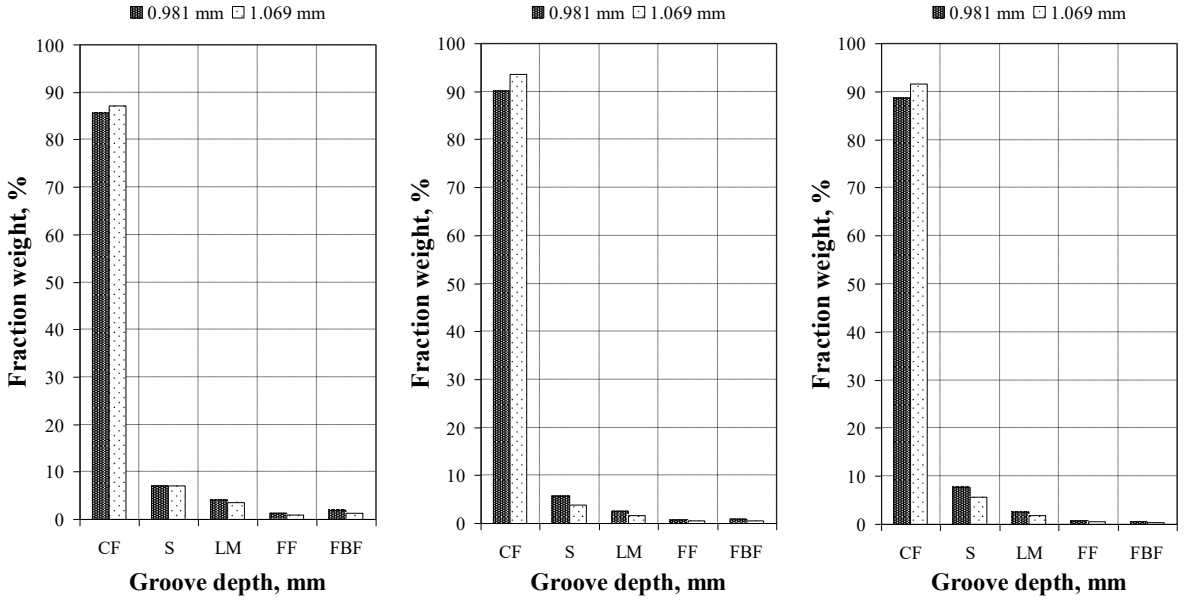


Figure. 3. Effect of groove depth on wheat size reduction process (Cvc. Gerek-79, Tosunbey, and Fırat-93, respectively)

However, cv. Gerek-79 was found to have more quantities of sizing, large middlings, fine fraction, and first break flour than the other two cultivars. The softer structure of cv. Gerek-79 could account for this pattern, as pressure applied during the first break rollers has a greater influence on wheat grains (Campbell 2007). Despite cv. Fırat-93's harder structure than cv. Tosunbey's, the size reduction process in cv. Fırat-93 may have been more successful due to roller disposition. Sharp-to-sharp roller disposition has a higher negative effect on the grain than dull-to-dull roller disposition (Elgün & Ertugay 2002).

3.2. Effect of groove depth on starch damage in the first break flour

The effect of groove depth on starch damage in the first break flour is presented in Fig. 4. Amounts of starch damage in cvc. Gerek-79, Tosunbey, and Fırat-93 at the first break rollers having groove depth of 0.981 mm were 4.07%, 7.14%, 9.77%, respectively. The amounts of stach damage decreased down to 3.87%, 6.73%, and 9.39%, respectively with increasing groove depth from 0.981 to 1.069 mm. Increase in the groove depth of the first break rollers during size reduction process was statistically effective to decrease the amount of starch damage for cv. Tosunbey ($p<0.05$), but its effect was limited for cvs. Gerek-79 and Fırat-93.

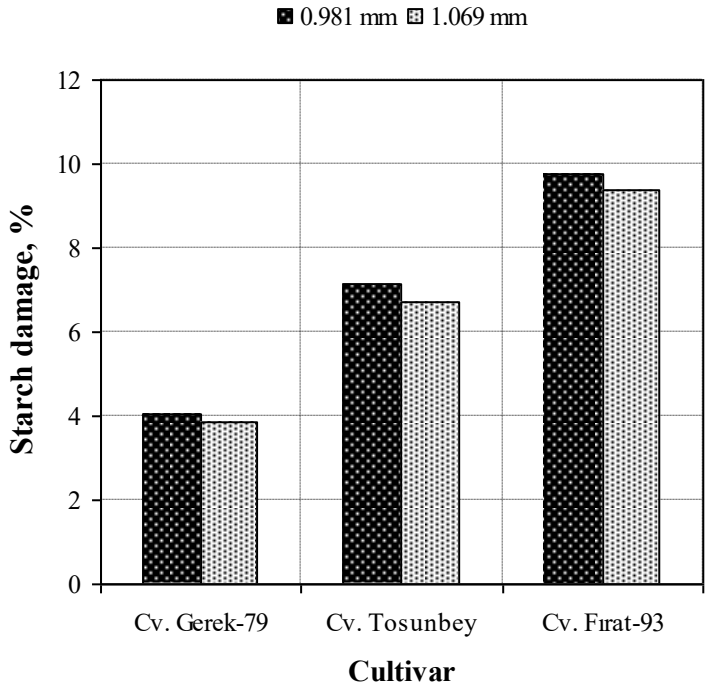


Figure. 4. Effect of groove depth on starch damage in the first break flour

At the end of the first break, Gerek-79 flour had the least amount of starch damage compared to Tosunbey flour and Fırat-93 flour. Flour milled from soft wheat grains has been found to have less starch damage than flour milled from hard wheat grains, according to a number of studies (Williams et al.1987; Pomeranz, 1988; Lin & Czuchajowska 1996; Barera et al. 2007; Reddecliffe 2001; Arora 2003; Dubat 2004; Keskin et al. 2012; Delcour & Hoseney 2013). Roller disposition and wheat hardness may both contribute to the increased starch damage observed in the first break flour produced from cv. Fırat-93. Additionally, the effect of a sharp-to-sharp roller disposition on the grain is more significant than a dull-to-dull roller disposition (Elgün & Ertugay 2002).

3.3. Effect of groove depth on level of Zeleny sedimentation in the first break flour

Figure 5 shows the correlation between the depth of the groove and the amount of Zeleny sedimentation in the first break flour. Zeleny sedimentation levels in the first break flour were 9.3 ml and 10.4 ml, 42.1 ml and 43.8 ml, and 25.5 ml and 24.0 ml for groove depths of 0.981 mm and 1.069 mm, respectively, for cvc. Gerek-79, Tosunbey, and Fırat-93. There was also no statistically significant relationship between groove depth and Zeleny sedimentation levels across evaluated cultivars.

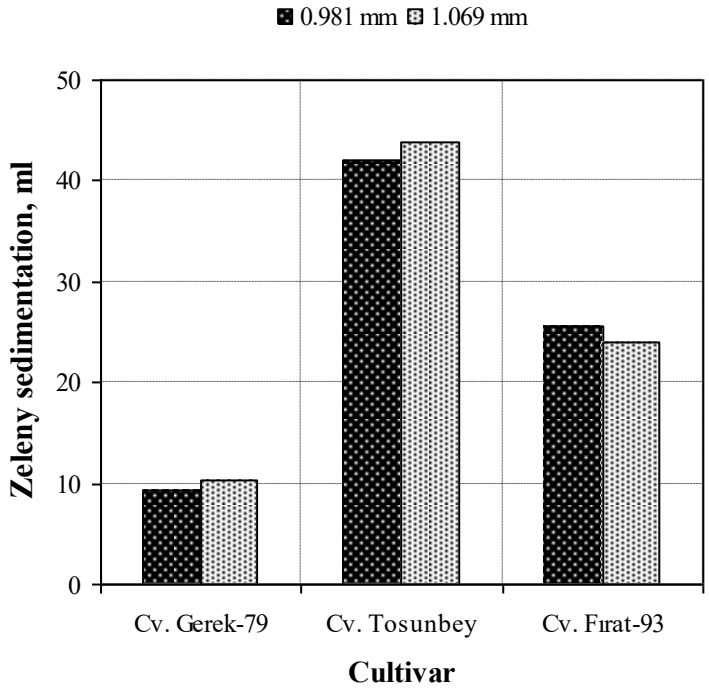


Figure 5. Effect of groove depth on level of Zeleny sedimentation in the first break flour

Zeleny sedimentation values in first break flour were lowest for cv. Gerek-79, then cv. Fırat-93, and finally cv. Tosunbey. Hrušková & Faměra (2003) have reported that value of Zeleny sedimentation is highly correlated with both protein concentration and protein quality, as shown by the data presented here. Even though cv. Tosunbey and cv. Fırat-93 have similar protein content, the quality of the protein they contain is clearly differentiated by the large difference in their Zeleny sedimentation values.

4. Conclusions

The percentages of coarse, sizing, large middlings, fine, and the first break flour for cv. Gerek-79 in the case of a groove depth of 0.981 mm at the first break rollers were 85.74, 7.05%, 4.17, 1.29, and 1.79, respectively. Cvc. Tosunbey and Fırat-93 had corresponding values of 90.22, 5.61, 2.51, 0.77, and 0.91, while 88.62, 7.66, 2.53, 0.69, and 0.55. Coarse fraction rose as groove depth reached 1.069 mm, while sizing, large middlings, fine fraction, and first break flour all fell. In comparison to the other cultivars, Cv. Gerek-79 was more vulnerable to the size reduction process due to its softer structure. Starch damage in first break flour decreased from 3.87 percent for cv Gerek-79 to 6.73 percent for cv Tosunbey and 9.39 percent for cv Fırat-93 as groove depth increased from 0.981 millimeters to 1.069 millimeters. As a result of the size reduction process, cv. Gerek-79 achieved the lowest level of starch damage. Groove depth had no effect on the Zeleny sedimentation levels of first break flours from the tested cultivars.

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