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PARTICLE SIZE DISTRIBUTION OF MILLED WHEAT AS AFFECTED BY BREAK ROLL DISPOSITION, GAP AND ENZYMATIC TEMPERING

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ABSTRACT: The main objective of this study was to study the influence of break roll disposition, roller gap, and enzyme tempering on particle size distribution during wet milling of Australian commercial wheat (*Triticum aestivum* L.). Roller disposition was evaluated at two levels: dull-to-dull and dull-to-sharp. Roller gap was tested at three levels across three groups (G_1, G_2, and G_3); (G_1): B_1, 0.3 mm; B_2, 0.2 mm; B3,0.1 mm, (G_2): B_1,0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, (G_3): B1,0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm). Enzyme addition was tested at two levels: no enzymes and a combination of hemicellulase, xylanase, and fungal α-amylase. Results showed that break rolls parameters (roller gap and disposition), along with enzyme addition, significantly influenced particle size distribution. Predicting equations were developed to predict the optimum particle size distribution based on the best milling combinations. Enzymatic tempering proved an effective role in modifying both particle size and distribution. The best-fit equations, with R^2 values ranging from 0.43 to 0.71, described the relationships among grain properties, roller position, roller gap, enzyme addition, and the resulting milling outcomes across different size fractions.

Keywords: Roller disposition, Roller gap, enzymatic tempering, Break system, Particle size distribution.

INTRODUCTION

Wheat milling is a complex process that involves breaking down wheat grains into various components, including flour, bran, and germ. The particle size distribution (PSD) of the milled products significantly influences their quality and functionality in downstream applications. A narrow PSD, for example, is often desired for baking, while a broader distribution might be suitable for animal feed. Understanding and controlling the PSD is therefore crucial for optimizing the milling process and producing high-quality products (Li, *et al*, 2021).

The break release percentage is the amount of ground material obtained, consisting mostly of sizing, middling, flour, and fine bran, reported as a percentage of the original material being tested through a certain sieve aperture. Measurement of grinding performance, whether in the break system or reduction system, is a useful tool in maintaining mill balance. It must be a well-thought-out method and procedure strictly followed. A complete understanding of wheat milling, therefore, requires knowledge of particle composition, as well as size within a compositional range. The objective of the break system is to shear and open wheat grains and scrape the endosperm away from the bran-skin in as large sizes as possible. At the same time, leaving bran as large flat flakes, when possible. It is essential in the discussion of mill balance and product distribution to understand that variability is endemic to any processing system and performance measures. The concept of break release balance is required between recovery (yield) and quality (flour color or ash content) (Gutteridge & van der Poel, 2004; Kulshrestha & Singh, 2007).

Particle size distribution (PSD) is a critical factor in wheat flour milling, which directly

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influences the performance of mill systems. A well-defined PSD ensures efficient separation of flour, bran, and other by-products, maximizing yield and minimizing waste. Additionally, the PSD of the final flour product significantly impacts its quality and suitability for various end-use applications. The basis for roller milling of wheat is that bran tends to break to produce large particles, whereas endosperm tends to produce small particles. These compositionally different components of the wheat kernel can be separated based on size. The breakage size gives a base for describing the size distribution of particles produced from roller milling of wheat, but does not indicate the composition of those particles. Particle composition and size would provide a comprehensive and powerful model of wheat roller milling.

The first break and the broken particles produced dictate the flows through the rest of the mill, affecting the rest of the milling process and thus determining the yields and quality of flour obtained. Different roller disposition of the first break produced a different particle size distribution (Fang & Campbell, 2003). Controlling roll settings and sifting process results in different types of refined flour with specific characteristics, representing levels of fineness and consistency. This technique is nowadays predominant in modern flour mills because of its efficiency and consistency in producing high-quality flour at a commercial scale (Cappelli *et al.*, 2020).

Corrugation of rolls is arranged in spiral pattern to facilitate a scissor-like cutting action. This is different from being aligned parallel to the long axis. Fluting can possess either a sharp or a dull profile, and the rolls can be arranged in four different sequences: dull-to-dull, sharp-to-sharp, dull-to-sharp, or sharp-to-dull. The type of fluting employed significantly influences the particle size distribution of the resulting flour (Cappelli *et al*, 2020). Research and technical attempts in modifying milling techniques have resulted in developing novel milling methods that result in producing more consistent, high-quality flour that might be used for various bakery products (Dziki, 2023).

The aims of the present study were to relate grain characteristics of the Australian wheat grade, roller position of first break, roller gap, and added tempering water enzymes to particle size distribution and mill balance.

MATERIALS AND METHODS

This study employed a methodology correlating the grain characteristics of the Australian wheat grade (Table 1) with roller position, roller gap, and the incorporation of an enzyme that affects particle size distribution. Facilities of the cereals quality lab of the crop science department, Alexandria University, and labs of quality control of the Arabian Milling and Food Industries (Abo-Donkol) were used to carry out this recent study. Studied treatments included two levels of roller position of first break represented by dull -to- dull and dull-to-sharp, three levels of roller gap (G_1): B_1, 0.3 mm; B_2, 0.2 mm; B3,0.1 mm, (G_2): B_1,0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and (G_3): B1,0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm, and two levels of added enzymes; ((E_0) no enzymes, (E_1) (hemicellulase + xylanase + fungal α-amylase). Wheat was tempered to 15.5% moisture. The enzyme mixture (hemicellulase + xylanase + fungal α-amylase) was added to tempering water, then allowed to condition for 16 hours.

1. Physical analysis

Physical properties of the studied wheat grades (Table 1) were determined as follows.

1.1. Test weight; determined according to AACC 2000 (method 55-10.01) after dockage removal.

1.2. Specific volume; determined according to AACC 2000 (method 55-50.01) after dockage removal.

1.3. Impurities, shrunken and broken kernels, foreign material, insect damage, total defects, and cleaning test; determined according to AACC 2000 (method 28-01-01).

1.4. Particle size index: hardness determined according to AACC 2000 (method 55-30, 01).

2. Chemical analysis

2.1. Moisture percentage; determined according to AACC44-19.01, 1999.

2.2. Crude protein percentage; determined according to AACC.46-11.02, 1999.

3. Physico-chemical properties

3.1. Gluten content (percentage); determined according to AACC 38-12.02, 2000.

3.2. Falling Number (sec): determined according to AACC 56-81.03Reapproval November 3, 1999.

4. Break Releases

Break release measures the amount of work performed during a specific break grinding passage. It is expressed as the percentage of material passing through a specific size-testing sieve. Sample determination was best taken under the roll, preferably at both ends and, if necessary, in the middle. A sample size of 100-200 grams was sieved on a test sifter within 10 minutes. Particle size distribution was shown as:

scalper > semolina > middling> Dunst > flour.

5. Statistical analysis

The Mstat-c program version (2.10) was used for data analysis. Data were statistically analyzed using the analysis of variance technique as a Completely Randomized Design (CRD) design. Means were compared using the least significant difference test at a 0.05 probability level (L.S.D.0.05) when the F value was significant, according to Gomez and Gomez (1984). Stepwise multiple regression equations were generated by CoStat software (version 6.311).

Table 1: Physical and chemical Characteristics of Australian wheat grade.

Character	Value
Test weight (kg/h)	$79.50^{\pm 0.500}$
1000 kernel weight (g)	$38.10^{\pm 0.400}$
Single kernel	
Weight (mg)	$38.00^{\pm 0.100}$
Diameter (mm)	$3.100^{\pm 0.500}$
Length (mm)	$6.100^{\pm 0.500}$
particle size index (psi)%	$15.00^{\pm 1.000}$ Hard
Dockage (%)	$0.900^{\pm 0.200}$
Damaged kernel (%)	$0.500^{\pm 0.200}$
Foreign material (%)	$0.800^{\pm 0.200}$
Shrunken & Broken (%)	$0.800^{\pm 0.500}$
Total defects (%)	$3.000^{\pm 1.000}$
Vitreous Kernels (%)	$85.00^{\pm 5.000}$
Moisture (%)	$11.00^{\pm 0.300}$
Crud protein (%)	$17.60^{\pm 0.300}$
Wet gluten content (%)	$37.70^{\pm 0.600}$
Gluten index (%)	$73.00^{\pm 7.000}$
Falling Number (sec)	$510.0^{\pm 20.00}$

±: stands for standard error.

Table 2: Characteristics of grinding rolls (B1, B2, and B3) of the mill.

Characteristics of grinding rolls			
	B1	**B2**	**B3**
Length(mm)	1250	1250	1000
Diameter(mm)	250	250	250
Flute's angle (β_d°/β_s°)			
T_1	65/30	65/30	65/50
T_2	30/65	65/30	65/50
Spiral (%)	6	6	8
Flutes per cm	3.2	4.8	6.4
Land (mm)	0.2	0.2	0.1
Differential	1:2.0	1:2.0	1:2.5
Flutes disposition			
T_1	D/D	D/D	S/S
T_2	D/S	D/D	S/S

B_1: First break, B_2: Second break, B_3: Third break, D/D: Dull-to-Dull, D/S: Dull-to-Sharp, S/S: Sharp-to-Sharp.

RESULTS AND DISCUSSION

The main objectives of this recent study were: to relate grain characters of wheat commercial grade, roller disposition, roller gap, and added enzyme to particle size distribution. Wet milling of wheat (*Triticum aestivum, L.)* applied to Australian commercial grade was included. Rollers' position for the first break is represented by two levels: dull-to-dull and dull-to-sharp. Rollers gap was represented by three levels (G_1): B_1, 0.3 mm; B_2, 0.2 mm; B3,0.1 mm, (G_2): B_1,0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, (G_3): B1,0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm. Added enzyme represented by two levels (E_0) no enzymes, and (E_1) hemicellulase + xylanase + fungal α-amylase. Means of particle size distribution as affected by the interaction between roller position, roller gap, and added tempering enzymes were presented in Figures 1-7. The highest significant values of particles (over 1400µm) were obtained with a dull-to-sharp roller combined with any of G_1 or G_2 gap and the addition of E_1 enzymes at the first break (81.40 and 80.93 %, respectively). The highest significant values of particles with (over 850 µm) were obtained with the combination of dull-to-dull with G_2 gap and the addition of (E_1) enzymes at the second break (29.32%). While, the highest significant values of particle with (over 710µm) was obtained with the combination of dull-to-dull and any of G_1 or G_2 gap along with no addition (E_0) of enzymes, or the combination of dull-to-dull with of G_1 gap and the addition of (E_0) enzymes at the third break roll (13.60 or 13.20 or 13.33%, respectively). The highest significant values of particle size (over 630µm) resulted from the combination of dull-to-dull with G_1 gap, and the addition of (E1) enzymes of the first break (20.30 %). Also, the highest significant values of particle size (over 250µm) were obtained with the combination of dull-to-sharp with any of G1, G2, or G3 gap and the addition of (E1) enzymes of the third break (38.05, 36.28, and 38.48 %, respectively). Meanwhile, the highest significant values of particles (over 150µm) resulted from the combination of dull-to-sharp with G_2 gap and the addition of (E_1) enzymes at the third break (18.20 %).

Commonly, the highest significant values of fine particles (through 150µm) resulted from the combination of dull-to-sharp and G_2 gap and the addition of (E_1) enzymes at the third break (7.800 %). Components of break release were cited as strongly dependent on roll gap, along with wheat variety (Campbell and Webb, 2001, and Farooqui *et al.,* 2011). Also, roller position and roller gap were two critical factors that significantly influenced particle size distribution (PSD) in the wheat milling process. The position of the rollers determines the angle at which the wheat kernels enter the mill, affecting the initial breakage pattern. The roller gap, or the distance between the two rollers, controls the severity of the milling action. Precise adjustment of these parameters is essential for achieving the desired PSD and optimizing flour quality. The major role of the sizing system in the mill is to transform larger sizes (such as scalper and semolina) into flour. This might be reached by classifying endosperm particles into different grades as a step towards refining endosperm particles to flour (Alfin, 2019). Change in starch structure during milling is the most important factor that affects starch digestibility. Starch structure changes due to a change in particle size distribution during milling (Fasahat *et al.,* 2014). The primary function of break release is to determine flour extraction and granulation distribution, which in turn affects the mill's balance. Adjustment of the break release schedule might be required with a variable kernel size. Targeting specific particle size fractions might be a help in keeping the mill in balance (Bojanic *et al.,* 2016).

Mathematical equations can be a powerful tool for supporting milling steps, particularly when predicting the particle size distribution of final wheat flour (Dayakar *et al.,* 2016). Controls of grinding parameters (roll gap and disposition) were noted as more efficient in determining the particle size distribution of milling output. Equations had been used to reach the optimum particle size distribution through compilation of optimum roll-gap combination (Fistes *et al.,* 2017). Low digestibility of flour with large particle size might be attributed to the slow diffusion of enzymes into the starch matrix because of large protein bodies or cell wall fragments (Guo *et al.,* 2018). Fine particles are increasing cell rupture and release of cellular components that are more susceptible to digestive enzymes (Boukid *et al.,* 2019; Rovalino-Cardova *et al.,* 2019; Lin *et al.,* 2020).

The recent results confirmed that different positions lead to varying degrees of material compression and shear, influencing particle size. Certain positions could be more effective at breaking down larger particles. A smaller gap generally results in finer particles due to increased pressure and friction. However, an excessively small gap can lead to uneven processing. Enzymes can weaken material structure, making it easier to break down into smaller particles. The effect of the enzyme might be more pronounced at certain stages of the process.

Overall, the obtained results may help explain the interactions among those factors in determining the final particle size distribution. Multiple regression equations that best fit describing the influence of grain characters of Australian wheat grade to the studied factors (break system, roller position, roller gap, and added enzymes) and particle size distribution were as follows:

Over $_{1400}$µm, R^2 = 0.71

- Y_{1400} = 32.556 - 9.856 [Break system] - 2.579 [Rollers position] +127.862 [Roller gap] + 6.238 [Added enzyme]

Over $_{850}$µm, R^2 = 0.58

- Y_{850} = 44.911 - 2.895 [Break system] - 3.477 [Rollers position] - 24.216 [Roller gap] - 9.849 [Added enzyme]

Over $_{710}$µm, R^2 = 0.53

- Y_{710}= 6.634 +2.587 [Break system] - 0.115 [Rollers position] + 0.869 [Roller gap] - 2.795 [Added enzyme]

Over $_{630}$, R^2 = 0.68

- Y_{630}= -13.616+ 6.580 [Break system] - 0.472 [Rollers position] + 11.822 [Roller gap] + 5.916 [Added enzyme]

Over $_{250}$, $R^2 = 0.43$

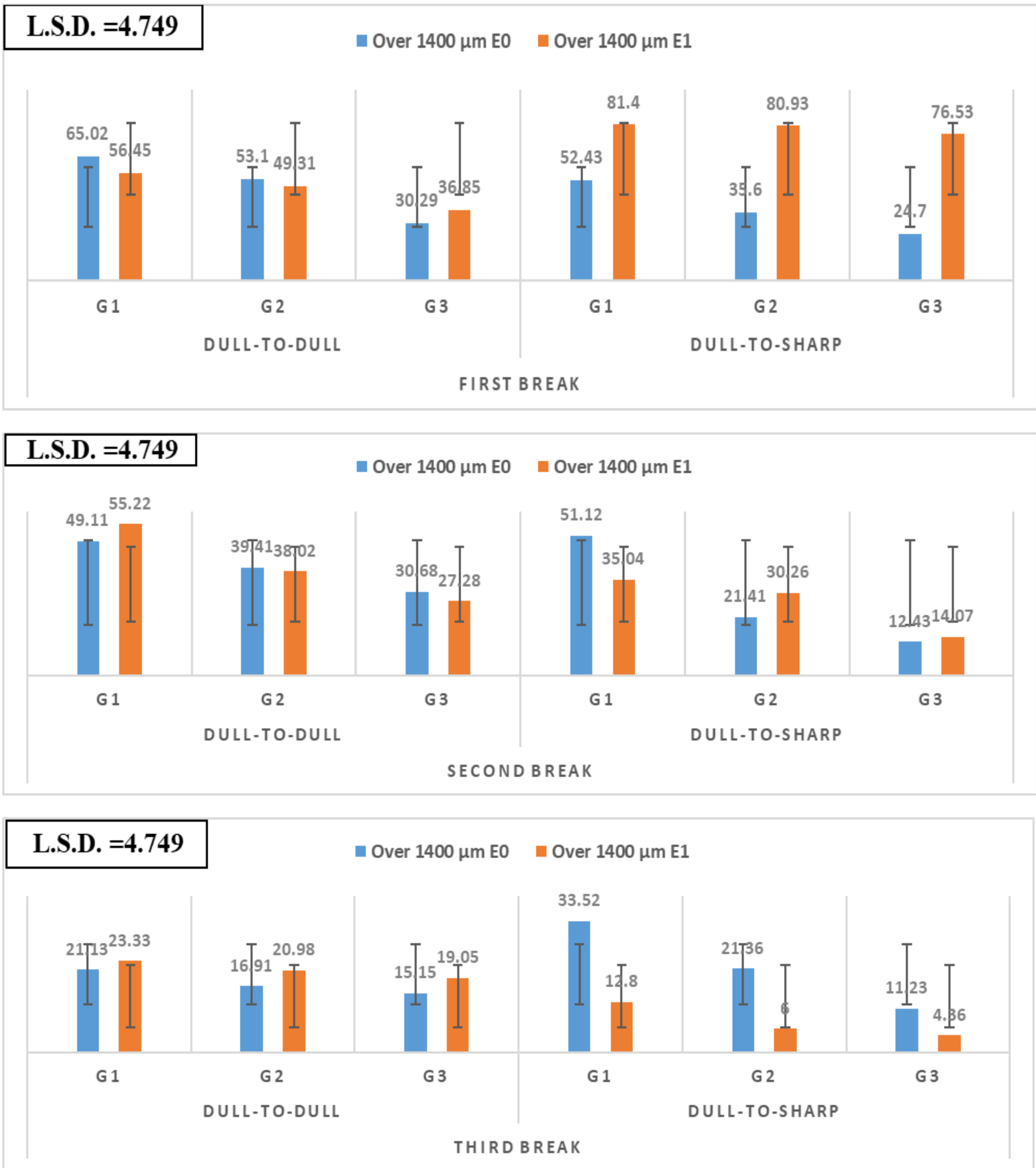
- Y_{250}= 19.912 +3.245 [Break system] +3.357 [Rollers position] -88.397 [Roller gap] +0.268 [Added enzyme]

Over $_{150}$, $R^2 = 0.52$

- Y_{150} = 5.561 + 0.773 [Break system] + 2.389 [Rollers position] - 29.681 [Roller gap] + 0.207 [Added enzyme]

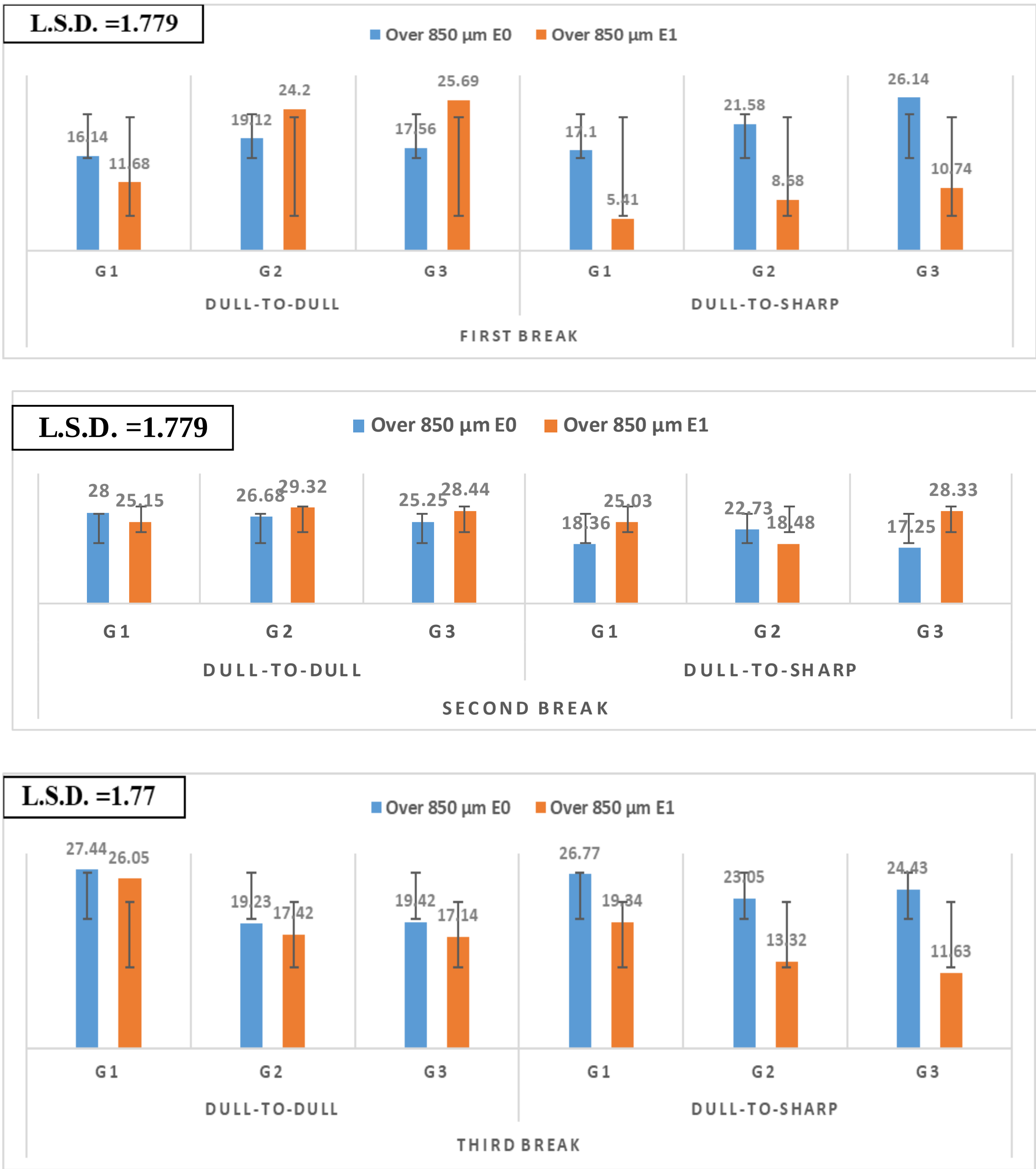
Through $_{150}$, $R^2 = 0.52$

- $Y_{through150}$= 5.555 +0.801 [Break system] +2.305 [Rollers position] -29.112 [Roller gap] +0.237 [Added enzyme].



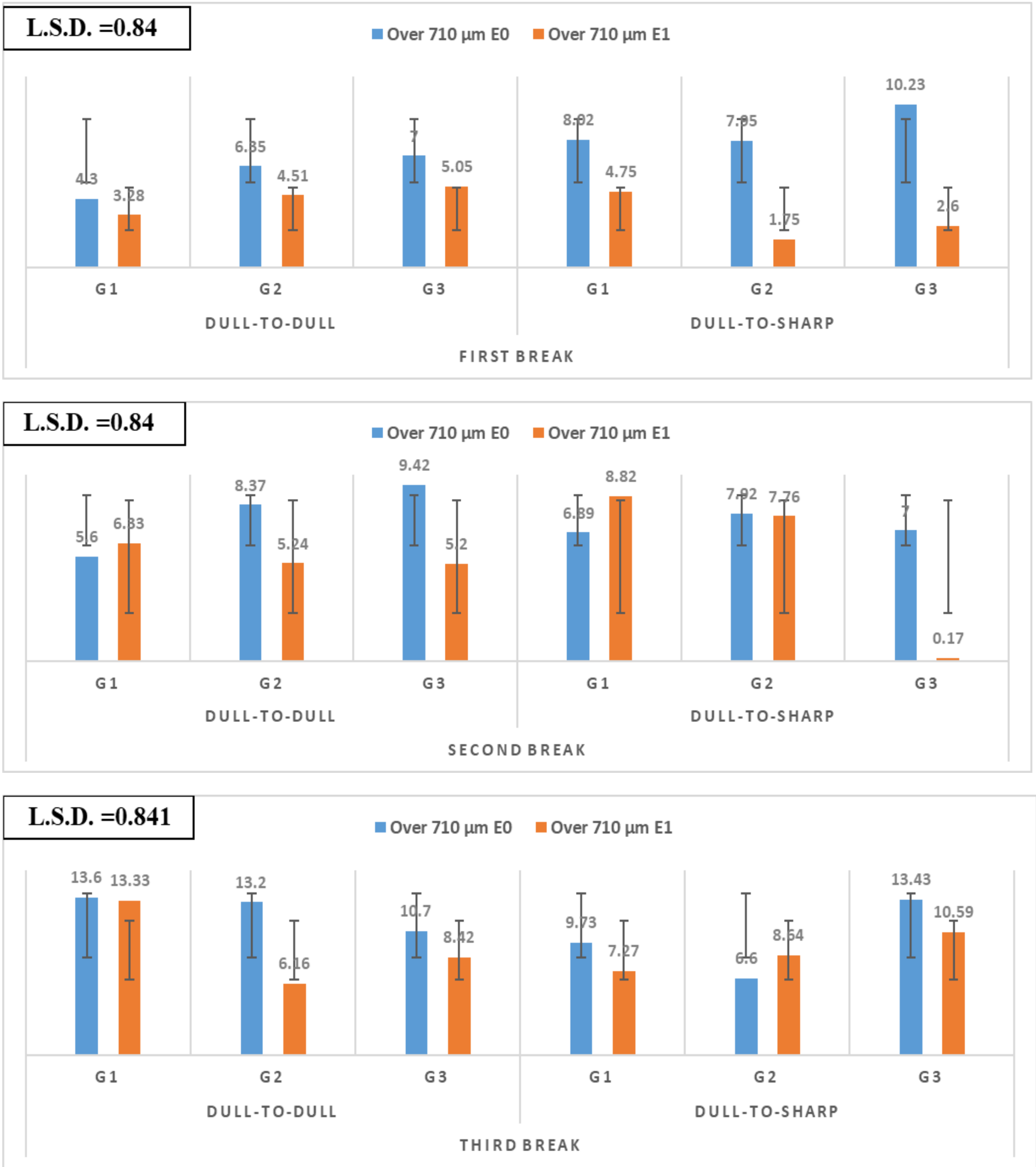
E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 1: Effects of roller position, roller gap, and added enzymes on particle size over 1400 µm of the first, second, and third break.



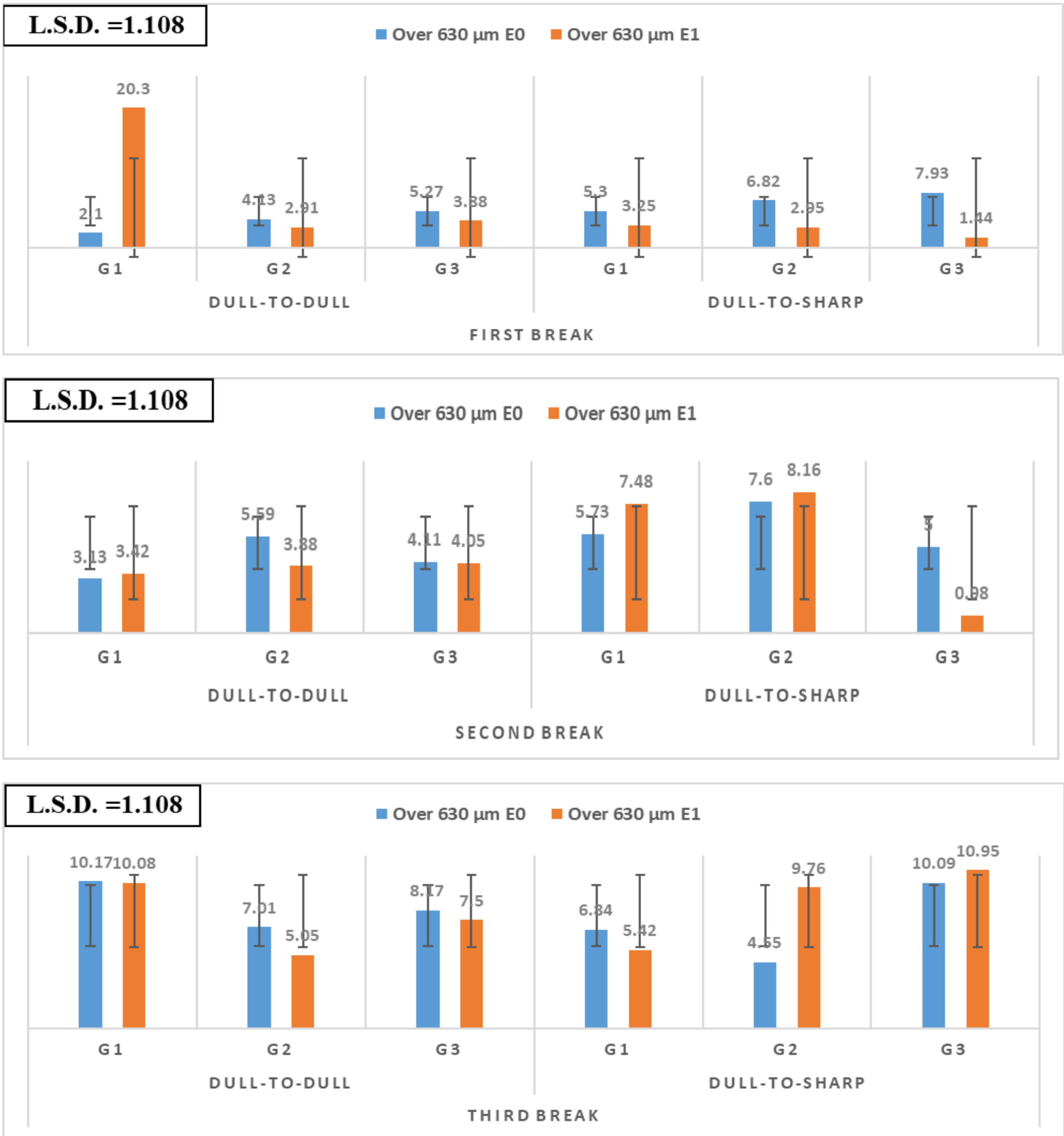
E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 2: Effects of roller position, roller gap, and added enzymes on particle size over 850 µm of the first, second, and third break.



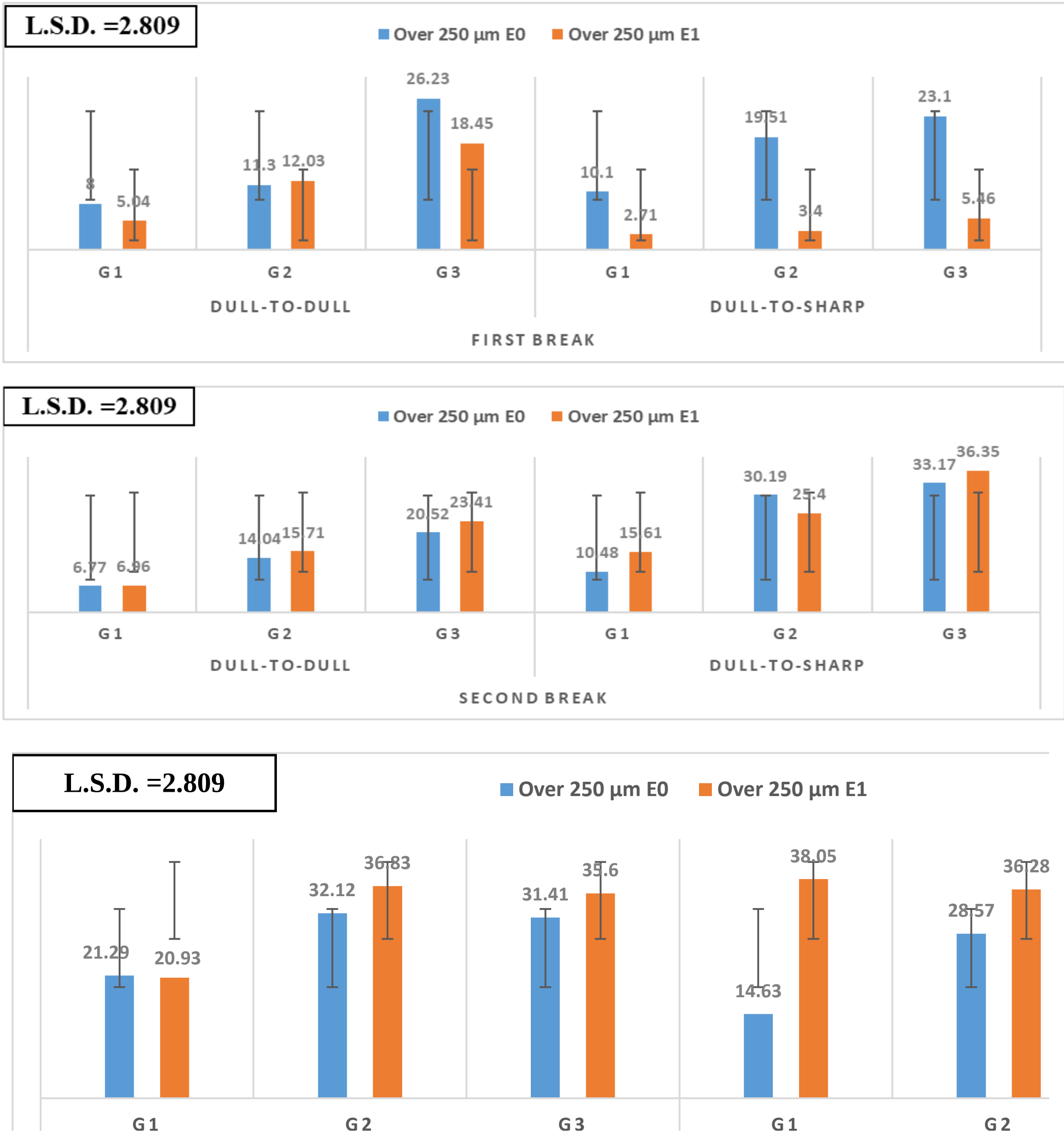
E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 3: Effects of roller position, roller gap, and added enzymes on particle size over 710 µm of the first, second, and third break.



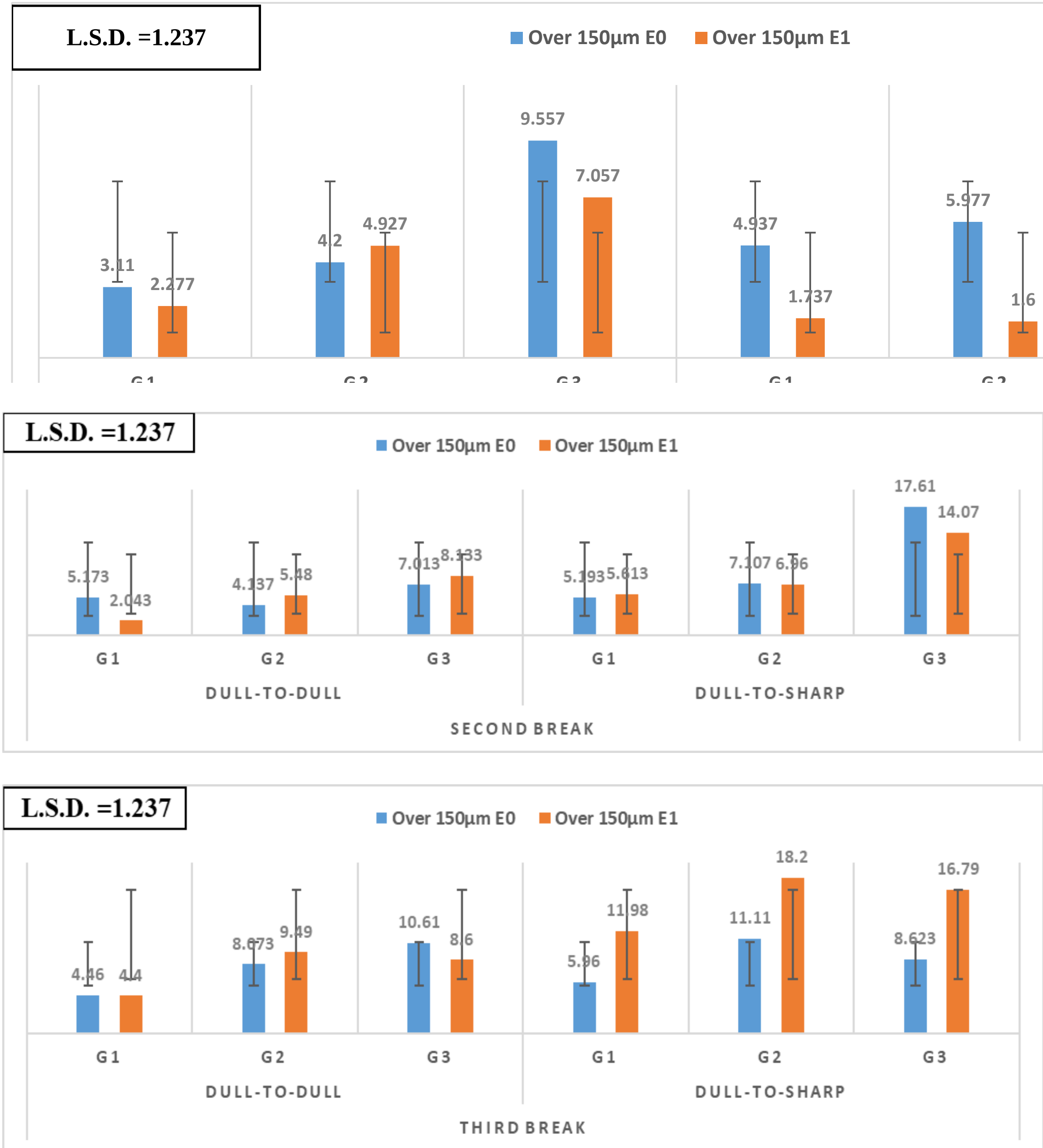
E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 4: Effects of roller position, roller gap, and added enzymes on particle size over 630 µm of the first, second, and third break.



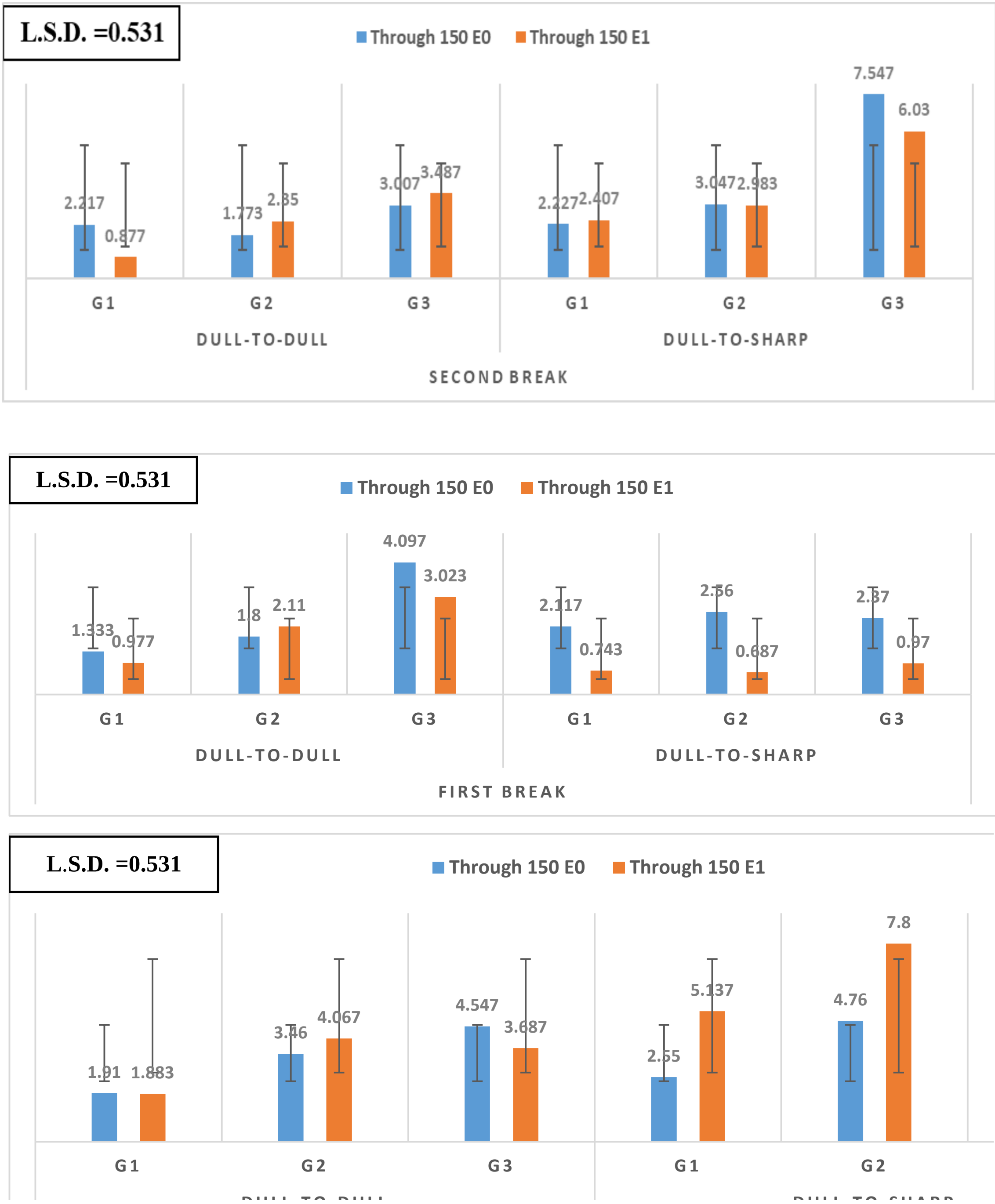
E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 5: Effects of roller position, roller gap, and added enzymes on particle size over 250 µm of the first, second, and third break.



E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 6: Effects of roller position, roller gap, and added enzymes on particle size over 150 µm of the first, second, and third break.



E_0: no enzymes, E_1: hemicellulase + xylanase + fungal α-amylase, G_1: B_1, 0.3 mm; B_2, 0.2 mm; B_3, 0.1 mm, G_2: B_1, 0.2 mm; B_2, 0.1 mm; B_3, 0.05 mm, and G_3: B_1, 0.1 mm; B_2, 0.05 mm; B_3, 0.05 mm.

Fig. 7: Effects of roller position, roller gap, and added enzymes on particle size through 150 µm of the first, second, and third break.

CONCLUSIONS

Understanding the wheat milling process for different wheat kernel grades requires knowledge of both particle composition and particle size within each compositional fraction. The objective of the break system, especially the first breaks, is to shear open the wheat grains and separate the endosperms from the bran skin in the largest possible piece, while simultaneously maintaining the bran in large, flat flakes. Controlling grinding parameters such as roll gap, roller disposition, and tempering, including the addition of enzymes, proved to be significant in determining particle-size distribution of the milling output. Mathematical equations can be used to determine the optimal particle size distribution by combining the optimal roll-gap and disposition set times. Enzymatic tempering was shown to be an effective method for influencing particle size distribution while improving milling balance.

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توزيع حجم الحبيبات الناتج عن طحن القمح وعلاقته بوضع سلندرات الدش والمسافه بينهما والترطيب الانزيمى

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الملخص العربى

الأهداف الرئيسية هى دراسة تأثير كل من: وضع درافيل الدش، المسافة بين الدرافيل والترطيب الأنزيمى على توزيع حجم الحبيبات. تم الطحن الرطب للقمح (*Triticum aestivum* L.) ممثلاً بالدرجة التجارية للقمح الأسترالي. تم تمثيل وضع الدرافيل لمرحلة الدش الأولى بمستويين، ظهر على ظهر وظهر على سن. تم تمثيل المسافة بين الدرافيل بثلاثة مستويات (G_1) و (G_2) و(G_3). وانزيمات الترطيب مثلها بمستويين (E_0) بدون إنزيمات و (E_1) هيميسيلوليز + زيلاناز + ألفا أميليز الفطري. أظهرت النتائج أن التحكم في معاملات الطحن (وضع الدرافيل، المسافة بين الدرافيل، والترطيب الإنزيمي) كان له تأثير في تحديد توزيع حجم الحبيبات لمراحل الطحن. تم استخدام المعادلات للوصول إلى التوزيع الأمثل لحجم االحبيبات. تعتبر طريقة الترطيب الأنزيمية طريقة فعالة في التأثير على حجم الحبيبات وتوزيعها. تصف هذه المعادلات، التي تتراوح قيم R^2 فيها من ٠,٤٣ إلى ٠,٧١ العلاقة بين المتغيرات المستقلة وتوزيع حجم الحبيبات.