DEBRANNING AFFECTS DURUM WHEAT MILLING PROPERTIES AND SEMOLINA QUALITY

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Delgersaikhan Shinezorigt

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Cereal Science

March 2019

Fargo, North Dakota

North Dakota State University
Graduate School

Title

DEBRANNING AFFECTS DURUM WHEAT MILLING PROPERTIES AND SEMOLINA QUALITY

By

Delgersaikhan Shinezorigt

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Frank A. Manthey
Chair

Dr. Senay Simsek

Dr. Elias M. Elias

Approved:

March 14, 2019
Date

Dr. Richard D. Horsley
Department Chair

ABSTRACT

Wheat can undergo debranning before milling. Debranning involves the removal of the outer bran layer from wheat kernels by friction and abrasion forces. This research was conducted to determine the effect of durum cultivar and debranning time on milling extraction and semolina and pasta quality. Four cultivars of durum wheat were debranned for 0, 1, 3 and 5 minutes and milled on a Bühler 202 MLU laboratory mill. Cultivars differed in the amount of bran removed at a given debranning time. Debranning for 3 min removed 8% of outer layer which resulted in 69% increase in mill throughput and 35% reduction in semolina speck count. Total and semolina extractions were increased with debranning when calculated based on milled products. However, debranning decreased both extractions when they were calculated using total bran removed during both debranning and milling. Cooking properties of spaghetti were not affected by debranning.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my advisor, Dr. Frank A. Manthey, for giving me the opportunity to pursue my master's degree. I am deeply grateful for his invaluable guidance and continues support throughout this research.

I also would like to thank my thesis committee members: Dr. Senay Simsek and Dr. Elias M. Elias for their thorough reading of this thesis and giving helpful advice and comments.

My appreciation also extends to my fellow graduate students in durum wheat quality and pasta processing laboratory: Yu Liu, Hiroshi Ando, Patricia Cabas luhmann, and Supun Sandaru for assisting me in laboratory experiments and their friendship. You made my graduate school years more enjoyable and memorable.

Last but not least, I would like to thank my family for their support and encouragement. Especial thanks to my dear loving husband, Azbayar Enkhbayar, for taking care of our kids and allowing me focus on my study for countless days and nights to complete this research work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The goal of durum milling is to produce semolina, which is coarsely ground endosperm that is free from bran and germ. Wheat kernels consist of three parts: bran (14-16%), germ (2-3%), and endosperm (81-84%) (MacMasters et al., 1964; Mousia et al., 2004). The three parts of the wheat kernel differ in their relative toughness and friability, giving different breakage patterns during milling (Fang and Campbell, 2003). These differences in toughness and friability are enhanced by tempering the grain, which is the addition of water to the wheat prior to milling. Moisture toughens the bran layer and reduces its friability, causes swelling around the germ, and softens the endosperm. Softening of the endosperm by water generally results in reduced particle size and subsequent increase in ground material released from the break rolls (Hsieh et al., 1980).

Wheat bran is composed of several layers: outer layer, seed coat, inner layer and aleurone layer. Botanically, the aleurone layer is part of the endosperm but in the milling discipline it is considered to be part of the bran. Debranning associated with wheat milling typically removes the outer 6 to 9% of the kernel by abrasion and friction (Satake Europe LTD). The crease of the wheat kernel prevents total bran removal, with about 25% of the bran associated with the crease (Sapirstein, 2016). While most of the material removed is bran, some endosperm is also removed. The shape of northern grown durum wheat kernel is irregular with outer surface having undulations which makes removal of some endosperm during debranning unavoidable.

The outer layers of bran are exposed to the environment and can become friable due to weathering, which can result in small bran particles that are difficult to remove during roller milling. Debranning to remove the outermost layers prior to milling has been shown to reduce bran breakage resulting in lower ash content and fewer bran specks in semolina (Singh and Singh, 2010; Satake Europe LTD). The outer layers also tend to contain soil particles, pesticide residues, microorganisms, and mycotoxins (Bottega et al., 2009). Therefore, removing the outer layer of bran reduces the amount of contaminated bran that enters the mill and needs to be removed during the milling process, all of which affects semolina quality and safety.

Several studies have shown that debranning of durum wheat before milling has a positive effect on milling performance (Dexter et al., 1994a, b). Milling quality can be evaluated by determining semolina extraction, semolina color, impurities (bran and ash contents), and particle size uniformity. Milling characteristics are important for the quality of the end-use product such as pasta (Dexter et al., 1994a). However, limited information is available concerning the effect of the amount of bran removed and cultivar differences on the milling process and on the subsequent quality of semolina and pasta. The overall objective of this research was to determine the effect of durum cultivars and debranning time on milling extraction and semolina and pasta qualities.

LITERATURE REVIEW

Wheat Kernel Structure

Durum wheat kernel consists of three main components: endosperm (83%), germ (2.5%), and bran (14.5%) (Maes and Delcour, 2002). Cross-section that includes the embryo shows the crease, endosperm, aleurone cell layer, bran, embryo and scutellum. Endosperm contains storage protein and starch necessary to sustain the growth and development, during germination, of the embryo into a seedling. The endosperm contains starch accounting for 80-90%, protein 6-12%, and lipid 1-2% of whole kernel (Shewry and Morrell, 2001). Germ consists of the embryo and scutellum. The embryo is high in oil content accounting 25-30%, protein about 25%, and starch less than 10% of the whole kernel (Fardet, 2010). The scutellum absorbs nutrients released from the endosperm during germination and transports them to the developing embryo. Germ has high oil content which can become rancid and decreased palatability of the flour. Wheat bran is the outer layer of the wheat kernel. It protects the endosperm and consists of inner and outer pericarp. Botanically, the aleurone cell layer is part of the endosperm, but from a milling point of view, it is part of the bran. The aleurone layer contains hydrolytic enzymes needed for degradation of endosperm during germination. Bran and aleurone layer contain relatively high levels of ash, protein, fat, vitamins, minerals and enzyme activities. Wheat bran is composed predominantly of non-starch polysaccharides (~58%), starch (~19%) and crude protein (~18%), with the non-starch polysaccharides being primarily ~70% arabinoxylan, ~24% cellulose and ~6% β-(1,3) (1,4)-glucan (Maes and Delcour, 2002). Bioactive compounds are mainly concentrated in the outer layers of kernels (Fardet, 2010).

Kernel Shape and Size

Durum wheat kernel has a generally ellipsoid shape, with the length being greater than the width. Novaro et al. (2001) reported that based on the average of 327 grain samples, the average durum kernel length was 7.5 mm and width was 3.2 mm. The dorsal side is rounded, with the embryo located on the basal end. The ventral side tends to be flat with a deep crease that runs the length of the seed (Figure 1).

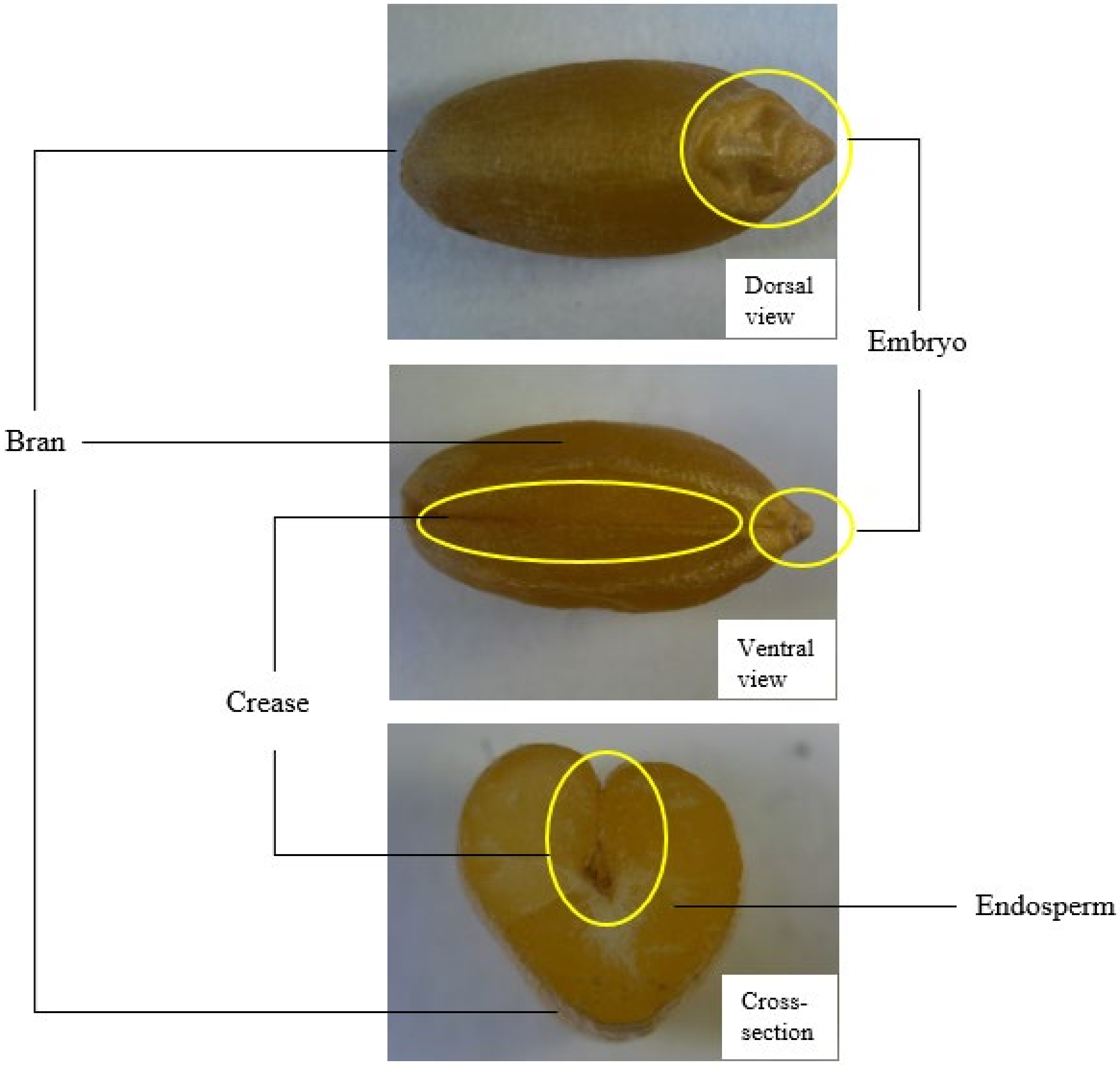

Figure 1. Durum wheat kernel

Kernel size and kernel size distribution affect grinding performance of a roller mill. Kernel size is important since large kernels will have a high endosperm to bran ratio, resulting in more endosperm available to produce semolina. Furthermore, kernel size influences grinding performance of roller mill, as wheat kernels of different sizes break up differently. Small kernels produce high ash containing flour and low yield. Kernel size distribution is important since the gap between paired rolls is set based on mean size. If there is a bimodal distribution of large and small kernels, then the gap setting is not optimal for any of the grain. A narrow distribution of kernel size is also important when applying premilling treatments such as tempering and/or debranning before milling. Even distribution of moisture during tempering or even removal of bran during debranning is favored by uniform narrow distribution of kernel size. Kernel size affects break release. Break release is the weight % of the stock remaining over the 20W sieve in each break system (Posner and Hibbs, 2005). Kernel size is often determined by single kernel characterization system or by sieving method described by Shuey (1960). Using the method described by Shuey (1960) the five-year crop average for durum grown in the northern plains of USA was 50% large and 47% medium (US Durum Wheat Regional Quality Report, 2018).

Kernel weight and test weight are measures of density and kernel soundness. Heavy kernels indicate a greater endosperm percentage which correlates with high flour yield. The five-year crop average for durum grown in the northern plains of USA was 39.9 g for 1000-kernel weight and 78.6 kg/hL for test weight (US Durum Wheat Regional Quality Report, 2018). Kernel weight, size, and shape affect test weight (Troccoli and Di Fonzo, 1999). Irregularities in kernel shape reduce the number of kernels that can occupy the test weight container and so reduce the weight per volume. Irregular kernel shape can also result in lower milling yield as it makes removing the bran from the endosperm more difficult. Thus, high 1000-kernel weight and test weight are associated with high semolina/flour extraction by the milling process (Simmons and Meredith, 1979; Matsuo and Dexter, 1980).

Durum wheat kernels have an amber, translucent, vitreous appearance. Kernel vitreousness is associated with endosperm compactness, which has been shown to be related to protein content. Kernel vitreousness is an important factor in determining milling performance of durum wheat. Vitreous character results in the kernel fracturing into coarse particles characteristic of semolina instead of being crushed into flour during roller milling. Nonvitreous durum kernels produce less semolina and more flour, thus reducing milling quality of the grain (Simmonds, 1974; Samson et al., 2005). Because vitreousness is important to semolina production during milling, the United States Grain Standard has durum wheat subdivided into three subclasses determined by the percentage of hard and vitreous kernels of amber color (HVAC): Hard Amber Durum which contains ≥75% HVAC, Amber Durum wheat which contains 60 to 74% HVAC, and Durum wheat which < 60% of HVAC (USDA, Grain inspection handbook, 2017).

Wheat Milling

The goal of durum milling is to produce semolina, which is coarsely ground endosperm that is free from bran and germ. The traditional semolina roller mill can be divided into a break system with seven break passages and a reduction/sizing system with six to seven reduction passages (Fowler, 2014; Dal-Pastro et al., 2016). Ground stock moves through the break system to the reduction/sizing system. The break system has two functions. The first function is to break the kernel into large pieces and the second function is to remove the bran and germ from the endosperm. The function of the reduction/sizing system is to reduce the large endosperm pieces to the desired granulation. Ideally the granulation range is narrow as particle size affects the rate of hydration during the hydration-mixing step of pasta processing.

Paired-rolls in the break system have wide and deep spiral corrugations and together with the wide gap between paired-rolls promote the breakage of kernel into large pieces. The width and depth of corrugations and space between rolls (roll gap) become progressively smaller as ground stock progresses through the mill. Each roll in a pair counter rotates and spins at a different rate which results in a shearing action that promotes the removal of bran and germ from the endosperm. After passing through a paired-roll, the ground stock is sized by passing over a series of sieves having different aperture sizes. The large particles are sent to the next set of break rolls and smaller material is sent to purifiers. Purifiers remove unattached bran by use of aspiration and sieving and fractionate the endosperm particles (semolina) by size.

Mass flow balance within the mill can be monitored by determining break release. Break release is the amount of ground stock that passes through a selected sieve with known aperture size. Generally, the overs reflect the ground stock sent to the next break roll and the throughs are ground stock sent to the purifiers. Mill balance depends on each break roll distributing the correct break release so that each subsequent roll, sieve, and purifier is processing the appropriate amount of ground stock (Fowler, 2012).

Break release is associated with semolina/flour extraction and quality (Fowler, 2012). Therefore, break release has been used to evaluate the effects of grain quality and pre-milling treatments such as grain tempering and debranning on milling performance. Changes in break release can indicate potential changes in mill flow/balance, as it detects changes in the amount of ground stock moving to the next break roll, sifter and purifier and can detect possible problems due to over or under loading sifters and purifiers (Fowler, 2012).

Even though, starchy endosperm constitutes 80% of the wheat kernel, it cannot be removed 100% by the milling due to its crease area (Dexter and Wood, 1996). Milling extraction is important characteristics of milling quality; however, higher extraction of semolina often results in lower quality of semolina. Wheat flour ash content and color begins deteriorating when extraction rate reaches 65% (Dexter and Wood, 1996). Ash content and color are some of the important characteristics of semolina that affect its' end-use product quality. Therefore, milling is the critical process where bran and germ is removed to its highest level without degrading semolina quality.

Pre-Milling Treatments

Tempering

Milling performance of wheat grain is enhanced by tempering which is the addition of water to the wheat prior to milling. The three parts of the wheat kernel, bran, germ, and endosperm, differ in relative toughness and friability, giving different breakage patterns during milling (Fang and Campbell, 2003). These differences in toughness and friability are enhanced by tempering the grain. Moisture toughens the bran layer and reduces its friability, loosens the germ from bran and endosperm, and softens the endosperm. Softening of the endosperm by water generally results in reduced particle size and subsequent increase in ground material released from the break rolls (Hsieh et al., 1980). Softening of endosperm causes less wear on the rolls and lower energy requirement for the milling process. Compared to bread wheat, durum wheat is tempered to higher moisture level due to its hard vitreous endosperm that requires a longer tempering time due to its slow water uptake; therefore, more time is required for even distribution of water in and among the grain.

Debranning

Many commercial durum mills use a debranner in a premilling step. Debranner is a machine that removes the outer layer of bran from the grain before milling with a roller mill. Thus, debranning can reduce the amount of bran that needs to be removed from grain and reduce potential contamination in semolina. Debranning process involves the application of two forces (friction and abrasion) on the kernel surface. Friction, caused by kernels rubbing against each other removes outer pericarp layer, and abrasion caused by kernels rubbing against the rough surfaced wall of the debranning chamber removes inner bran and aleurone layers.

There have been reports of increased milling yield and improved semolina and pasta quality with debranning (Dexter et al., 1994a; Dexter and Wood, 1996; Mousia et al., 2004). For example, Dexter and Wood (1996) reported that debranning increased milling yield and reduced energy consumption by simplifying the milling process compared to conventional milling. Debranning affects grain color by increasing brightness (L*) and decreasing redness (a*) value (Singh and Singh, 2010). Mousia et al. (2004) milled debranned wheat on a Bühler MLU 202 laboratory mill reported 5% more milling yield than of nondebranned wheat samples. Dexter and Wood (1996) reported that durum wheat debranned 12.9% had higher semolina yield, lower ash content and specks in semolina, and higher cooking score in spaghetti. Similarly, debranning increased spaghetti brightness and decreased brownness when compared to spaghetti made of unprocessed wheat (Dexter et al., 1994a).

There are many studies that show that debranning has a positive effect on grain from microbial aspect. Cereal grain is more susceptible to microbial contamination during growth from environment, water, soil, insects, and improper handling during harvesting and storage (Los et al., 2018). Mousia et al. (2004) and Laca et al. (2006) reported that 87-90% of the total microbial contamination was removed when only 4% of the grain surface was removed by debranning. Debranning can reduce mycotoxin content in debranned kernel, but the amount varies depending on the procedure (Cheli et al., 2013). Deoxynivalenol from *Fusarium* is the major mycotoxin found in wheat and is hazardous to human and animal health when consumed. Mycotoxin contamination level varies between regions, years, and weather (Cheli et al., 2013). Longer debranning decreased alpha-amylase activity and xylanase activity in flour, as well as flour yield. However, 8 seconds of debranning resulted large decrease in xylanase in flour, but only 2% decrease in milling yield (Gys et al., 2004).

Semolina Quality

According to the Food and Drug Administration, *(a) Semolina is the food prepared by grinding and bolting cleaned durum wheat to such fineness that, when tested by the method prescribed in 137.300(b)(2), it passes through a No. 20 sieve, but not more than 3 percent passes through a No. 100 sieve. It is freed from bran coat, or bran coat and germ, to such extent that the percent of ash therein, calculated to a moisture-free basis, is not more than 0.92 percent. Its moisture content is not more than 15 percent.* (Sec. 137. 320). Thus, this definition stresses the importance of bran and germ removal, low ash content, and coarse particle size distribution.

Particle Size Distribution

Granulation of semolina is dependent on roll corrugations. Deep large corrugations will result in large particles. Small shallow corrugations will result in small particles. Rolls with no corrugations will produce flour. Large size distribution of particles affects hydration uniformity which will affect end-use quality. Fin particles have a higher water absorption rate than coarse particles. A wide distribution of particle sizes will result in fine particles that become overhydrated and in coarse particles that are underhydrated. Over hydration results in weak, sticky dough that can result in the formation of large aggregates that can interfere with uniform movement in mixing chambers during pasta processing. Over hydration can also result in particles adhering to metal surfaces and represent sites of potential microbial growth. Under hydration results in stiff dough that is difficult to extrude. Particles that are underhydrated will not form gluten network. Pasta manufacturers have their own specific granulation range. Semolina particle size normally ranges between 425 and 250 µm (Dick and Youngs, 1988).

Specks, Ash, and Color

Specks are undesirable brown and black particles that come from bran or diseased seeds. Specks in semolina are readily noticed in dry pasta and can cause spaghetti to break after drying. Proper conditioning and purifier adjustment can reduce the number of specks in semolina. Ash is the mineral content that is left from flour after incinerations. Ash content is often used to assess performance of the mill. Ash content decreases from the outer layers to the center of the wheat kernel (Hinton, 1959), therefore, high ash content in semolina indicates bran contamination in the milled product. High ash content is often associated with dull color to dough and to the subsequent dry pasta product.

Endosperm from durum wheat contains xanthophylls such as lutein which give the semolina and its end-use products a yellow appearance (Delgado et al., 2014). Yellowness of semolina can be affected during milling. Particle size of semolina will affect the yellow appearance of the semolina. Coarse granulation will appear darker yellow than fine granulation. In addition, lipoxygenase activity is important in semolina color (Borrelli et al., 1999). Lipase and lipoxygenase found in bran and germ can be activated during the hydration step of pasta processing. If the bran and germ are not removed during milling, lipase can release free fatty acids from triacylglycerides whereupon lipoxygenase can oxidize unsaturated free fatty acids to form free radicles. Lutein in the semolina acts as an anti-oxidant to neutralize the fatty acid free radicle. In doing this, the lutein is oxidized and loses its yellow color which will result in poor pasta color.

Pasta Quality

Pasta quality is often assessed by pasta color and cooking quality. Checking, surface smoothness, and speckiness affect the consumer acceptability of pasta (Feillet and Dexter, 1996). These three characters are related to bran specks.

Pasta color is often assigned a color score which is based on Hunter L (brightness) and b (yellowness) values as described in AACC International method 14-22.01. Debranning has resulted in a lower number of bran specks in semolina and subsequent pasta. The lower number of specks has been associated with increased spaghetti brightness and decreased brownness when compared to spaghetti made of unprocessed wheat (Dexter et al., 1994a). Color can be affected by drying temperature which can promote darkening due to Maillard reaction of sugars with lysine. Sugar can be available with damaged starch. Starch damage can occur during the milling process. During pasta drying, Maillard reactions involving the terminal amino group of free amino acids, proteins and reducing sugars, lead to a change in color of pasta by non-enzymatic reactions (Acquistucci, 2000). The occurrence of Mailard produces during pasta drying is undesirable because it increases the redness and brownness of the pasta.

Cooking quality is the characteristic of greatest importance to consumers (Hahn, 1990). Cooked pasta quality is defined as cooked firmness, cooking loss, and cooked weight (Debbouz and Doetkott, 1996). Cooking loss determines the amount of solids that migrate from the pasta to the cooking water during cooking. Cooking losses are mostly amylose and soluble protein (Matsuo et al., 1992), and is greater with increased starch damage. Spaghetti firmness is attributed to the protein content and protein quality of the semolina (Del Nobile et al., 2005).

MATERIALS AND METHODS

Grain Quality

Foundation seed of durum wheat cultivars Alkabo (Elias and Manthey, 2007), Carpio (Elias et al., 2015), Joppa (Elias and Manthey, 2016), and Tioga (Elias and Manthey, 2012) were obtained from the North Dakota Agricultural Experiment Station at Williston, ND. Test weight (kg/hL) was determined by AACC International Approved Method 55-10.01 (AACC International, 2010). 1000-Kernel weight was determined by counting with an electronic seed counter (Seedburo Equipment Co., Chicago, IL) the total number of kernels in 10 g of cleaned grain and adjusting the weight to 1,000 kernels. Kernel size distribution was determined using the methodology described by Shuey (1960); where kernels were classified as large when remained on Tyler No 7 sieve with 2.92 mm opening (top sieve); medium when they remained on Tyler No 9 sieve with 2.24 mm opening (middle sieve); and small kernels passed directly through both sieves. Vitreous kernel content was determined using a farinator. Kernels (200) were cut in half and the number of kernels with white opaque regions was counted nonvitreous. Grain color was determined by Minolta CR410 Chromameter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ, USA) configured to measure Commission Internationale d' Eclairage (CIE) L*, a*, and b*-color values. L* measures the lightness of samples from black (0) to white (100), a* measures the greenness (-60) and redness (60), and b* measures blue (-60) to yellow (60).

Grain protein and moisture contents were determined using FOSS Infratec^{TM} 1241 Grain Analyzer (FOSS Tecator, Hogonas, Sweden). Grain ground using a Falling Number mill was used to determine ash content and falling number using AACC International Approved Methods 08-01.01 and 56-81.03, respectively.

Debranning

Preliminary researach was conducted to determine optimum debranning parameters including length of time of debranning, effect of initial grain moisture level, and effect of tempering, including the amount of water to hydrate the grain and time needed for water to move into the bran layer.

Preliminary results indicated that initial grain moisture content did not affect the amount of bran removed by the debranning process if grain moisture content was increased by 1% (w/w) 10 min before debranning. Debranning for 5 minutes removed material much greater than 13-15% that bran makes up in the kernel. There were little or no differences in debranning level when grain was tempered for 10 minutes or longer. Therefore, tempering time was determined to be 10 minutes. Tempering level was determined to be 1% unit. Debranning time was suggested not longer than 5 minutes. Debranning procedure was based on these results.

Grain (300 g) was tempered by adding water (1% wt/wt) to the grain and allowed to equilibrate for 10 min. The wetted grain was immediately shaken for 30 seconds and again 5 min after water was added.

The tempered durum wheat grain (300g) was debranned using a compact rice milling device (Twinbird MR-E500, Twinbird Corp., Niigata, Japan) at ‘Butsuki’ setting (bran layer 100% removal) for 0, 1, 3, and 5 minutes. This machine was designed to remove bran from brown rice to produce a polished white rice. Following debranning, temperature of grain and bran were measured using an infrared thermometer (TN408LC, Metris, NJ, USA).

Bran and Debranned Grain Quality

Moisture content of bran was measured according to AACC International Method 44-15.02. Debranned grain was measured for protein content and moisture content by Near-Infrared (NIR) technology using Infratec 1241 grain analyzer (FOSS, Hilleroed, Denmark). Color measurements on debranned grain (CIE L*, a*, and b*) were measured with a Minolta CR-410 Chromameter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ, USA). Percent kernel breakage was estimated by sieving debranned kernels over a 2.24 mm screen for 2 minutes. Kernels that passed through the screen were considered broken.

Roller Milling

Debranned grain was milled on a MLU-202 Bühler laboratory mill that was configured with two Miag purifiers (Figure 2). Each purifier had two sections. All samples were conditioned using a three step tempering process. First, the grain was tempered to 12.5% mb and allowed to equilibrate in a closed plastic container at room temperature for at least 72 hours. Second, the grain samples were tempered to 14.5% mb 24 hours before milling. The last tempering step occurred 45 minutes before milling, where the original grain and grain debranned for 1 minute were tempered to 17.5% mb; grain debranned for 3 minutes were tempered to 16% mb; and grain debranned for 5 minutes was not furthered tempered. Adjustments to the final tempering were made due to the reduction in bran content of the grain. Grain debranned for 5 minutes had little or no bran on the kernels (Figure 3). Overhydrating the debranned grain caused the grain to become sticky and posed a risk of clogging the tubes associated with pneumatic system that was used to move ground stock to adjacent rolls and between the mill and the purifiers.

Milling yield was calculated based on total material recovered during milling. Total milling yield was calculated based on the total material recovered during milling plus the weight of bran removed during the debranning step. Each mill stream was weighed and calculated as percentage of total milling yield basis. Milling time (min) was recorded and milling rate was measured as gram product per minute.

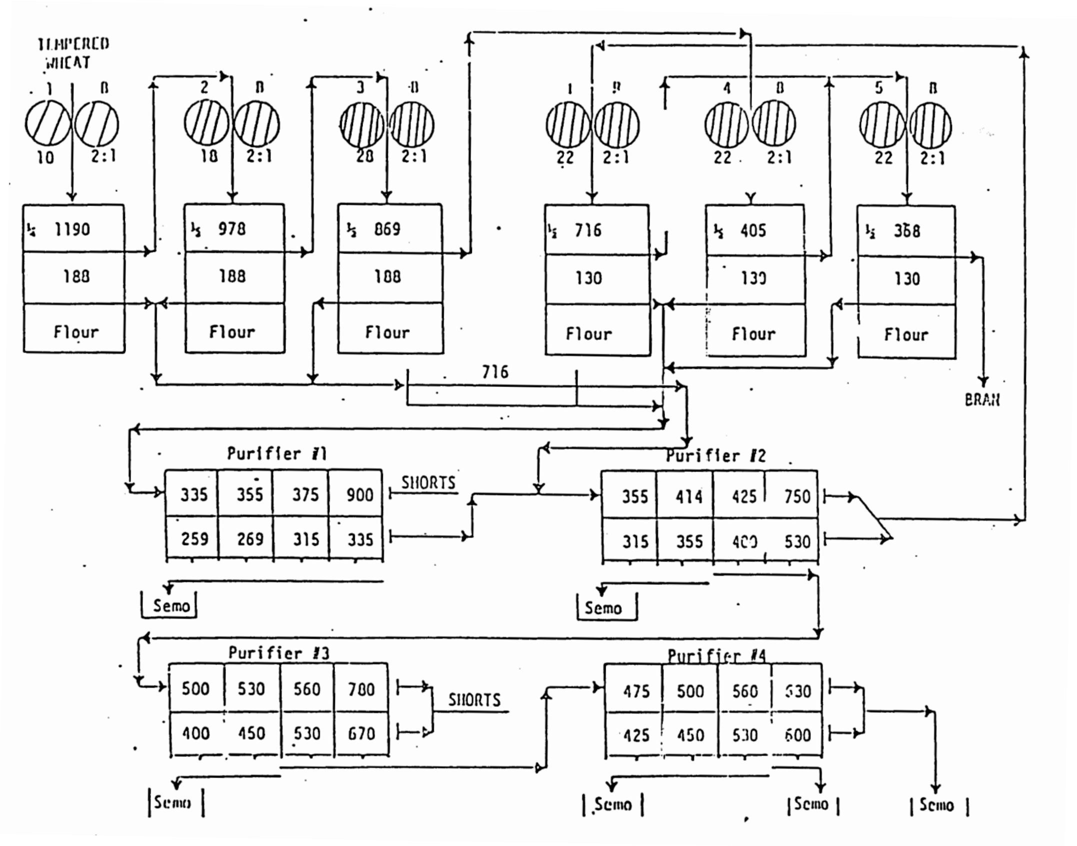

Figure 2. Mill flow chart for Bühler 202 MLU roller mill configured with two Miag purifiers. Each purifier had two sections.

Break Release

Break release was determined for Alkabo, Joppa, and Tioga samples that were debranned for 0, 1, and 3 minutes. Carpio was not evaluated due to insufficient quantity of available sample. Break release was determined for the first, second and third break rolls. Break release was determined as the proportion by weight of broken particles that passed through 1,180 µm sieve (U.S standard sieve #16) for the first break, 1,000 µm sieve (U.S standard sieve #18) for second break, and 850 µm sieve (U.S standard sieve #20) for the third break rolls. Grain (500 g) was passed through the first break, the overs were weighed and passed through the second break and these overs were weighed and passed through the third break. The amount of flour produced by

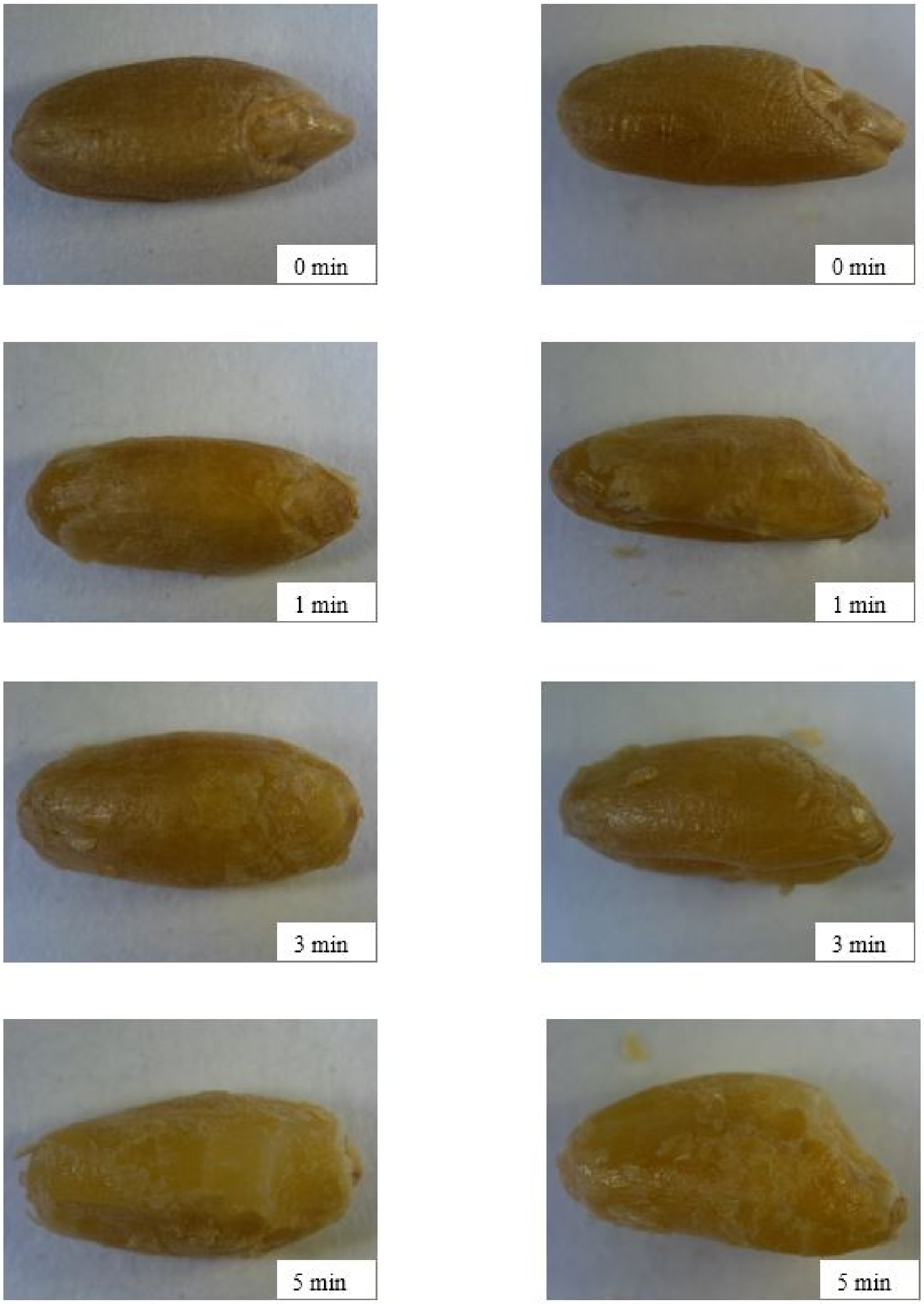

Figure 3. Dorsal (left column) and lateral (right column) views of kernel debranned for 0, 1, 3, and 5 minutes.

each break was determined by weight of particles that passed through a 180 μm sieve (U.S standard sieve #80). Samples were sieved using a rotary sifter for 2 minutes.

Semolina Characteristics

Protein (14% mb) and moisture content was measured on Infratec 1241 grain analyzer (FOSS, Hilleroed, Denmark). Ash content was determined according to AACCI Method 08-01.01. Gluten index and wet gluten of semolina was determined according to AACCI Method 38-12.02 using Glutomatic System (Perten Instrument, Hagersten Sweden). Total starch content was determined using an enzymatic total starch assay kit (Megazyme International, Co. Wicklow, Ireland) according to AACC International Approved Method 76 - 13.01 and the amount of starch damage was determined using an enzymatic starch damage assay kit according to AACC International Approved Method 76-31.01. Color measurements were (CIE L*, a*, and b*) measured with a Minolta CR-410 Chromameter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ, USA). Semolina was placed into a black cell that was 1.3 cm deep and had a quartz glass window. Semolina size distributions were determined by Retsch Vibratory Sieve Shaker AS 200 (Verder Scientific, Inc., Newtown, PA, USA). Particle size distribution was determined using sieves with aperture sizes of 600, 500, 425, 250, 150, 100, and 50 μm.

Pasta Processing

Semolina (1000 g) was hydrated to 32% moisture, mixed (4 min) and processed into spaghetti using a DeMaCo semi-commercial pasta extruder (DeMaCo, Melbourne, FL). Extrusion conditions were extrusion temperature, 45°C; mixing chamber vacuum, 46 cm of Hg; an auger length to diameter ratio of 8.1:1; and extrusion speed, 25 rpm. The spaghetti was dried in a laboratory dryer (Standard Industries, Fargo, ND) using high temperature drying cycle (length 10 h; peak temperature 73°C) as described by Yue et al (1999). Dry spaghetti color

Hunter L, *a*, and *b* values were measured using a Minolta CR410 Chromameter (Konica Minolta Sensing Americas, Inc, Ramsey, NJ, USA). Spaghetti was placed on a black template that was 1.3 cm deep. Three measurements were taken at three different locations on the spaghetti. The data recorded was the average of the three readings.

Pasta Cooking Quality

Dry spaghetti strands (10g, 5cm length) were cooked in boiling distilled water (300 g) in glass beaker for different periods of times (2, 4, 6, 8, 10, and 12 min) (AACCI 66-50.01). Cooked spaghetti was drained using Büchner funnel, and weighed on tared plastic tray for cooked weight (g). Cooked firmness and cooking loss were determined according to AACC International Method 66-50.01. Cooked firmness (g.cm) was determined by work required to shear sample (5 strands) by 0.1 x 5 cm pasta blade probe using TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY). Five measurements were done per sample. Cooking loss was determined by placing pre-weighed beaker containing cooking water in an air oven at 110°C overnight to evaporate cooking water. Residue in the beaker was weighed and reported as cooking loss (g).

Experimental Design and Statistical Analysis

Bulk seed of each cultivar was divided into three sets and each set was considered a replicate. Each replicate of all treatments was separated in time. Statistical analysis was performed using the Statistical Analysis System Software 9.4. The experimental design was a randomized complete block with a split-plot arrangement, where whole plot was durum cultivar and subplot was debranning time. Treatment means were separated by Fisher's protected Least Significant Difference test calculated at P=0.05.

RESULTS AND DISCUSSION

Grain Characteristics

Mean values for kernel characteristics of durum wheat used in this research are presented in Table 1. Grain used in the research was sound and of good quality. Test weight, vitreous kernel content, ash content, and protein content are similar to or higher than those for the five-year crop average. 1000-Kernel weight, percent large kernels, and falling number are higher than the five-year average and reflect the quality associated with Foundation seed.

Table 1. Proximate analysis of grain from four durum cultivars.

Cultivars	TW[a] (lb/bu)	1000-KWT[a] (g)	VK[a] (%)	Lar[b] (%)	Med[b] (%)	FN[a,c] (sec)	Ash[c] (%)	Protein[c] (%)
Alkabo	59.2±0.1	45.8±0.9	94±1	70±1	29±1	408±17	1.58±0.02	15.1±0.1
Carpio	60.4±0.1	47.3±1.1	84±3	78±3	21±2	766±58	1.53±0.03	14.1±0.1
Joppa	61.5±0.3	50.6±0.2	89±1	78±1	22±1	587±26	1.55±0.02	13.8±0.1
Tioga	61.9±0.1	46.1±1.0	86±3	73±1	26±1	673±26	1.64±0.01	13.6±0.1
5-year Crop Average[d]	60.4	39.9	86	50	47	374	1.57	13.6

[a] TW = test weight; KWT = kernel weight; VK = vitreous kernels; FN = falling number.
[b] Percentage large kernels; Percentage medium kernels.
[c] FN, Ash, Protein 14% moisture basis.
[d] 2013-2017 Average for durum grown in the Northern Plains, USA.

Debranning Process

Temperature of bran removed and of the debranned kernels did not differ with cultivar but did increase with debranning time (Table 2). Friction and abrasive forces applied to the grain during the debranning process generated heat. The longer debranning occurred, the more friction/heat was generated. The temperature of the removed bran was always lower than that of the debranned grain. Once the bran was removed from the grain it was no longer exposed to friction/abrasive forces that generated the heat, thus allowing the bran to cool. The grain was constantly exposed to friction/abrasive forces and the heat that they generated. Bran and grain temperatures generated would not be expected to affect functionality of protein or starch. Cook

(1931) reported that functionality of gluten was not significantly changed when gluten with moisture content 12-14% was heated to 70°C.

Table 2. Effect of durum cultivar and debranning time on the temperature and moisture content of bran and debranned grain, the amount of bran removed and starch in removed bran*.

Cultivar	Temperature (°C)		Moisture (%)		Crude bran removed (g/100g grain)	Starch in crude bran (%)	Starch removed during debranning (g/100 g grain)
	Bran	Grain	Bran	Grain			
Alkabo	32.3a	35.2a	11.7a	9.8a	7.2b	18.6c	1.3b
Carpio	31.7a	33.8a	11.0b	9.6b	10.1a	25.6ab	2.6a
Joppa	31.5a	33.8a	10.7b	9.8a	10.3a	23.3b	2.4a
Tioga	33.1a	34.0a	10.2c	9.1c	10.1a	27.0a	2.7a
Debranning time, min							
1	27.3c	27.9c	11.8a	9.9a	1.4c	25.3a	0.4c
3	32.0b	34.9b	10.9b	9.6b	8.2b	19.9b	1.6b
5	37.2a	41.3a	10.1c	9.6b	18.7a	25.7a	4.8a

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Crude bran consists of the outer portion of the kernel removed during debranning. This would include bran, germ, and endosperm (Figure 3). The amount of crude bran removed by the debranning process, when averaged over debranning time, was similar (~10.2% w/w) for Carpio, Joppa, and Tioga and their crude bran removal was 30% more than the crude bran removed from Alkabo (7.2% w/w). The low crude bran removal from Alkabo might be related to its higher vitreous kernel content (94% vs 84-89%) and protein content 15.1% vs 13.6-14.1%) compared to the other cultivars. Singh and Singh (2010) reported that debranning levels were lower for wheat with high protein content and vitreousness. They attributed this to increased kernel hardness with high than low protein. The debranning process is similar to the pearling process used to determine kernel hardness (McCluggage, 1943). These results suggest that kernels of Alkabo were harder than kernels of Carpio, Joppa, and Tioga.

Debranning time had significant effect on crude bran removal (Table 2). Amount of material removed was 1.4% with 1 minute, 8.2% with 3 minutes, and 18.7% with 5 minutes or 1.4, 2.7, and 3.7 g/min (Figure 3). The increase in amount of material removed is thought to reflect change in texture of kernel and ease of removing bran/germ and removing endosperm. Optimum bran removal for durum semolina was 8-8.5% (Satake Europe LTD); thus the 3 minutes debranning time removed bran that reflects the level of debranning occurring during commercial milling.

Bran makes up 13-15% in the kernel. Therefore, 5 minutes of debranning removed more materials than was targeted to remove. Pagani et al. 2002 reported that debranning levels greater than 10-12% indicated excessive endosperm abrasion. Bran contains different layers including: the outer pericarp, the inner pericarp, the testa and the aleurone layer, respectively and they represent 3.9, 0.9, 0.7, and 9.0% of the kernel weight (Shetlare, 1947). Shetlare et al. reported that debranning up to 4% level on average removed most of the outer pericarp while at 8% level the non-aleurone along with some of the aleurone layers were removed. At 5 minutes, 18.7% of the kernel was removed. This indicates that significant amount of endosperm was removed with the bran since wheat kernels only contain 13-15% bran and that 20-25% of the bran associated with the crease area would not be available to be removed during debranning (Pagani et al., 2002.) Pagani et al. (2002) and DeBrier et al. (2015) reported that debranning levels greater than 10-12% were associated with excessive endosperm abrasion as indicated by increased starch content in the removed bran.

Bran Properties

Bran Starch

Starch was detected in all bran samples regardless of debranning time (Table 2). Bran layers do not contain starch (Antonine et al., 2004); so the presence of starch indicates the presence of endosperm. The shape of Northern Grown durum wheat kernel is irregular with outer surface having undulations which makes removal of some endosperm during debranning unavoidable, even with 1 minute of debranning. Debranning process does not remove the kernel outer tissues homogeneously as abrasion affects especially the accessible parts of the kernels (DeBrier et al., 2015). Peyron et al. (2003) and Bottega (2009) reported that friction and abrasion did not remove the bran layers close to or in the crease of the kernel. Bottega (2009) reported that debranning was not homogenous. They reported that on some surface areas the outer layers were still present while in other regions the aleurone was completely absent. Gys et al. (2004) suggested that debranning proceeds unevenly over the grain surface since the thickness of the pericarp-seed coat layers differs among wheat varieties.

The lower level of bran removed from Alkabo (~30% less) probably resulted in the bran removed from Alkabo having 20.2 to 31.1% less starch than bran removed from other cultivars, when averaged over debranning time (Table 2). Percentage of starch in bran varied with debranning time. Other researchers have reported similar percentages of starch associated with debranned bran (Peyron et al., 2003; Bottega et al., 2009; Ciccoritti et al., 2017). Interestingly, the percentage of starch in removed bran was similar for bran removed after 1 and 5 minutes of debranning and both of which had greater percentage of starch in bran than the bran removed after 3 minutes of debranning. The decline in starch content with 3 minutes of debranning was probably due to dilution with more bran removed relative to the amount of starch. However, 0.4, 1.6, and 4.8 g of starch was detected in the 1.4, 8.2, and 18.7 g of bran removed from 100 g of grain. Thus the 18.7 g of bran material contained 4.8 g starch and 13.9 g of bran and non-starch material.

Bran Moisture

Grain moisture did not vary significantly among varieties. Grain was tempered by 1 percentage unit for 10 minutes before debranning. Preliminary research indicated that tempering grain reduced the variability associated with starting grain moisture content (data not presented). Grain is generally tempered prior to the debranning process (DeBrier et al., 2015). Bran moisture content declined with longer debranning time. Decline in bran moisture content is attributed to the rise in temperature and increased contamination of bran with endosperm.

Moisture content was greater with bran removed from Alkabo than from Carpio, Joppa and Tioga (Table 2). These results correlate with the level of debranning. Alkabo had the lowest level of bran removed and highest moisture content. This supports the premise that decline in moisture content with time reflects the relative amount of endosperm contamination.

Debranned Kernel Properties

Broken Kernel Content and Kernel Size

Small differences in large kernel content were detected among cultivars (Table 3). Debranning for 1 minute did not significantly reduce kernel size; however, large kernel content was reduced 5% with 3 minutes of debranning and 31% with 5 minutes of debranning. Cultivars seemed to differ in their tendency to produce broken kernels during debranning (Table 3). Broken kernel content was greatest for Carpio and Joppa, intermediate for Tioga, and least for Alkabo, which might reflect the level of debranning (kernel hardness) and moisture content of bran. Hydration before debranning has been reported to reduce kernel breakage during debranning (Bottega et al., 2009). In addition, removing bran has been associated with weakening of the kernel (Peyron et al., 2003). Results suggest that Alkabo had harder kernels than the other cultivars and had the highest moisture (Table 2) content in bran and the least amount of bran removed (Table 2). Broken kernel content increased with debranning time with broken kernel contents of 1, 3, and 14% when debranned for 1, 3, and 5 minutes, respectively. Pagini et al. (2000) reported that broken kernels increased to 30% at 19.5% debranning level.

Table 3. Effect of durum cultivar and debranning time on kernel size, broken kernel content and kernel color.

Cultivar	Debranned kernel size (% large)	Broken debranned kernels (%)	Debranned kernel color		
			L*	a*	b*
Alkabo	67a	2.6c	54.39c	6.20d	18.17c
Carpio	66a	7.8a	54.87b	6.62a	19.35a
Joppa	64b	7.7a	54.78b	6.31c	18.60b
Tioga	64b	5.4b	55.27a	6.56b	18.63b
Debranning time, min					
0	74a		53.20d	6.56a	16.87d
1	75a	0.7c	53.84c	6.44b	17.42c
3	70b	2.6b	55.22b	6.47b	19.36b
5	51c	14.4a	57.05a	6.18c	21.10a

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Debranned Kernel Color

Durum cultivars differed in their color as determined by CIE L*, a*, b* (Table 3). Brightness was greatest with Tioga, intermediate with Carpio and Joppa, and lowest with Alkabo. Redness and yellowness did not seem to relate to brightness of different cultivars. However, brightness and yellowness increased and redness decreased with increased debranning time. Singh and Singh 2010 reported similar results with L value increase, a-value decreased and b-value increased for durum but decreased for bread wheat. Increase in b-value reflects the removal of the bran which increased exposure of yellow endosperm of durum wheat.

Milling Debranned Grain

Debranned grain was milled on a Bühler mill configured with two Miag purifiers. Mill flow chart is presented in Figure 2. All grain passes through the first break rolls. For the first three break rolls, the overs from a given break roll were sent via pneumatic lines to the next break roll and the throughs were passed over a sieve with 716 µm aperture. The ground stock that passed through this sieve (716 µm aperture) was sent to the first purifier and the overs were sent to the second purifier 2. The overs from third break were sent to the fourth break, the overs from the fourth break were sent to the fifth break and the overs of the fifth break were collected as bran. The throughs of fourth and fifth break were sent to the second purifier where the overs of the second purifier went to the first (and only) reduction roll. The overs of the reduction roll were sent to the fifth break roll the throughs were sent to the second purifier, and the overs of the second purifier were sent to the third purifier. Granulated semolina greater than 670 µm was sent to the fourth purifier.

Milling Rate and Break Release

Milling rate, the time for grain to pass through the Bühler mill and purifiers, tended to be greatest for Joppa and Tioga, intermediate for Carpio, and least for Alkabo (Table 4). Milling rate increased with debranning time. The mill was able to process 17, 69, and 97% more grain (based on weight) when the grain was debranned for 1, 3, and 5 minutes, respectively. Removing bran allowed the ground stock to pass through the mill quicker. Debranning has been reported to increase mill throughput and allow for shortening or simplifying the mill flow (Dexter and Woods, 1996; Mousia et al., 2004; De Brier et al., 2015). McGee (1995) reported that debranning durum wheat improved milling performance, which would allow the number of grinding passes during milling to be reduced.

Table 4. Effect of durum cultivar and debranning time on mill rate and break release from first, second and third break rolls.

		Break release, %		
Cultivar	Mill rate[†] (g/min)	First break roll	Second break roll	Third break roll
Alkabo	150a	9.8c	59.7b	41.5a
Carpio	159a	na	na	na
Joppa	174a	12.6a	65.2a	37.4c
Tioga	180a	12.0b	65.2a	38.6b
Debranning time, min				
0	113d	11.8a	62.3b	37.6b
1	132c	10.9b	60.4c	37.6b
3	191b	11.6a	67.4a	42.3a
5	223a	na	na	na

Values in the same column followed by different letters are significantly different ($P < 0.05$).
[†]Total product (g) per minute.

To evaluate the effects of debranning on milling properties, the break releases from Alkabo, Joppa, and Tioga debranned 0, 1, and 3 minutes were determined for the first three break rolls (Table 4). Carpio was not evaluated due to lack of sufficient sample. Relatively small differences occurred between Joppa and Tioga, both of which had greater break releases from the first and second break rolls and lower break releases from the third break roll when compared to Alkabo. The hard kernels of Alkabo associated with its high protein content and vitreousness, fractured into large pieces and produced fewer small particles resulting in low break release which is supported by the results reported by Mousia et al. (2004) and Hsieh et al. (1980). The 5 minutes debranning time was not evaluated, since the debranning level at 5 minutes was greater than what would be used commercially and do to the high level of broken kernels. Overall, break releases from the Bühler mill were 11.5, 63.4, and 39.2% for the first, second and third break rolls. These break releases similar to those reported by Dexter et al. (1990) 4, 55, and 45%

respectively. They used an Allis-Chalmers laboratory mill flow. Break release from first break rolls is lower when milling semolina than for flour (Li and Posner, 1989). Posner and Hibbs (2005) reported that percentage break release from first break was 9 and 30% for durum wheat milled to semolina and hard wheat milled to flour, respectively. Similarly, Sebastian (2018) reported that flour mill first break was 35-45% break release. When flour milling, it is desirable to produce small particles with the first break. Low release from the first break reflects the desire to produce coarse granulation with little or no flour. Flour mills have higher release since they want to produce smaller granulation (more flour) in the first break. Single kernel from first break release is shown in Figure 4.

The break releases from the first break rolls were not greatly impacted by debranning time as they varied by less than 1 percentage unit (Table 4). In general, the break releases for the 0 and 1 minute debranned grain were similar for the second (62.3 and 60.5%) and third break rolls (both 37.6%). The break releases for 0 and 1 minute debranned grain were lower than that for the 3 minute debranned grain. The break releases represent ground stock not sent to the next break roll. So, high break release would result in less material fed onto the subsequent break roll. Higher break releases resulted in greater amount of ground stock being sent to purifiers which is where the semolina is removed from the milling material (Figure 2). Hence, less material passing through the remaining mill flow.

Except for flour content, there was no or little difference in mill fractions among the four cultivars (Table 5). Less flour was produced when milling Alkabo than Carpio, Joppa, and Tioga. Less flour is produced when milling hard kernels of wheat (Tsuge, 1985), which again indicates that Alkabo had harder kernels than the other varieties. However, debranning time had effect on mill fractions. The amount of semolina coming off purifiers 1-4, flour, and shorts all increased with debranning. Conversely, the bran collected from the debranned grain while milling on the Bühler mill decreased with debranning time. DeBrier et al. (2015) reported similar results with

Figure 4. Effect of debranning time on the outer layer (left column) and inner layer (right column) views after debranned kernels passed through the first break roll.

bread wheat. However, total bran removed (bran removed by debranning and bran removed by Bühler mill) increased 4.3, 7.1, and 33.2% with 1, 3, and 5 minutes of debranning. The large increase in bran with 5 minutes of debranning is in part a result of significant amount of endosperm being removed during the 5 minutes debranning.

The percent of starch in bran fraction removed during milling on Bühler mill increased from 15.4% to 17.4% as debranning time increased from 0 to 5 minutes, respectively (Table 5). However, for every 100 g grain milled, the amount of starch removed per in the bran decreased from 3.25 to 1.93 g starch. The level of starch found in bran removed during milling is similar to that reported by Peyron et al. (2003).

Table 5. Effect of durum cultivar and debranning time on mill fractions and starch in the bran and starch removed during milling.

	Mill fraction (%)									
Cultivar	P1	P2	P3	P4	Flour	Shorts	Bran (milled)	Bran (total)	Starch in removed bran (%)	Starch removed during milling (g/100g bran)
Alkabo	42.5a	7.5a	13.5a	8.2b	6.5b	1.5a	17.3a	22.2c	18.5a	3.2a
Carpio	42.9a	7.7a	13.5a	8.2b	7.1a	1.7a	16.3b	23.2b	16.3b	2.7b
Joppa	42.6a	7.3a	13.4a	8.5a	7.2a	1.5a	17.1a	24.1a	15.4c	2.6b
Tioga	42.9a	7.3a	13.1a	8.0c	7.4a	1.5a	17.2a	24.0a	15.3c	2.6b
Debranning time, min										
0	41.3c	7.0d	12.8c	7.7c	6.4c	1.1c	21.1a	21.1d	15.4b	3.2a
1	41.3c	7.3c	13.1b	7.7c	6.2d	1.3b	20.8b	21.9c	16.4ab	3.4a
3	43.0b	7.7b	13.7a	8.5b	7.4b	1.9a	15.0c	22.6b	16.2ab	2.4b
5	45.3a	7.8a	13.8a	9.1a	8.2a	1.9a	11.1d	28.1a	17.4a	1.9c

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Total and Semolina Extraction

Cultivars varied with their total (semolina + flour) and semolina extraction (Table 6). Alkabo tended to have the lowest extraction rates, while Carpio tended to have the highest extraction rates, when extraction was based on bran removed only during roller milling. Conversely, Alkabo had the highest extraction rate when extraction was calculated based on bran removed during debranning and during roller milling. Carpio had the lowest amount of bran removed during roller milling while Alkabo had the lowest amount of bran removed by debranning and roller milling.

Total (semolina + flour) and semolina extraction were increased with longer debranning for all four varieties when calculated based on milled products of Bühler mill (Table 6).When extraction was calculated after including the weight of material removed during debranning, both total and semolina extractions decreased with increased debranning time (Table 6). De Brier et al. (2015) reported similar results for bread wheat. The decline in extraction indicates that more endosperm was removed with the ban during the debranning step than during the milling process.

Table 6. Effect of durum cultivar and debranning time on total and semolina extraction.

Cultivar	Total extraction (%)		Semolina extraction (%)	
	Milled'	Total''	Milled'	Total''
Alkabo	78.1c	73.5a	71.7bc	67.5a
Carpio	79.4a	72.9b	72.3a	66.3b
Joppa	79.0ab	72.3c	71.8ab	65.8bc
Tioga	78.5bc	72.0c	71.2c	65.4c
Debranning time, min				
0	75.1d	75.1a	68.8d	68.8a
1	75.5c	74.5b	69.3c	68.4a
3	80.3b	73.1c	72.9b	66.4b
5	84.1a	68.0d	76.0a	61.5c

Values in the same column followed by different letters are significantly different ($P < 0.05$).
'based on milled products of Bühler mill.
''based on milled product and bran removed during debranning.

Semolina Quality

Overall, the effect of cultivar and debranning time on particle size distribution was small (Table 7). Only 100, 50, and <50 µm fractions differed with cultivars. Alkabo had more semolina particles on 100 µm but less on 50 µm screens than did Carpio, Joppa, and Tioga. Otherwise, cultivar did not affect semolina particle size distribution. Alkabo had harder kernels than the other cultivars and would be expected to break into larger particles and produce less flour than softer cultivars (Table 5).

Debranning resulted in a shift towards smaller particle size. Semolina particle size distribution on 425μm decreased from 9.3 to 6.8% while on 150μm sieve increased from 27.0 to 29.5% with increased debranning time (Table 7). Difference in particle size with debranning indicates that the lack of bran caused the kernels to break differently. Mousia et al. (2004) reported that the removal of bran weakens wheat kernels which results in easier breakage since bran only remained in the crease of the kernels.

Table 7. Effect of durum cultivar and debranning time on semolina particle size distribution.

Cultivar	Semolina particle size distribution (%)						
	500μm	425μm	250μm	150μm	100μm	50μm	bottom
Alkabo	0.037b	8.2a	55.2a	27.8a	7.6a	0.5b	0.0b
Carpio	0.034b	7.6a	54.4a	28.7a	6.1b	2.4a	0.1b
Joppa	0.042b	7.9a	54.3a	28.4a	6.2b	2.5a	0.1b
Tioga	0.077a	8.4a	54.7a	27.5a	6.0b	2.7a	0.2a
Debranning time, min							
0	0.075a	9.3a	54.2b	27.0c	6.6a	2.2ab	0.1ab
1	0.047b	8.5b	54.6ab	27.3c	6.5a	2.2a	0.1a
3	0.034b	7.4c	55.0a	28.5b	6.3a	2.0bc	0.1a
5	0.033b	6.8d	54.7ab	29.5a	6.5a	1.7c	0.0b

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Semolina speck counts were similar for Alkabo, Carpio, Joppa, and Tioga (Table 8). Debranned grain produced lower speck counts in semolina than did the original grain. Speck counts declined from 60/dm^2 (decimeter) without debranning to 50/dm^2 for 1 minute and 39 and 40/dm^2 for 3 and 5 minutes of debranning, respectively.

Ash content varied with cultivar, with ash content greatest with Alkabo and Tioga, intermediate with Carpio and least with Joppa. Ash content declined with debranning. Greatest ash content occurred with no or 1 minute debranning, intermediate with 3 minute debranning and least with 5 minute debranning. Gys et al. (2004) and Singh and Singh (2010) also reported that ash content declined with debranning.

Table 8. Effect of durum cultivar and debranning time on speck count, ash content, starch damage, protein content gluten index, wet gluten content and moisture content of semolina.

	Semolina characteristics						
Cultivar	Specks (No/dm)	Ash (14% mb)	Starch damage (%)	Protein (%)	Gluten index	Wet gluten (%)	Moisture (%)
Alkabo	50a	0.73a	3.2a	13.7a	62c	38.9a	13.0b
Carpio	47a	0.67b	3.0a	12.8b	99a	32.6c	13.0ab
Joppa	47a	0.63c	3.2a	12.4c	77b	34.8b	13.2a
Tioga	46a	0.71a	2.7b	12.2d	54d	34.2b	13.0b
Debranning time, min							
0	60a	0.71a	3.1a	12.8a	75a	35.0a	13.1ab
1	50b	0.71a	3.1a	12.8a	72a	35.2a	13.2a
3	39c	0.68b	3.0ab	12.8a	73a	35.2a	13.0b
5	40c	0.65c	2.9b	12.7b	71a	35.1a	12.8c

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Starch damage was similar for Alkabo, Carpio, and Joppa but lower for Tioga (Table 8). Debranning had small effect on starch damage, as starch damage was greatest with no or 1 minute, intermediate with 3 minutes and least with 5 minutes debranning. However, the range in damage was quite narrow and is probably of no practical importance. Other researchers have reported lower speck counts, ash content and lower starch damage for flour milled from debranned wheat (Pagini et al., 2000; Dexter and Marchylo, 2001 Mousia et al., 2004).

As expected, cultivars differed in their protein content, gluten index and wet gluten content (Table 8). Debranning time had little or no effect on protein content, gluten index, and wet gluten content of semolina. Gys et al. (2004) also reported that debranning had little or no effect on protein content of flour. Dexter and Woods (1996) reported a decrease in protein content and increased dough strength with debranning. The outer endosperm layer has higher contents of protein and ash. So it would be expected that protein and ash content in semolina would decline with increased or prolonged debranning.

Although semolina from different cultivars differed in their L, a b values, there was not a clear effect of debranning on these parameters (Table 9). Dexter and Woods (1996) reported an increase in semolina brightness (L-value) with debranning.

Table 9. Effect of durum cultivar and debranning time on semolina and dry spaghetti color.

	Semolina color			Dry spaghetti color		
Cultivar	L*	a*	b*	L*	a*	b*
Alkabo	83.43c	-2.54a	27.78c	58.74b	3.04ab	41.21c
Carpio	84.02b	-2.71b	30.14a	60.53a	3.23a	42.92b
Joppa	84.19ab	-2.68b	28.80b	60.72a	2.84b	44.18a
Tioga	84.30a	-2.52a	28.02c	60.73a	3.18a	43.65a
Debranning time, min						
0	83.72b	-2.58a	28.69ab	59.84b	3.32a	43.74a
1	84.18a	-2.70c	28.58b	60.04ab	3.15b	43.66a
3	84.04a	-2.66bc	28.70ab	60.18a	2.85c	42.56b
5	84.00ab	-2.51a	28.76a	60.30a	2.97c	41.99c

Values in the same column followed by different letters are significantly different ($P < 0.05$).

Pasta Quality

Cultivars differed in dry spaghetti color (CIE L*, a*, and b*) (Table 9). Spaghetti made from Alkabo had the lowest L-value (brightness), intermediate a-value (redness) and lowest b-value (yellowness). Dry spaghetti made from Carpio, Joppa, and Tioga were similarly bright and were brighter than spaghetti made from Alkabo. Dry spaghetti yellowness was greatest with Joppa and Tioga, intermediate with Carpio and least with Alkabo. Dry spaghetti brightness increased, redness decreased, and yellowness decreased with debranning time (Table 9). Brightness was greatest with 3 minutes and 5 minutes debranning, intermediate with 1 minute debranning, and least without debranning. Conversely, redness was greatest without debranning, intermediate with 1 minute and least with 3 minutes and 5 minutes debranning. Yellowness was greatest with 0 minute and 1 minute debranning, intermediate with 3 minutes debranning and least with 5 minutes debranning.

Cultivar and debranning time had no effect on cooking loss or cooked weight (Figure 5a, b). At two minutes of cooking, firmness was greater with Alkabo and Carpio than with Joppa and Tioga (Figure 5c). Durum cultivars did not differ in firmness at the other cooking times. Debranning time did not affect cooked firmness. Dexter and Marchylo (2001) also reported that debranning did not affect cooking properties.

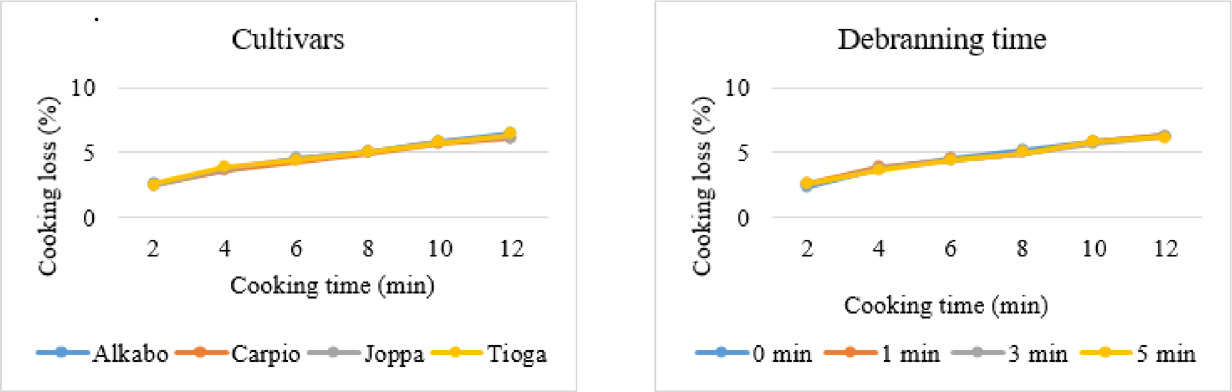

Figure 5a

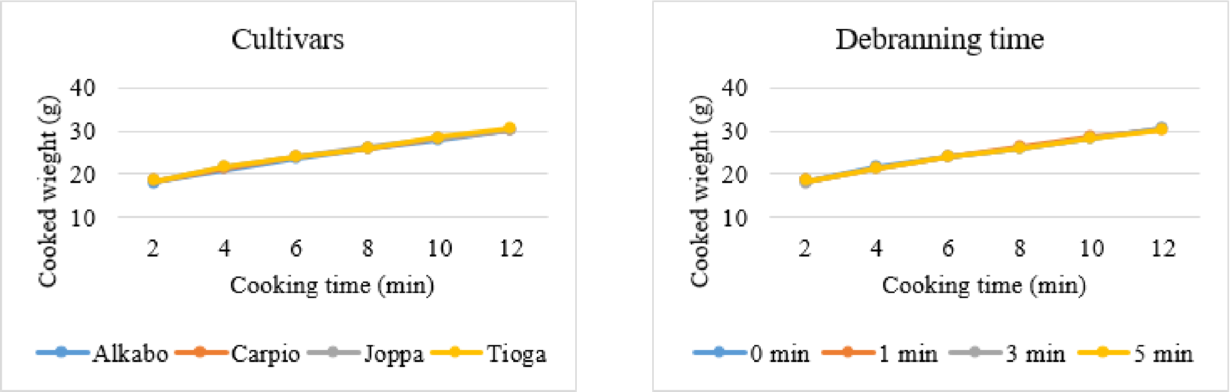

Figure 5b

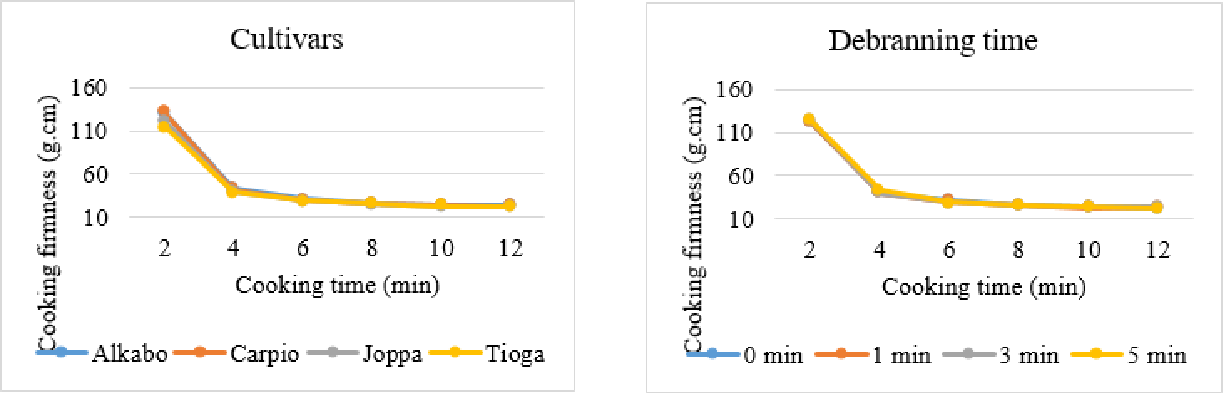

Figure 5c

Figure 5. Effect of durum cultivar (left column) and debranning time (right column) on spaghetti cooking loss (5a), cooked weight (5b) and cooked firmness (5c).

CONCLUSIONS

Debanning affected kernel characteristics. The amount of crude bran along with its' starch content, broken kernel content, brightness and yellowness of the kernel were increased, while kernel size and redness were decreased. More than 3 minutes of debranning was associated with excessive endosperm abrasion; therefore, for the equipment used, 3 minutes was the maximum time for debranning process. Debranning increased milling rate, break releases, and mill fractions such as semolina, flour, and shorts except bran. Bran was decreased with debranning time when debranned grain was milled on the Bühler mill. Total extraction and semolina extraction were increased with debranning for all varieties when calculated based on materials after milling. However, when it is calculated based on total material which includes bran removed during debranning, both total and semolina extractions were decreased with increased debranning time. Semolina characteristics were affected by debranning, where ash content and speck counts were lower than semolina derived from original grain. Protein content, gluten index, and wet gluten content were not affected by debranning. Semolina particle size was not affected significantly but shifted towards smaller particle size. Dry spaghetti brightness was increased with debranning, while redness and yellowness were decreased.

Cultivars responded similarly to debranning except for Alkabo. Since Alkabo had higher protein content and vitreousness, it was harder than kernels of Carpio, Joppa, and Tioga. Crude bran percentage, broken kernel content, break releases, flour produced during milling, and extraction rates were lower for Alkabo. Semolina characteristics such as specks count, ash content, protein content, gluten index and wet gluten content varied with cultivars. Cultivars had similar spaghetticooking properties. Debranning did not affect spaghetti cooking properties

INDUSTRIAL APPLICATION AND FUTURE RESEARCH

Foundation seed was used in this research that was sound and of good quality. Except for a reduction in speck count in the semolina and increasing milling rate, there was no big advantage to debranning such good quality durum grain. Numerous studies have concluded that sprout damage had reverse impact on spaghetti quality such as cooking loss and cooked firmness. Research should be conducted to determine the advantages of debranning when milling poor quality or weathered durum. This information would be very useful for the millers when milling poor quality or weathered grain.

LITERATURE CITED

American Association of Cereal Chemists. 2010. Approved Methods of AACC, 11th Ed. Methods (08-01.01), (66-50.01), (25-50.01), (54-40), (55-10.01), (56-81.03), (38-12.02) and (44-15.02), (76-13.01), (76-31.01). The Association: St. Paul, MN.

Antonine, C., Peyron, S., Lullien-Pellerin, V., Abecassis, J., and Rouau, X. 2004. Wheat bran tissue fractionation using biochemical markers. *Journal of Cereal Science* 39, 387-393

Borrelli, G. M., Troccoli, A., Di Fonzo, N., and Fares, C. 1999. Durum wheat lipoxygenase activity and other quality parameters that affect pasta color. *Cereal Chemistry*, *76*, 335-340.

Bottega, G., Caramanico, R., Lucisano, M., Mariotti, M., Franzetti, L., and M. Ambrogina Pagani, M. 2009. The debranning of common wheat (*Triticum aestivum* L.) with innovative abrasive rolls. *Journal of Food Engineering, 94*, 75-82.

Cheli, F., Pinotti, L., Rossi, L., and Dell'Orto, V. 2013. Effect of milling procedures on mycotoxin distribution in wheat fractions: A review. *LWT - Food Science and Technology, 54*, 307-314.

Ciccoritti, R., Taddei, F., Nicoletti, I., Gazza, L., Corradini, D., D'Egidio, M. G., and Martini, D. 2017. Use of bran fractions and debranned kernels for the development of pasta with high nutritional and healthy potential. *Food Chemistry, 225*, 77–86

Cook, W. H. 1931. Preparation and heat denaturation of the gluten proteins. *Canadian Journal of Research, 5*, 389-406.

Dal-Pastroa, F., Faccoa, P., Bezzoa, F., Zamprognab, E., and Baroloa, M. 2016. Data-driven modeling of milling and sieving operations in a wheat milling process. *Food and Bioproducts Processing.* 99:99–108

De Brier, N., Hemdane, S., Dornez, E., Gomand, S. V., Delcour, J.A., Courtin, C. M. (2015). Structure, chemical composition and enzymatic activities of pearlings and bran obtained from pearled wheat (*Triticum aestivum* L.) by roller milling. *Journal of Cereal Science 62,* 66-72.

Delgado, M., R., Sulyok, M., Jirsa, O., Spitzer, T., Krska, R., and Polišenská, I. 2014. Relationship between lutein and mycotoxin content in durum wheat, *Food Additives & Contaminants:* Part A, 31:7, 1274-1283, DOI: 10.1080/19440049.2014.925589

Dexter, J. E., Martin, D. G., Sadaranganey, G. T., Michaelides, J., Mathieson, N., Tkac, J. J. and Marchylo, B.A. 1994a. Preprocessing: Effects on durum wheat milling and spaghetti making quality. *Cereal Chemistry, 71*, 10-16.

Dexter, J. E., Symons, S. J. and Martin, D. G. 1994b. Enhancement of durum wheat milling quality by preprocessing and an evaluation of flourescence imaging as a rapid technique for monitoring preprocessing efficiency. Association Operative Millers Bulletin, August, 6415- 6420

Dexter, J. E., and Wood, P, J., 1996. Recent application of debranning of wheat before milling. *Trends in Food Science and Technology, 7*, 35-41

Dexter, J. E. and Marchylo, B. A. 2001. Recent trends in durum wheat milling and pasta processing: Impact on durum wheat quality requirements. In Durum wheat, semolina and pasta quality. Montipellier, France, November 27, 2000. Ed. INRA, Paris, 2001, page 139-164.

Elias, E. M. and Manthey, F. A. 2007. Registration of 'Alkabo' durum wheat. *Journal of Plant Registrations*, 1:10-11.

Elias, E. M., Manthey, F. A., and AbuHammad, W. A. 2015. Registration of 'Carpio' durum wheat. *Journal of Plant Registrations* 9:78–82. doi: 10.3198/jpr2014.05.0030crc

Elias, E. M. and Manthey, F. A. 2016. Registration of 'Joppa' durum wheat. *Journal of Plant Registrations* 10:139–144. doi: 10.3198/jpr2015.11.0071crc

Elias, E. M. and Manthey, F. A. 2012. Registration of 'Tioga' durum wheat. *Journal of Plant Registrations,* 7: 69-74. doi: 10.3198/jpr2012.04.0244crc

Fang, C., Campbell, G. M. 2003. On predicting roller milling performance V: Effect of moisture content on the particle size distribution from first break milling of wheat, *Journal of Cereal Science 37*, 31-41

Fardet, A. 2010. New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre? *Nutritian Research Reviews*, 23:65-134

Food and Drug Administration. 21CFR137.320 https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=137.320 Accessed February 27, 2019

Fowler, M. 2012. Balancing the mill. World-Grain. February 23. www.world-grain.com/articles/10199-balancing-the-mill Accessed February 27, 2019.

Fowler, M. 2013. Flour mill contamination. May 15. www.world-grain.com/articles/10205-flour-mill-contamination Accessed February 27, 2019.

Fowler, M. 2014. The complexities of durum milling. July 2. www.world-grain.com/articles/10208-the-complexities-of-durum-milling

Gys, W., Gebruers, K., Sørensen, J. F., Courtin, C. M., Delcour, J. A. 2004. Debranning of wheat prior to milling reduces xylanase but not xylanase inhibitor activities in wholemeal and flour. *Journal of Cereal Science, 39*, 363-369.

Hinton, J. J. C. 1959. The distribution of ash in the wheat kernel. *Cereal Chemistry, 36*, 19-31

Hsieh, Martin, D. G., Black, H. C., and Tipples, K. H. 1980. Some factors affecting the first break grinding of Canadian wheat. *Cereal Chemistry, 57*, 217-223.

Laca, A., Mousia, Z., Diaz, M., Webb, C., and PAndiella, S. 2006. Distribution of microbial contamination within cereal grains. *Journal of Food Engineering. 72,* 332-338.

Los, A., Ziuzina, D., and Bourke, P. 2018. Current and Future Technologies for Microbiological Decontamination of Cereal Grains. *Journal of Food Science, 83,* 1484-1493

Li, Y. Z., and Posner, E. S. 1989. An experimental milling technique for various flour extraction levels. *Cereal Chemistry, 66*, 324-328

MacMasters, M. M, Bradbury, D., & Hinton, J. J. C. 1964. Microscopic structure and composition of the wheat kernel. In I. Hlynka (Ed.), Wheat: Chemistry and technology (pp. 55–110). St. Paul, MN: American Association of Cereal Chemists.

Matsuo, R. R., and Dexter, J. E. 1980. Relationship between some durum wheat physical characteristics and semolina milling properties. Can. J. Plant Sci. 60:49-53.

McCluggage, M. E. 1943. Factors influencing the pearling test for kernel hardness in wheat. *Cereal Chemistry, 20*, 686-700.

McGee, B. C. 1995. The Peritec process and its application to durum wheat milling. *Association of Operative Millers,* March, 6521-6528.

Mousia, Z., Edherly, S., Pandiella, S. S., and Webb, C. 2004. Effect of wheat pearling on flour quality. *Food Research International, 37*, 449–459.

Novaro, P., Colucci, F., Venora, G., and D'Egidio, M. G. 2001. Image analysis of whole grains: A noninvasive method to predict semolina yield in durum wheat. *Cereal Chemistry,* 78, 217-221.

Pagani, M.A., De Noni, I., D'Egidio, M.G., Cecchini, C., 2002. Effectiveness of debranning process of durum wheat for improving semolina quality. In: Proceedings of Second International Workshop on ''Durum Wheat and Pasta Quality: Recent Achievements and New Trends", Rome 19–20 November, pp. 157–161.

Pagani M.A., D'Egidio M.G., De Noni I., Gasparro O., Cecchini C.Effect of industrial debranning of durum wheat on milling and pasta-making quality. In: Proceedings of the International Workshop on: "Durum wheat, semolina and pasta quality. Recent achievements and new trends", France 27 November, pp. 165-169

Peyron, S., Mabille, F., Devaux, M. F., and Autran, J. C. 2003. Influence of structural characteristics of aleurone layer on milling behavior of durum wheat (*Triticum durum* Desf.). *Cereal Chemistry, 80*, 62–67.

Posner, E. S., and Hibbs, A. N. 2005. Milling of durum wheat. Pages: 329-351 in: Wheat Flour Milling. American Association of Cereal Chemists: St. Paul, MN.

Samson, M.F., Mabille, F., Cheret, R., Abecassis, J., and Morel, M.H. 2005. Mechanical and physicochemical characterization of vitreous and mealy durum wheat endosperm. *Cereal Chemistry,* 82:81-87.

Sapirstein, H. 2016. Bioactive compounds in Wheat Bran. *Encyclopedia of Food Grain*. 2:268-276.

Satake Europe LTD. The PeriTec wheat debranning system. www.satake-europe.com/peritec/index.html https://www.satake-usa.com/cereal-grain-equipment.html#

Sebastian, R. 2018. The importance of break system in flour milling process. Miller Magazine. September 13, 2018. http://www.millermagazine.com/english/the-importance-of-break-system-in-flour-milling-process/

Shetlar, M. R., Rankin, G. T., Lyman, J. F., and France, W. G. 1947. Investigation of the proximate chemical composition of the separate bran layers of wheat. *Cereal Chemistry, 24,* 111−122.

Shewry P.R. and Morrel, M. 2001. Manipulating cereal endosperm structure, development and composition to improve end-use properties. *Advances in Botanical Research*. 34:165-235.

Shuey, W.C. 1960. A wheat sizing technique for predicting flour milling yield. *Cereal Science Today, 5,* 71-75.

Simmons, L., and Meredith, P. 1979. Width, weight, endosperm, and bran of the wheat grain as determinants of flour milling yield in normal and shriveled wheats. *New Zealand J. Sci*. 22:1-10.

Singh, S., and Singh, N. 2010. Effect of debranning on the physico-chemical, cooking, pasting and textural properties of common and durum wheat varieties. *Food Research International, 43*, 2277-2283.

Troccoli, A., and di Fonzo, N. 1999. Relationship between kernel size features and test weight in *Triticum durum*. Cereal Chem. 76:45-49.

Tsuge, N. 1985. The effects of the first break roller mill differentials and speeds. MS thesis, Kansas State University 115 pages.

US Durum Wheat Regional Quality Report, 2018. NDWC. 20 pages. https://www.ndwheat.com/publications/cropqualityreports/ Accessed February 27, 2019.

USDA, Grain Grading Procedures, 2017. p.13-35 in Grain Inspection Handbook. https://www.ams.usda.gov/sites/default/files/media/Book2.pdf Accessed February 27, 2019.

Yue, P., Rayas, P., and Elias, E. 1999. Effect of drying temperature on physicochemical properties of starch isolated from pasta. *Cereal Chemistry, 76*, 541-547.