Determining the impact of semolina extraction rate with low hard vitreous kernel durum wheat

by

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ABSTRACT

This is a study of supply chain inputs of different quality in a real-world processing setting. This thesis will compare the processing yield loss of a 50/50 blend of a) Grade 1 Hard Amber Durum (HAD) Wheat, and b) Grade 2 Amber Durum wheat to that of a 100% Grade 1 Hard Amber Durum wheat blend. The lower HVAC (Hard Vitreous Kernel of Amber Color) quality of durum wheat will likely have a varying impact on raw materials yield, also known as dirty wheat yield as well as milling yield, also known as the extraction rate. The lower grade wheat was purchased at a discount. The thesis will investigate whether or not the discount was enough to cover the loss in yield.

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CHAPTER I: INTRODUCTION

Columbia, South Carolina is home to a 10,000 CWT durum wheat mill, and it is designed to produce semolina for its neighboring pasta plant. It was built in 1998 and is North America's first and only "lights out" durum wheat mill. This means that the mill is fully automated and capable of running unattended overnight. The facility also includes a 400,000 bushel capacity grain elevator.

Durum Wheat is originated from North Dakota, South Dakota, Arizona, Southern California and Western Canada. It is transported and delivered to the facility by the Norfolk Southern Railroad. Purchasing lower grade durum wheat often results in a price discount. Factors resulting in a lower grade may vary and have differing impacts on mill yield or extraction rate. In the application addressed in this paper, lower grade wheat with lower HVAC (hard and vitreous kernels of amber color) was purchased at a $1.50/bu discount to higher grade durum wheat with higher HVAC.

This Thesis will compare the processing yield loss of a 50/50 blend of a) Grade 1 Hard Amber Durum (HAD) Wheat, and b) Grade 2 Amber Durum wheat to that of a 100% Grade 1 Hard Amber Durum wheat blend. Grades of durum wheat are established and managed by the United States Department of Agriculture (USDA), Agricultural Marketing Services (AMS), Federal Grain Inspection Service (FGIS)[1]. The lower HVAC quality of durum wheat will likely have a varying impact on milling yield, also known as the extraction rate (Pomeranz 1988). Durum wheat is one of eight classes of wheat recognized by the U.S. Grain Inspection, Packers and Stockyards Administration (GIPSA)[2]. These

[1] Information on the USDA Federal Grain Inspection Service is available at the following web address: https://www.ams.usda.gov/about-ams/programs-offices/federal-grain-inspection-service

[2] https://www.gipsa.usda.gov/fgis/standards/810wheat.pdf

include durum wheat, Hard Red Spring wheat, Hard Red Winter wheat, Soft Red Winter wheat, Hard White wheat, Soft White wheat, Unclasses wheat, and Mixed wheat. The durum subclass is determined by HVAC (Hard and Vitreous Kernels of Amber Color) content. Table 1.1.

Table 1.1: USDA Durum Wheat Grading Standards [a]

Grading Factors	Grades U.S. Nos.				
	1	2	3	4	5
Test Weight	60	58	56	54	51
Damaged Kernel	2	4	7	10	15
Foreign Material	0.4	0.7	1.3	3	5
Shrunken and Broken Kernels	3	5	8	12	20
Total Defects	3	5	8	12	20
Contrasting Classes	1	2	3	10	10

[a] Source: https://www.ams.usda.gov/sites/default/files/media/WheatStandards.pdf

The biggest indicator of the processing yield loss will be to compare raw materials yield between the 50/50 blend and 100% HAD. Raw materials yield, also known as "dirty wheat yield" is the amount of finished product semolina made from raw dirty wheat[3]. This includes all the non-wheat material and undesirable removed during the cleaning process. "Dirty wheat yield" is a snapshot measure of overall performance of raw material purchased to produce a unit of semolina.

To classify finished product as semolina, it needs to meet the granulation, bran specks, black specks, moisture and ash specifications. As a miller the objective of this process is to get the highest dirty wheat yield possible while maintaining required finished product specifications.

[3] "Dirty wheat" in the Durum wheat milling process differs from "foreign material" or FM in wheat, especially as wheat is harvested coming from the field. "Foreign material refers to all matter other than wheat, including stones, that is not separated from the wheat in the proper removal of dockage. It is recorded to the nearest tenth of a percent." https://ag.purdue.edu/agry/extension/Documents/AY-243.pdf

With lower quality wheat[4], the yield will necessarily be less to keep the finished product semolina within the required specifications. From the technical perspective of the wheat milling process, a key question in this research is how low will the yield go down or be reduced to keep within these product specifications. From an economic net returns and profitability point of view, will the benefits of a discounted purchase price outweigh the "cost" of processing yield loss. Taken together, the key research question of this thesis is whether the discounted purchase price on the wheat will offset the increased cost from processing yield loss. The Columbia, South Carolina plant utilizes 100% of its finished products, so the selling price of semolina will be compared to the purchase price of the durum wheat.

The intent of this research is to provide a practical example and a framework of how to evaluate the technical production and economic factors involved in effectively using low quality durum wheat in semolina milling. This is an empirical study of the milling process as applied to this specific mill. This decision framework can provide wheat milling businesses a tool for determining the breakeven purchase price for low quality "dirty" durum wheat when there is the opportunity to do so in the market.

[4] In defining small grain wheat quality, official USDA standards include key factors such as test weight, presence of foreign material or contrasting classes, and damaged or shrunken kernels. Other factors include moisture, protein, falling number and deoxynivalenol (DON). Higher or lower quality is defined as levels of these "factors that indicate how these grains will perform or function in their intended end use." For Durum wheat, quality factors are measured based on how they effect economic value of semolina flour milling properties. https://extension.umn.edu/small-grains-crop-and-variety-selection/understanding-grain-quality

CHAPTER II: LITERATURE REVIEW

Triticum Durum is one of three significant wheat species grown in North America (Pomeranz 1988). It is produced mainly in the north central and southwestern United States. It is also grown primarily in southern Saskatchewan with a lesser amount in southern Manitoba in Canada[5]. Triticum Durum is planted in the spring and its kernels are generally very hard in texture and high in protein. Almost all of the crop is used to make semolina for the production of pasta because of its durum gluten (Pomeranz 1988)[6].

Kernel vitreousness is primarily associated with kernel hardness and semolina yield. It may be more of a result of environmental conditions than of the hardness of the kernel. It is a subjective classification and does not correlate directly with any known objective quality factors except semolina yields (Pomeranz 1988).

Pomeranz (1988) discusses how the proportion of hard vitreous kernel (HVK), protein content and pigment concentration are the three most important specifications in determining the commercial value of durum wheat. It also addresses how durum wheat high in HVK and test weight will generally give high yield of semolina with a minimum number of white starchy particles.

Vitreousness is a primary grade factor for durum wheat because of its impact on semolina milling performance and end-use quality. As an externally visible sign of grain

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[5] Source: https://cigi.ca/wp-content/uploads/2018/10/Durum-Production-Manual_181022_18073001.pdf

[6] Semolina can used to make umpa, pasta, and couscous. Umpa is a dish originating from the Indian subcontinent and is prepared in various ways, including as a thick porridge. Pasta is a stape food in Italian cuisine, having a variety of uses as a base for sauces, in soups, or in baked dishes. Couscous is a staple food in northern African countries and among immigrant populations from these countries in France. Source: https://en.wikipedia.org/wiki/Semolina

hardness, vitreous kernels are characterized by a natural translucent coloring or "glassy" appearance. In this situation kernels having an externally visible starchy spot of any size are considered to be non-vitreous.

In the mid 80's, hardness began to attain the status of a major factor in the description of wheat because of the attempt of the Federal Grain Inspection Service (FGIS) to use hardness as a means of differentiating the hard and soft wheat classes. Various procedures for measuring hardness have been proposed including particle size index, pearling index, time to grind, sound of grinding, starch damage, near-infrared (NIR) analysis, and crushing and slicing individual kernels. Researchers have proposed that hardness, protein quantity, and protein quality be the initial guideposts in the description of wheat quality.

Dry dirty grain yield is defined in the Dictionary of Milling Terms and Equipment. The flour produced is divided by the grain used before it is cleaned or tempered. This type of yield reporting is used to determine the cost of raw grain used to produce a given amount of flour. This type of yield is important form an economic sense, but is of lesser importance to indicate milling efficiency. Sometimes referred to as a gross yield (Wingfield 1989). This is also referred to as dirty wheat yield.

Wet clean yield is the flour produced divided by the grain used after it has been cleaned and tempered. This type of yield provides the best milling efficiency, or milling performance, comparison as it is independent of the amount of foreign material or the moisture content of the grain used (Wingfield 1989).

Najafi (2012) addressed how supply chain management principles applied to quality controls in the semolina supply chain for wheat milling. Najafi discusses an integrated group of milling-related processes that source, make and deliver durum wheat-related products. In Najifi's application from the Iranian milling industry, the semolina supply chain was defined as starting with procurement of wheat raw inputs or "materials", to at least temporary storage, into production and packaging, and finally to delivery of processed products to buyers. The possibilities for inefficiencies or "risks" to enter into the SCM process for semolina production were examined on a stage-by-stage basis – including risks from using lower quality wheat in the production process. While Najafi (2012) identifies where quality, handling and logistics problems can cause inefficiencies in the durum wheat milling process, there is no specific application of the application presented where lower quality durum wheat is blended to produce semolina products that meet industry quality standards.

Pasini, Visioli and Moran (2020) address the issue of how variations in the quality of durum wheat by geographic locations in Italy ultimately affect pasta quality. Their paper analyzes how varying crop fertility zones and fertilization / management practices in these geographic areas can affect the quality of durum wheat flour production and associated flour milling processes, as well as the final quality of pasta produced. Similar to this Kansas State University Master of Agribusiness thesis, Pasini, et al. (2020) focus on how durum wheat quality can impact the semolina production process.

However, contrary to Pasini, et al. (2020) in this thesis specific geographic locations for North American durum wheat are not the key issue explicitly. Rather, cash market forces with reliance on USDA quality grades are the determinants of input costs for "dirty wheat" being used in the semolina milling process. If there were widespread production and/or harvest problems for the U.S. and Canadian durum wheat crops in a particular year, then in a broad aggregate implicit sense, geographic production factors in

North America could impact the semolina product quality and economics of the milling process on this continent.

This study is an application of supply-chain management (SCM) principles (Anderson et al. 2016). By definition, supply chain management (SCM) is "the management of the flow of goods and services, and includes all processes that transform raw materials into final products." In general, SCM involves the active streamlining of a business's supply-side activities to maximize customer value, in order to gain a competitive advantage in the marketplace. SCM represents an effort by suppliers to develop and implement supply chains that are as efficient and economical as possible[7]. Supply chains "cover everything from production to product development to the information systems needed to direct these undertakings." [8]

Anderson, et al. (2016) define "The 7 Principles of Supply Chain Management." Of these principles, this study is relevant to #5) manage sources of supply strategically to reduce the total cost of owning materials and services; and #6) develop a supply chain-wide technology strategy that supports multiple levels of decision making and gives a clear view of the flow of products, services, and information.

In summary, the literature presents the broader principles of grain milling as applied to durum wheat and semolina production in Pomeranz (1988) and Wingfield (1989). While Najafi (2012) discusses how varying quality of durum wheat can affect and be managed in production of semolina, the author provided no specific example or application of these

[7] Note the exception to this statement in a quote from Keith Harris, Agricultural Economist and Associate Professor, Kansas State University: "Not all supply chains are designed to operate efficiently. Some are designed to operate more responsively."
[8] Investopedia, https://www.investopedia.com/terms/s/scm.asp.

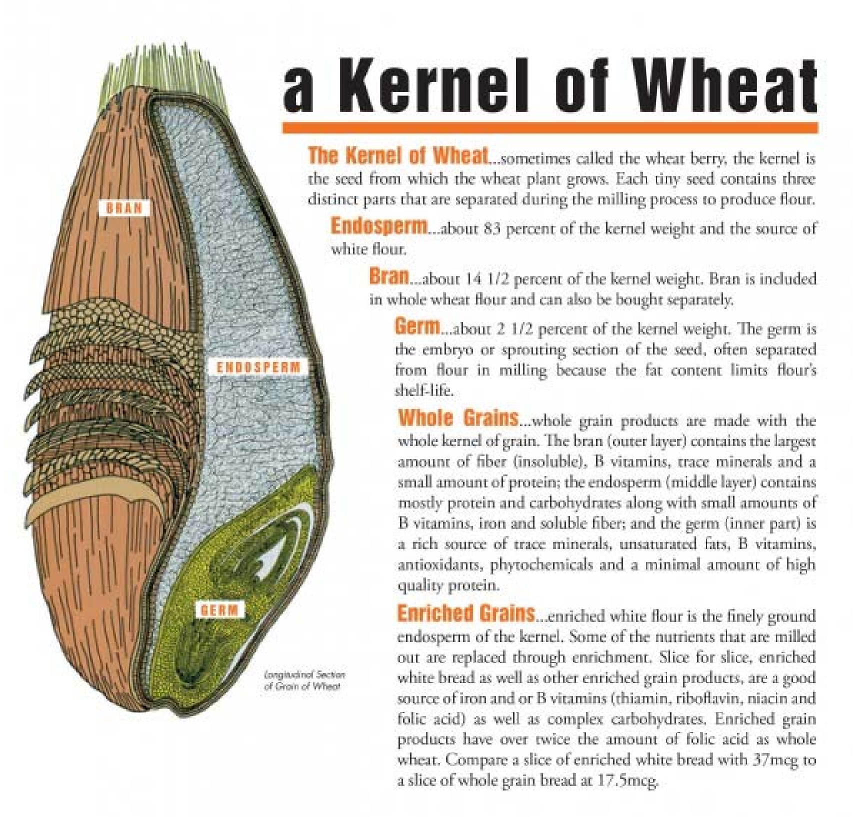
general principles. Pasini et al. (2020) does address the issue of how varying durum wheat quality impacts pasta quality. However, there is not a detailed description of the technical process of mixing of low- and high-quality durum to produce its acceptable minimum quality pasta products. Broader supply chain management (SCM) principles are defined in the literature, with the principles of strategically managing input supplies and the flow of products and information throughout the business system.

CHAPTER III: METHODS

3.1 **The Anatomy of a Wheat Kernel**

A kernel of wheat is composed of three parts, germ, bran and endosperm. Figure 3.1 illustrates the wheat kernel and its parts. The purpose of the milling process is to separate these three parts.

Figure 3.1: Anatomy of a Wheat Kernel



The bran makes up roughly 14.5% of the wheat kernel. Bran is found in the outer layers of the kernel, and is a byproduct of the milling process. Figure 3.1 Germ is the embryo section of the wheat kernel. It makes up 2.5% of the wheat kernel and because of its fatty make up, is removed in the milling process to increase flour shelf life.

The third part of the kernel is the endosperm. It is what semolina is made of and the part of the wheat kernel that is trying to be recovered in the milling process. It makes up 83% of the wheat kernel and is the “fruit” part.

3.2 Durum Wheat Grades and Standards

Defined by the United States Department of Agriculture, wheat is grain that before the removal of dockage, consists of 50 percent or more common wheat, club wheat and durum wheat, and not more than 10 percent of other grains for which standards have been established under the United States Grain Standards Act, and that after the removal of the dockage, contains 50 percent or more whole kernels of wheat.

Durum wheat is one of 8 classes of wheat and is divided into three subclasses including Hard Amber Durum wheat, Amber Durum wheat, and Durum wheat. The content of hard vitreous kernels determines which of the 3 subclasses it is categorized as. Hard vitreous kernels are defined by the Canadian Grain Commission as having a natural translucent coloring which is an externally visible sign of hardness. Kernels having a starch spot of any size are categorized as non-vitreous, also known as starchy, yellow berry, or mealy kernels.

The Hard Amber Durum wheat subclass has 75 percent or more of hard and vitreous kernels of amber color. The Amber Durum wheat subclass has 60 percent or more, but less than 75 percent of hard and vitreous kernels of amber color. The durum wheat subclass has less than 60 percent of hard and vitreous kernels of amber color (USDA standards). Grading factors include dockage, damaged kernels, shrunken and broken kernels, foreign materials, total defects, contrasting classes, and test weight. Depending on these factors, durum wheat is graded 1-5, with a grade of 1 being the best quality and 5 being the worst.

Dockage is all matter other than wheat that can be removed from the original sample by use of an approved device – also known as a “dockage tester”. Damaged kernels are pieces of wheat kernels and other grains that are badly ground damaged, badly weather damaged, diseased, frost damaged, germ damaged, heat damaged, insect bored, mold damaged, sprout damaged, or otherwise materially damaged. Shrunken and broken kernels are all matter that passes through a 0.064 x 3/8 oblong hole sieve during the sieving process. Foreign material is all matter other than wheat that remains in the sample after the removal of dockage and shrunken and broken kernels. Total Defects are the combined sum of damaged kernels, foreign material and shrunken and broken kernels. Contrasting classes of wheat as defined by the USDA in addition to the HAD, AD and Durum wheat subclasses defined above, are Hard Red Spring wheat, Hard Red Winter wheat, Hard White wheat, Soft Red Winter wheat, Soft White wheat, and remaining Unclassed wheat in the class of Durum wheat (USDA FGIS Handbook, Book II, Grain Grading Procedures. 2020).

3.3 Semolina Standards

The Food and Drug Administration categorizes Semolina as food prepared by grinding and bolting of cleaned durum wheat to such fineness that 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 and germ to such extent that the percent of ash therein, calcuted to a moisture-free basis of not more than 0.92 percent. Its moisture content is not more than 15 percent.

(see Sec. 137.320 Semolina in FDA regulations). For the purpose of this section, ash and moisture are determined by the methods therefore referred to in FDA regulations section137.105(c) (U.S. Food and Drug Administration 2019).

3.4 Processing Durum Wheat into Semolina

The process of turning durum wheat into semolina is basically that of separating the endosperm from the bran and germ. At the American Italian Pasta Company (AIPC) in Columbia, South Carolina, the mill has a capacity of 10,000 cwt per day – equivalent to 1,000,000lbs of semolina produced on a daily basis. It takes approximately 1,400,000 lbs. of raw uncleaned wheat to produce 1,000,000 lbs. of semolina each day. This process is broken down into the following seven stages, i.e., 1) receiving, 2) blending, 3) preconditioning, 4) cleaning, 5) conditioning, 6) pearling, and 7) milling.

The first stage is the receiving stage and is the process of unloading railcars of durum wheat that are supplied by the Norfolk southern railroad. Durum wheat is transported from primary North American production areas in Canada, Montana and the Dakotas. The wheat is emptied out of the lbs. railcar hopper doors into a pit and transferred through a scale, and then ran through and across a separator that removes non wheat material that is larger and smaller than wheat kernels. This includes any material larger than the 12 mm diameter openings and small enough to pass through the 2 mm openings of the sand screens. At the Columbia, South Carolina plant the wheat is then stored in one of the twelve 30,000 bu grain silos based on grades, and is then blended from these 12 silos and placed into five 5,000 bu interstice bins.

From these interstice bins, the wheat is further blended or “melded” into a uniform blend and transferred into the mill to be cleaned and conditioned. With the use of Buhler©

flow balancers, the wheat can be blended out of these five interstice bins down to the percent level of accuracy. This stage is called the preconditioning or pre-tempering stage because of the ability when needed to add water to the raw uncleaned wheat to be preconditioned to an acceptable moisture level for further processing (i.e., between 11 and 13 percent).

The next stage is the cleaning stage where all non-wheat material as well as undesirable wheat is removed. This is achieved by a series of grain cleaning machinery and equipment, and is referred to as "the cleaning house". The durum wheat is first ran through and across a milling separator, which removes all material bigger and smaller than the wheat kernel. The wheat passes through a screen with 7 mm diameter openings that are too small for other grains such as corn and soybeans, chaff, and anything else larger than a wheat kernel to pass through. The wheat also passes across a sand screen with 2 mm diameter openings that are too small for a wheat kernel to pass through but allows dirt and sand to pass through. Smaller pieces of chaff and grain dust are removed next by aspirators with the use of forced or pressured air. Next, the grain passes through a pair of combistoners. The name "combistoner" refers to the dual functions of this equipment. It uses specific density to not only remove heavier stones that are the same size and shape of the wheat kernels, but also separates the more dense kernels from those with less density. The lighter, less dense kernels are sent to a trio of gravity tables to further separate and remove the less dense product (consisting of shrunken and broken kernels) from whole kernels. These lighter whole kernels rejoin the denser kernels and go to the Color Sorters. Here, the Satake Scanmaster© Color Sorters take an image of each individual kernel and eject the undesirable ones that are discolored and/ or diseased with air jets. Four of these machines send the rejected kernels to a fifth machine where the kernels are either resorted back to the four machines or they are rejected and sent to screenings. All of the discarded non-wheat and/or undesirable wheat that is removed in the cleaning house is run through a sifter, with the larger particles being pulverized by a hammermill. What remains is all sent to be loaded into trucks along with the bran from the milling process to be sold as a byproduct called millfeed. This concludes the wheat cleaning process, with the clean wheat being ready for conditioning.

During the conditioning process, the wheat is tempered to a desired target moisture content of 16%. The purpose of this is to "toughen" the bran and "mellow" the endosperm for the milling process. This is achieved by adding water to the wheat in a temper mixer, giving it six hours to absorb the water and reach a moisture content of around 14.8%. Then more water is added by another temper mixer, as well as another 6 hours of absorption time to reach the 16% moisture content target.

Next, the wheat is debranned in what is referred to as the pearling stage. Buhler© vertical whiteners use friction and abrasion to remove the outer layers of the wheat kernel referred to as "bran" prior to the milling process. The bran makes up roughly 15% of the wheat kernel, and during the debranning process 1/3 of the bran is removed – consisting of 5% of the wheat kernel. The milling process is made more efficient by not having to account for removing this bran during subsequent stages of the milling process.

Now the wheat is ready for the actual milling stage (i.e., the milling process). The gradual reduction process is a "long flow", consisting of grinding sifting and most importantly purifying. The durum wheat mill consists of 48 rollermills, 38 sifter sections, and 56 purifiers streams. Finished products consist of semolina and first clear flour.

Byproducts consist of millfeed and second clear flour. The main goal in the milling process is to achieve the highest extraction rate of semolina while staying within the required semolina specifications.

Each day of the Columbia, South Carolina mill is broken down into a 24-hour run time from 6:00 a.m.-to-6:00 a.m. In this process, each morning at 6:00 a.m. the contents of each bin are measured. These bin measurement along with a total production report of the totals of each product scale are tabulated to encompass a daily inventory of products produced versus the amount of wheat received and used. This is how the “dirty wheat yield” is calculated for each day’s processing run.

CHAPTER IV: DATA

Table 4.1 shows the wheat grades for the railroad cars of wheat used for each processing run. The top 7 railcars of wheat in Table 4.1 were used for the 50/50 blend run, and the bottom 8 railcars of wheat were used for the 100 percent HAD run. The HVAC came in under 75, putting the three lower grade railcars of wheat in the subclass of AD (Amber Durum). These three railcars of wheat were graded as number 2 because of their count of total defects exceeded the number of 3 which is the standard required to grade total defects at a grade 1. All the other cars had a HVAC over 75 which placed them in the HAD (Hard Amber Durum) subclass and all of their grades were number one.

The blending process used is illustrated in Figure 4.1. Four railcars of Grade 1 HAD wheat (identified in Table 4.1 as CP 604070, SMW 847146, GWRS 306154 and SOO 124334) were mixed in equal proportions to make an HAD blend with an HVAC of 90%. Similarly, three railcars with Grade 2 AD wheat (identified in Table 4.1 as SOO 118600, SOO 119309 and SOO 118280) were mixed to make an AD blend with a significantly lower HVAC of 62.0%. Then, a 50:50 mixture of these two groups was labeled as the 50:50 blend and sent to the subsequent steps of processing (Figure 4.1).

A separate group of eight railcars with high grade wheat (identified in Table 4.1 as CN 111196, BNSF 473457, BNSF 495789, BNSF 475224, CN 101276, DME 51998, SMW 830149, CITX 702185) had a HVAC over 75%. Their blend yielded an average HVAC of 88%, and was designated as the 100% HAD run.

Table 4.1. Railcar grades of durum wheat

Grade	Car ID	DKG	MT	TW	DKT	FM	S&B	TD	CC	HVAC	VOM	PRO	FN
US 1 HAD Wheat	CP 604070	0.2	11.8	61.8	0.60	0.10	0.5	1.20	0.10	87.0	0.5	13.3	309
	SMW 847146	0.1	11.9	61.8	0.30	0.10	0.4	0.80	0.25	89.0	0.5	13.8	346
	GWRS 306154	0.6	11.1	61.4	0.30	0.10	0.9	1.30	0.00	95.0	0.5	13.2	417
	SOO 124334	0.4	11.6	62.5	1.80	0.00	0.6	2.40	0.60	88.0	1.1	13.6	400
	HAD blend - Average	***0.3***	***11.6***	***61.9***	***0.75***	***0.08***	***0.6***	***1.43***	***0.24***	***89.8***	***0.7***	***13.5***	***368***
2AD Wheat	SOO 118600	0.7	12.1	60.8	1.80	0.10	1.4	3.30	0.40	63.8	1.8	13.2	391
	SOO 119309	0.9	12.1	60.7	1.90	0.10	1.6	3.50	1.50	62.0	1.8	13.2	400
	SOO 118280	0.8	12.0	61.3	2.20	0.10	1.4	3.70	0.80	60.2	1.8	13.3	400
	AD blend - Average	***0.8***	***12.1***	***60.9***	***1.97***	***0.10***	***1.5***	***3.50***	***0.90***	***62.0***	***1.8***	***13.2***	***397***
	50:50 blend	***0.6***	***11.8***	***61.4***	***1.36***	***0.09***	***1.0***	***2.46***	***0.57***	***75.9***	***1.2***	***13.4***	***383***

Grade	Car ID	DKG	MT	TW	DKT	FM	S&B	TD	CC	HVAC	VOM	PRO	FN
US 1 HAD Wheat	CN 111196	0.5	10.8	62.7	0.20	0.10	0.1	0.40	0.20	88.0	0.4	14.0	411
	BNSF 473457	0.2	11.6	60.7	0.30	0.10	1.2	1.60	0.20	87.0	0.6	15.2	427
	BNSF 495789	0.2	11.8	61.0	0.30	0.10	1.6	2.00	0.10	88.0	0.5	15.0	416
	BNSF 475224	0.3	11.6	60.3	0.50	0.10	1.2	1.80	0.10	85.0	0.5	14.7	404
	CN 101276	0.5	11.8	62.1	0.30	0.40	0.5	1.20	0.42	90.0	0.3	14.6	373
	DME 51998	0.8	10.9	60.8	0.95	0.10	0.5	1.55	0.35	88.0	0.4	13.9	414
	SMW 830149	0.2	11.9	61.0	0.60	0.10	0.8	1.50	0.20	89.0	1.1	14.1	358
	CITX 702185	0.4	11.8	62.5	0.70	0.16	0.5	1.36	0.44	88.0	0.3	13.4	391
	100% HAD	***0.4***	***11.5***	***61.4***	***0.48***	***0.15***	***0.8***	***1.43***	***0.25***	***87.9***	***0.5***	***14.4***	***399***

where

DKG	Dockage	**FM**	Foreign material, %	**HVAC**	Hard vitreous kernel of amber color, %
MT	Moisture content, %	**S&B**	Shrunken and broken kernels, %	**VOM**	Vomitoxin, %
TW	Test weight , lb/bu	**TD**	Total dockage, %	**PRO**	Protein, % (@12% moisture)
	Damaged kernals total	**CC**	Contrasting classes, %	**FN**	Falling number, sec

Figure 4.1: Processing steps: Processing Durum Wheat into Semolina

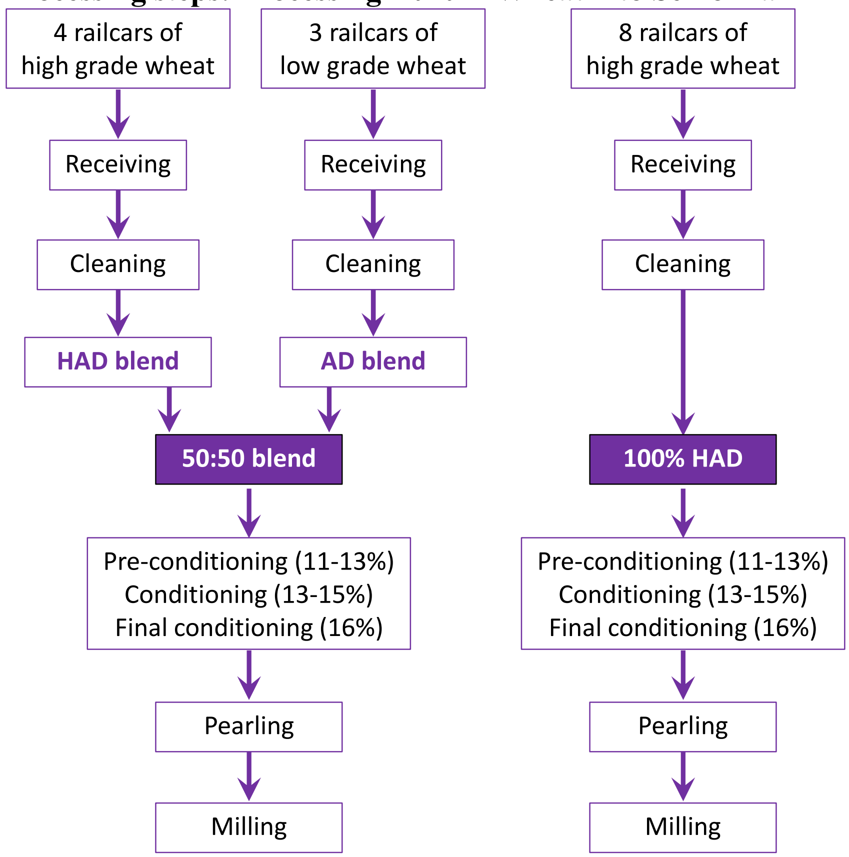


Table 4.2 shows the results of the 24 hour runs of each of the blends, i.e. the 50/50 "dirty wheat" blend run and the 100% HAD run. Restating, "dirty wheat" is the total amount of raw wheat before any of the non-wheat material undesirable wheat is removed. "Dirty wheat yield" is the percent of semolina produced from this "dirty wheat". It takes into account the non-wheat materials that were removed during the cleaning process. The extraction percentages are based on clean wheat yield. Keep in mind that a kernel of wheat contains 83% endosperm, which consists of semolina, 1st and 2nd clear flours and 17% of bran and germ which consists of the millfeed.

Table 4.2. Milling run data

	Dirty wheat (lb)	Clean wheat (lb)	Semolina (lb)	D1C (lb)	D2C (lb)	Bran and Shorts (lb)
100% HAD	1,368,800	1,367,684	1,024,664	41,234	1,402	271,195
50:50 blend	1,512,292	1,380,881	995,337	44,276	1,263	277,808
	143,492 ↑	13,197 ↑	29,327 ↓	3,042 ↑	139 ↓	6,613 ↑

	Dirty wheat (%)	Clean wheat (%)	Semolina (%)	D1C (%)	D2C (%)	Bran and Shorts (%)	Milling loss (%)
100% HAD	74.86%	99.92%	74.92%	3.01%	0.10%	19.81%	2.15%
50:50 blend	65.82%	91.31%	72.08%	3.21%	0.09%	20.12%	4.50%
	9.04% ↓	8.61% ↓	2.84% ↓	0.20% ↑	0.01% ↓	0.31% ↑	2.35% ↑

where
D1C Durum 1st Clear Flour – a finished product used in pasta production
D2C Durum 2nd Clear Flour – a byproduct sold as feed

The milling loss between the two runs varied by 2.35% where the 50/50 run had a milling loss of 4.5% and the 100 HAD was 2.15. Milling loss is the missing amount of the total clean, conditioned wheat that is unaccounted for at the end of the process. It is the amount missing from the total finished products and byproducts (clean wheat minus semolina, 1st clear and 2nd clear flour, and bran and shorts).

Milling loss is hard to specifically define as it could be affected by many different factors. These factors include product moisture loss, product loss and scale discrepancies just to name a few. During the milling process product streams are conveyed pneumatically. The use of this air to convey the product can reduce the moisture of these product streams. Humidity also plays a factor in how much moisture is lost by pneumatic conveying. The pneumatic conveying system also has filters that some products could escape through. The finished products and byproducts are tabulated by dump scales that with wear over time could have discrepancies. System losses such as those coming from varying humidities and their impact on the pneumatic conveying process are part of the overall milling loss, and are challenging to measure relative to other possible sources of milling loss in the process – especially for durum wheat of varying qualities.

Figure 4.2 Semolina Quality lab data

a) Moisture and ash content

Date	Mill Run	Sampling time (sec)	Moisture (%)	Ash (%) @ 14% moisture basis
8/1/2018	100% HAD	700	14.2938	0.7287
			14.2711	0.734
		1100	13.8536	0.7359
			13.9568	0.7359
		1500	13.7366	0.7242
			13.7119	0.739
		1900	13.7772	0.719
			13.7578	0.7239
		2300	14.3684	0.7189
			14.3289	0.7186
8/2/2018 a.m.		300	14.2601	0.7238
			14.2718	0.7187
		Ave	14.049	0.7267
8/9/2018	50:50 blend	700	14.1622	0.7474
			14.1315	0.7728
		1100	13.9231	0.7564
			13.9472	0.7717
		1500	13.3924	0.7667
			13.2289	0.7702
		1900	13.7816	0.7555
			13.6829	0.7697
		2300	13.7721	0.8188
			13.8227	0.7394
8/10/2018 a.m.		300	14.1796	0.7285
			14.0929	0.7533
		Ave	13.8431	0.7625

b) Color (L-a-b) and bran specks

	Time (sec)	L-value	a-value	b-value	ΔE	Bran specks (120 max)	Black specks (10 max)
100% HAD	700	-	-	-	-	52	4
	1500	81.51	-1.80	25.83	33.31	84	3
50:50 blend	700	82.59	-1.97	25.63	33.48	57	1
	1500	-	-	-	-	53	4

c) Particle size analysis [1]

	Time (sec)	Sieve US 30 600µ (0*)	Sieve US 35 500µ (0-1)	Sieve US 40 425µ (7-8)	Sieve US 60 250µ (54-62)	Sieve US 80 180µ (16-20)	Sieve US 100 100µ (4-5)	Pan (6-10)
100% HAD	700	0	2	9	52	20	4	13
	1500	0	3	8	53	20	4	13
50:50 blend	700	0	2	9	53	20	4	12
	1500	0	2	8	52	20	4	13

[1] The numbers in parenthesis are standards ranges (%) for each sieve

Semolina quality is measured by six different attributes. They are compiled in Figure 4.2 from the 2018 run data in the Columbia, South Carolina mill. This data shows ash, moisture, bran specs, black specs, color and granulation for both 50/50 blend run and 100% HAD runs. The ash needs to be below 0.72 and moisture below 15%, bran specs below 120 and black specs below 10. The granulation and color need to be within spec as well.

Moisture analysis is a method that determines the moisture content as loss in weight of a semolina sample when heated under specific conditions. Semolina moisture content cannot exceed 15%.

The Rapid Ash Method (AACC Method 08.03, 1983) determines total ash content as a weight measurement of mineral residue when a 2g semolina sample is heated at 600° in an ash oven for two hours. The semolina sample has a moisture basis of 14% converting the moisture free ash standard of less than 0.92 to less than 0.791.

The color intensity method determines the color intensity of a semolina sample relative to calibrated color standards utilizing a light reflectance colorimeter. Lighter “L” values are desirable, “a” values measuring near zero are desirable and “b” values greater than 20 are acceptable.

Bran and black speck analysis is a method used to determine the amountof bran specking in a given sample of semolina. Bran and black specks are counted on a 200-300 gram sample of semolina that is placed on a flat surface with a ¼ in thick 25 sq. in. glass plate. The bran and black specks cannot exceed 120 and 10 accordingly.

Granulation analysis is a method that determines the granular consistency of semolina using a Ro-Tap® sieving apparatus[9] equipped with nested sieves of US mesh 30, 35, 40, 60, 80, 100 and pan. The sieves are stacked in ascending order with the coarsest on the top. A 100g sample is placed on the top of the nested sieves and the Ro-Tap® apparatus is ran for 5 minutes. The desired percent granulations are listed in Figure 4.2.

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[9] A Ro-Tap® sieving apparatus is a commercial "coarse sieve shaker" machine, provided W.S. Tyler™, Mentor, Ohio.

CHAPTER V: ANALYSIS AND DISCUSSION

For this specific application, three railcars of USDA FGIS lower grade 2 amber durum were purchased at $6.40 per bushel (Table 4.4) which was $1.50 per bushel less than the higher quality grade 1 hard amber durum. These three railcars are in the subclass of Amber Durum because they had vitreous counts of 63.8, 62.0, and 60.2 averaging 62.0 (Table 4.1). They were graded number two because of their higher count of total defects. The four additional railcars that were blended with the three grade 2 cars had an average vitreous count of 89.8 – so the total average of the 50/50 blend was 75.9 for Hard Vitreous Kernels of Amber Color. This put the combined 50/50 blend just inside that 75% threshold for the subclass of hard amber durum wheat. Conversely, the 100% Number 1 Hard Amber Durum Blend had an average HVAC of 87.9 that makes a HVAC difference of 12.

The biggest indicator of wheat quality was shown when looking at the dirty wheat yields. The 24-hour run of the 50/50 blend required 143,491 lbs. or 2,337 more bushels of dirty wheat. This means that more defects were removed during the cleaning process to make the wheat adequate for milling. This reduced the dirty wheat yield by 9.04% when comparing the 50/50 blend of 65.82% to the 100 HAD of 74.86% (Table 4.2).

Looking at the cost of raw materials, it cost $176,105.61 for the wheat used on the 24hr 50/50 blend run (Table 4.4). Because so much more of the discounted wheat was needed for the 24 hour run of the 50/50 blend, it came in very close to the same cost of the 100 HAD wheat blend of $176,115.97 – which was only $10.36 less than the wheat used for the 50/50 blend.

Table 5.1: Gross Margin Calculations

50/50 Blend		Semo $/CWT	$ 18.75	$ 186,625.69
Dirty Wheat lbs	1,512,292	D1C $/CWT	$ 15.50	$ 6,862.84
Avg Test Wt lbs/Bu	61.4	D2C $/CWT	$ 8.50	$ 107.39
Dirty Wheat Bushels	24,630.15	Millfeed $/MT	$ 75.00	$ 10,417.80
Wheat $/Bu	$ 7.90		TOTAL	$ 204,013.72
Disc Price $/Bu	$ 6.40		Net Profit	$ 27,908.11
Total Cost of Dirty Wheat	$ 176,105.61			
		Semo$/CWT	$ 18.75	$ 192,124.41
		D1C $/CWT	$ 15.50	$ 6,391.19
100% Hard Amber Durum		D2C $/CWT	$ 8.50	$ 119.20
Dirty Wheat lbs	1,368,800	Millfeed $/MT	$ 75.00	$ 10,169.82
Avg Test Wt lbs/Bu	61.4		TOTAL	$ 208,804.62
Dirty Wheat Bushels	22,293.16		Net Profit	$ 32,688.65
Wheat $/Bu	$ 7.90			
Total Cost of Dirty Wheat	$ 176,115.97		Net Benefit	$ (4,780.54)
		Added Bu		12,315.08
		Additional Discount Needed		$ (0.39)
		Total Discount Needed		$ (1.89)

When looking at milling yields, there was not as much semolina produced when comparing the 50/50 yield to the 100 HAD yield. The 50/50 yielded only 995,337 lbs. of semolina (Table 4.2) which is 29,327 lbs. lower than the 100 HAD that yielded 1,024,664 lbs. of semolina. With the price of semolina at $18.75, that is 10,998 more dollars' worth of semolina produced that day (Table 4.4). When comparing the gross margins between the 50/50 "dirty wheat" blend and the 100 HAD run, (i.e., which would be profitable if the semolina product produced minus cost of wheat inputs is positive), it netted $4,780 less when using the 50/50 blend. In order for the 50/50 to net the same profit as the 100HAD, the purchase price of Grade 2 Amber Durum wheat would have had to be discounted an additional $0.39 in addition to the original $1.50 per bushel. This means that to compensate for the lost semolina yield, the cost have wheat would have to be discounted greater than $1.89 to be profitable to use in the milling process in this application.

CHAPTER VI: CONCLUSION

This is an empirical study of the durum wheat milling process as applied to this specific mill. Efforts to apply these results to other semolina processing facilities would have to account for the specific conditions and technical efficiencies of those particular wheat mills.

Because more of the 50/50 wheat was needed and yielded less semolina, the discount of $1.50 was not enough to make using the lower grade wheat feasible. An additional $0.39 discount would be needed to break even, therefore, a discount of more than $1.89 would be needed to make using the lower grade wheat profitable. There is no way of knowing exactly how the quality of the wheat will directly be affected, until said grain is actually processed through the milling process.

This analysis illustrates the production efficiency and economic tradeoffs that occur when quality adjustments are made in the production of Semolina from durum wheat. The tradeoffs in process efficiency in this analysis are not readily explained or examined in practical depth in most Grain Science texts. Rather, these practical tradeoffs in the Semolina production process are somewhat particularly associated with the particular mills and their technical production equipment and managerial approaches. That said, there are basic principles of flour milling that are applicable across various mills in the grain processing industry which are fundamental to this particular milling application.

In this analysis, the process of transforming raw materials (i.e., "the 50/50 blend and 100% HAD" into a final product (i.e., Semolina) is a primary focus – which is associated with the principles and practices of Supply Chain Management (SCM). The production aspect of Supply Chain Management (SCM) is the key focus of this thesis, especially as alternative inputs with quality and cost differentials are considered.

To enhance these findings a sensitivity analysis could be applied to the gross margin calculations. The sensitivity of these results to changes in purchase prices of 100% HAD and also lower quality wheat blends would be the most easily analyzed factors in this framework. To actually vary the physical characteristics of the low quality durum wheat analyzed in the context of this specific processing facility would provide the most definitive type of sensitivity analysis to perform in this study. However, the physical realities of doing so in a functioning "for profit" milling business environment severely limit the opportunity to make such milling runs for the sake of research.

That said, if a milling business either thought such an analysis was to their benefit in investigating possible profit opportunities from using low quality wheat, they may choose to do so. Alternatively, if a market scenario came about where there were limited quantities of high quality durum wheat available, forcing the miller to purchase sizable amounts of lower quality wheat, then this sort of analysis could be done as a matter of milling business investigation and practice. That said, absent the occurrence of these two or other similar milling business scenarios, it is not feasible to have repeated tests of low quality durum wheat milling performance and profitability in a regular functioning processing plant context. This presents a problem in academic environmental that regularly rely on repeated independent sampling procedures – from hypothesis-based tests of statistical significance come.

In terms of future applications of this research, it is hoped that this thesis can be a practical resource for aspiring grain scientists and agricultural economists who may become involved in the grain milling industry. The pragmatic, partial budget approach used in this thesis provides a pragmatic viewpoint on the process of how technically efficient and economical production decisions can be addressed in a milling context.

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