Protein Indicators, Quality, and Yield of Winter Durum Wheat Grown in Virginia

by

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Abstract

Durum wheat (*Triticum durum* Desf.) is produced primarily in the Northern Great Plains and the Pacific Southwest of the United States. Current germplasm is predominantly of the spring growth habit. The objective of this study was to determine the feasibility of winter durum production in Virginia based upon both yield and quality parameters. Adaptation and yield potential of available winter durum lines were assessed from 1993-1998, in three physiographic regions in Virginia. The highest average durum yields were produced in the northern piedmont plateau at the Orange County location. Winter durum yields generally averaged 1600-2800 kg/ha less than soft red winter wheat, traditionally grown in the state. The price premium for high quality durum can compensate for this difference in yield. Based on average durum yields, and assuming the grain meets U.S. No. 2 Hard Amber Durum standards, durum production in Virginia would have been more profitable than soft red winter wheat production in 1994 and 1997. Physical and chemical quality analyses of the top 19 performing durum lines were performed to determine grain marketability, suitability for pasta, and potential consumer acceptance of the end product. Protein content and gluten strength of the Virginia grown durum were acceptable. Color, firmness, and cooking loss of pasta produced from Virginia grown durum were comparable to pasta produced from commercial semolina. Requirements for U.S. No. 2 Amber Durum were met by 21% of the lines in both 1996 and 1997. Overall, the wet, humid Virginia climate was the greatest hindrance to durum production and quality. The field trials and quality analyses showed that high quality durum production in Virginia is possible, but not consistent over all years.

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Chapter I
Introduction

Approximately five percent of the worldwide wheat production is comprised of durum wheat (*Triticum durum* Desf.) (Foreign Agricultural Service, 1998). About six percent of the total wheat producing land in the United States is utilized for durum wheat production (United States Department of Agriculture-Economics and Statistics System, 1998). Durum wheat is well adapted to droughty, semi-arid regions, which typically have hot, dry days and cool nights with winter rains and dry summers. In the United States, durum is primarily grown in the Northern Great Plains (Montana, North Dakota, South Dakota) and in the Pacific Southwest (Arizona and California). The Northern Great Plains accounts for at least 75% of the durum wheat production in the United States (U.S. Wheat Associates, 1997). Approximately four million acres of durum are planted in the United States every year (National Agricultural Statistics Service, 1999).

The product of milled durum wheat is coarse, granular semolina. The high protein content, excellent amber color, kernel hardness, granular semolina, and superior cooking quality of durum wheat makes it the most suitable wheat for high quality pasta products. Dough produced from durum wheat is good for pasta products because of its bright yellow color, stiffness and ability to retain its shape (not get soft and mushy) (Dexter and Matsuo, 1977). Spaghetti, linguini and other long goods are made from the highest quality durum wheat, U.S. No. 1 Hard Amber Durum; while elbows, twists and other short goods may be produced from blends with high protein bread wheat (North Dakota State University (NDSU), 1992).

Interest in producing durum wheat in Virginia, typically a soft red winter wheat region, began in 1993. A milling company in Winchester, Virginia, prompted extension agents in Shenandoah County, Frederick County, Clarke County and Page County to request an investigation into the possibility of growing durum wheat in Virginia. At the time, the milling company was importing approximately a million bushels of durum wheat by rail from North Dakota. Speculation was that if durum wheat could be successfully produced in Virginia, the reduction in transportation costs and traditionally higher price for durum would translate into increased income for Virginia wheat producers.

To gain a better understanding of the feasibility of durum production in Virginia, over 60 durum wheat lines were grown in field trials at different locations within the three main physiographic regions in Virginia from 1993-1998. The overall objective of this study was to investigate the feasibility of successfully producing winter durum wheat in Virginia. Specific objectives of this study were:

1. To determine the adaptivity of available durum cultivars to a region south and east of its traditional areas of production in the United States,
2. To determine the yield potential of durum wheat grown in Virginia,
3. To characterize the physical and chemical qualities of durum wheat grown in Virginia, and
4. To examine the quality of pasta produced from Virginia durum wheat.

Chapter II

Literature Review

Origin of Durum Wheat

The development of agriculture and civilization has been closely linked with the production and utilization of wheat as early as 16 300 -15 000 BC (Harlan, 1981). Wheat cultivation is thought to have originated in the Fertile Crescent of the Middle East (Inglett, 1974). Durum wheat (*Triticum durum* Desf.) is derived from a tetraploid hybrid of the diploid *T. monococcum* (einkorn) and a diploid wild grass of unknown origin (Schmidt, 1974). During the Roman empire, wheat was primarily of the *Triticum durum-turgidum-dicoccum* group. Both *T. durum* and *T. turgidum* were once utilized for several foods, including breads, couscous, bulger, chapatis, etc. (Bozzini, 1988). After thousands of years of natural and human selection, *T. durum* is now primarily used for high quality pasta products, couscous and some flat breads.

Geographical Distribution of Durum Wheat

According to 1991/1992 USDA official statistics, 33.5 million metric tons of durum wheat were produced worldwide, making up six percent of the total world wheat production (NDSU, 1992). Durum wheat production covers approximately eight percent of the world's total wheat cultivated land area (Porceddu and Srivastava, 1990). It is grown in the Mediterranean countries, Eastern Europe, North Africa, West Asia, North Central and Southwestern United States, Mexico, and Canada (Gooding and Davies, 1997), with Canada being the world's largest producer of durum wheat (Wheat Yearbook, 1998). The United States, Canada and the European Countries (mainly France) account for 95% of all durum wheat exports, and Algeria is the primary world durum wheat importer (NDSU, 1992).

Durum wheat was first introduced to the United States in the 1850's (Joppa and Williams, 1988). Durum wheat in the United States is primarily grown in the Northern Great Plains (Montana, North Dakota, South Dakota) and in the Pacific Southwest (Arizona and California) (Wrigley, 1995). The Northern Great Plains accounts for at least 75% of the durum production in the United States (U.S. Wheat Associates, 1997). Although the U.S. is one of the primary centers of durum production, the history of higher prices of U.S. durum has prompted many U.S. millers to buy Canadian durum. Additionally, the increased incidence of scab (*Fusarium graminearum*) has caused U.S. millers to turn to Canadian durum. Even still, in 1998, the U.S. remained a net exporter of durum grain and products mainly to the European Union, Morocco and Tunisia (Wheat Yearbook, 1998).

Introduction of Durum to the United States

The first durum wheat cultivars introduced to the United States originated from Algeria, Turkey and Palestine. The hard kernels were difficult for flour millers to mill, so at first, most of the durum produced was used for livestock feed. More adapted durum wheat cultivars were collected in the 1890's and tested at agricultural experiment stations across the United States (Joppa and Williams, 1988). Studies in the early 1900's clearly indicated that durum wheat grown in North Dakota, South Dakota and Central Nebraska produced higher yields and was more resistant to leaf rust than hexaploid spring wheat (Salmon and Clark, 1913, as cited in Joppa and Williams, 1988). Cultivars introduced from other countries, especially the Russian cultivar Kubanka, were grown from 1850-1920. In 1929, the first durum breeding program was started in Langdon, ND. The focus of durum breeding in the United States was necessarily on stem rust resistance until the release of the cultivars Wells and Lakota in 1960 (Joppa and Williams, 1988). Since both cultivars possessed stem rust resistance, the focus of breeding was able to shift to yield and quality improvement.

Climatic Adaptation

Durum wheat is adapted to many of the same areas as common bread wheat, but it is not as inherently tolerant to long, cold winters. However, durum wheat is often more productive in marginal areas and soils than common bread wheat. Durum wheat is well adapted to the steppes or semi-arid regions, which typically have hot, dry days and cool nights with winter rains and dry summers (Bozzini, 1988). The highest durum wheat yields are associated with a long, moist and cool grain-fill period (Gebeyehou et al., 1982). Most of the world durum wheat production is under rainfed conditions, with a significant portion being produced in areas with less than 350 mm rainfall annually (Bozzini, 1988). It is especially well adapted to droughty areas such as the Mediterranean region of the Syrian wheat belt, which receives only about 300-400 mm of rainfall annually (Pecetti and Annicchiarico, 1993). Forty-five percent of the world durum wheat is grown in North Africa and West Asia due to the tolerance of durum wheat to hot and dry conditions (Porceddu and Srivastava, 1990). Durum wheat landraces, rather than cultivated pure lines, are still grown in these marginal regions because of their innate adaptation to drought, minimum fertilizer inputs, and area specific stresses. In addition, the landraces produce high grain yields with good quality (Srivastava and Damania, 1989).

Although irrigation may improve durum yields, there is a potential of reducing protein content with the use of too much water. Unfortunately, moisture related problems may also arise in rainfed regions. Humid weather or weather that is excessively wet before harvest can greatly reduce the quality of durum wheat. Too much moisture may result in preharvest sprouting, leading to reduced kernel vitreousness, reduced market quality and increased cooking loss (Clarke et al., 1994). The best quality durum wheat is produced in regions with rainfall during the vegetative growth stage and dry periods during later grain maturation (Berzonsky and Lafever, 1993).

Management and Environmental Factors Affecting Durum Yield and Yield Components

Cultural Practices

Currently, the United States primarily grows spring type durum, but some spring durum is fall sown in the Pacific Southwest (Ottman et al., 1990). Entz and Fowler (1991) suggested the fall planted spring type durums were more productive in winter wheat regions because of the available moisture and favorable temperatures during the spring. Wheat planted in the spring will develop later, and thus may encounter poorer environmental conditions. Additionally, a study performed at the Colorado State University Fruita Research Center near Grand Junction, Colorado, found that higher grain yields, test weights and kernel mass were associated with fall- and early spring- planted durum (Pearson, 1994). For these reasons, spring durums are planted in December or January in the Pacific Southwest. However, fall-planted spring types are usually not cold hardy enough to survive winters in the northern part of the country. So, spring durum wheat is typically planted in April or May in those regions (Quick and Ball, 1981).

High durum wheat yields result from the combination of high yielding cultivars, good management practices, and sufficient rainfall (500-700 mm) (Bozzini, 1988). Yields may simply be improved by using certified seed due to the high level of germination and purity. In fact, a

North Dakota study estimates that by using certified seed as opposed to bin-run seed, the 1988 durum wheat production could have been increased by $6.0 million (Spilde and Hafdahl, 1994). Spilde and Hafdahl (1994) also found that large durum seeds tended to have better viability and performance.

Yield increases have been indirectly achieved by breeding for certain traits, such as drought resistance. Yield increases have been successfully achieved by selecting for drought tolerance particularly during the grain filling stage (McCaig and Clarke, 1994). The lower the rate of water loss from the plant, the higher the yield. Low rate of water loss is associated with tall plants that are able to withstand environments of low moisture and low input. An experiment conducted to investigate drought responsive characteristics in Syria found most plants with low rates of water loss to also be late flowering, late maturing and tall, with glaucous and nonchlorotic leaves (Yang et al., 1991). In India, plant height, grains per spike, spikelets per spike and grain weight were all positively correlated with durum grain yields (Hanson et al., 1982). A study in Canada, spanning a test period from 1964 to 1992, determined that most yield increases in the durum cultivars have been due to increases in the number of kernels produced (McCaig and Clarke, 1994). Similarly, Gebeyehou et al. (1982) reported that grain yield is positively correlated with the number of kernels per spike and kernel mass. Furthermore, these traits are affected by the length of developmental periods. Kernel weight and kernels per spike are both positively affected by longer vegetative periods, and higher yields are associated with longer grain fill periods. Environmental effects must be taken into consideration when indirectly breeding for improved yields by altering traits associated with a particular growth stage. For example, lengthening the grain filling period to increase yields is not reasonable in areas where frost or summer rains, and thus, preharvest sprouting, are a danger.

Soil Characteristics and Fertilization

Soil type is an important consideration in the production of durum wheat. Well-drained clay or clay loam soils, at least 0.5 m deep, that are not too compacted are ideal for durum wheat. Soil pH is also an important consideration. Durum wheat is most successful in soils of pH 6 (in $CaCl_2$), but it may also grow where the surface pH is 5 and the subsoil is pH 7 or greater (Impiglia and Anderson, 1998). In addition to soil type and pH, soil fertilization is an important consideration in durum production. Nitrogen, in particular, is often necessary to raise both yields and quality. Crop rotations with legumes may be used to build up the soil nitrogen, to provide a disease break and to control weeds (Gooding and Davies, 1997). Nitrogen deficiency is a common problem in cool, wet areas, or places where the soil is waterlogged, such as in highland Vertisols (Geleto et al., 1996). Split nitrogen applications are often employed to reduce nitrogen losses due to leaching, denitrification, volatilization, and erosion run-off. Specific fertilization requirements will vary by location, so durum wheat fertilization should be based on soil test recommendations.

A premium price is paid for durum wheat containing a high amount of protein. The demand for high protein durum wheat (in excess of 13%) stems primarily from pasta manufacturers in Europe, Japan and North America (ESSO Farm-Tek, 1997). Some cultivars inherently produce more protein; however, protein content is actually influenced more by environment than genotype. Proper fertilization may help to increase the protein levels. For example, both grain and total nitrogen uptake increased with split nitrogen applications in Ethiopia, where continuous cropping has depleted the soil (Geleto et al., 1996). Nitrogen applied up to and at the tillering stage increases yields, while later nitrogen applications increase grain protein content. However, it is important to consider the environmental conditions before fertilizing, as there may be little response under dry conditions, or too much leaching under wet conditions. One way to determine the need for extra nitrogen to increase grain protein is to test the flag leaf. If the nitrogen content is less than 4%, the crop may need more nitrogen to increase the protein content. A foliar application of nitrogen between heading and flowering stages may increase protein by 0.5%. The additional nitrogen should not be applied when the plant is under stress, between 11 am and the evening, or before a rainfall (ESSO Farm-Tek, 1997). Protein synthesis requires two times the energy required for starch synthesis (Lásztity, 1996), and, therefore, a negative correlation exists between grain yield and protein concentration.

Diseases of Durum Wheat

Durum wheat is susceptible to numerous diseases at all stages of development. Leaf spots, rusts, scab (*Fusarium* head blight), black point, root and crown rots, powdery mildew and smuts are all diseases of economic importance in durum wheat (Miller et al., 1988). Every year, about 20% of the wheat crop is lost due to disease either in the field or storage (Wiese, 1987). Disease control in durum wheat generally includes the use of resistant cultivars, if available, seed and foliar fungicides, foliar sprays and crop rotations. Specific control measures depend upon the pathogen and the expense to the producer. The use of foliar sprays, resistant or tolerant cultivars, disease free seed, wheat stubble removal, and crop rotations all aid in the control of leaf spots (Miller et al., 1988). Leaf (*Puccinia recondita*) and stem (*Puccinia graminis*) rust are best controlled by the selection of resistant cultivars, however; the development of new pathogen races through mutation or hybridization necessitates the use of cultivars with more than one resistance gene (Statler et al., 1982; Miller et al., 1988). Fungicides also help to reduce the incidence and severity of rust. Scab (*Fusarium graminearum*) may be reduced by burying crop debris, rotating to a non-host crop, and not planting wheat near corn fields; however, this is not always practical. Currently, there are no scab resistant durum cultivars (North Dakota Extension Service, 1998). Black point of wheat (*Cochliobolus sativus*) may be controlled by using resistant cultivars (Statler et al., 1975). Root and crown rots (*Cochliobolus sativus* and *Gaeumannomyces graminis*) are best reduced through use of fungicide seed treatments, such as triademenol, imazalil, and difenoconazole, and crop rotations. Smuts (*Tilletia* spp.) may be reduced with the use of seed treatment fungicides (NDES, 1998), but some types, such as karnal bunt (*Tilletia indica*), are extremely difficult to control and no cultivars are known to be immune (Wiese, 1987).

Viruses have not been extensively studied in durum wheat. Wheat streak mosaic and wheat striate do occur in North Dakota, but have rarely created a serious problem (Joppa and Williams, 1988). Wheat streak mosiac virus may be controlled by destroying volunteer wheat, not planting near corn fields, and adjusting the planting date for winter wheat to later in the fall and for spring wheat to earlier in the spring (NDES, 1998).

Insect Control in Durum Wheat

Hessian fly (*Mayetiola Destructor* Say), aphids, especially greenbug (*Schizaphis Graminum* Rondani), and cereal leaf beetle (*Oulema Melanopus* L.) are the three most troublesome insects for wheat. Damage by the Hessian fly results in dwarfed plants, reduced tillering, increased winter injury in winter types, and straw breaking. Burying stubble and rotating crops with non-susceptible plants such as oats may control hessian fly. Both the greenbug and the cereal leaf beetle feed on the wheat leaves, with the cereal leaf beetle often responsible for yield losses up to 25% (Poehlman and Sleper, 1995). Cereal leaf beetle damage may be reduced by planting winter wheat early and by insecticides (Youngman et al., 1994). Aphid lions, Syriphid fly, lady beetles and parasitic wasps all provide natural controls for aphids (NDES, 1998). Depending on the location, there are other possible pest problems, such as wheat stem sawfly damage in North Dakota, so it is helpful to familiarize oneself with the environment and potential pests before growing durum wheat. For example, powdery mildew will likely be the most important disease of durum in the eastern United States, while it is not a problem elsewhere in the United States.

Durum Wheat Quality

Milling companies dictate specifications for durum wheat to better meet the demands of the pasta industry, which responds to consumer uses and preferences. Therefore, the consumer indirectly dictates the requirements for high quality durum wheat. The quality of durum wheat refers to both physical and chemical characteristics. Physical qualities are those characteristics of the wheat kernel that affect semolina characteristics, milling or processing. Chemical qualities include those innate properties of the wheat that affect the end product quality, such as protein quantity, gluten strength and pigment content.

Physical Characteristics

Grading

Durum wheat is one of seven classes of wheat that fall under the U.S. Grain Standards Act. The durum wheat grain is typically ovoid and elongated with a pronounced ventral ridge, and short brush hairs at the apex (Pomeranz, 1987). The vitreous amber colored durum seed is the hardest of all wheat seeds (NAWG, 1996). All cultivars of white, or amber, durum wheat are divided into three subclasses: Hard Amber Durum, Amber Durum, and Durum (Smith, 1995). These subclasses are differentiated by the percent of durum wheat with hard and vitreous kernels of amber color. Hard Amber Durum wheat is the most desirable subclass, with 75% or more hard and vitreous amber kernels. Amber Durum wheat has 60-75% hard and vitreous amber kernels. Durum wheat includes all durum with less than 60% hard and vitreous kernels of amber color. Each subclass is further broken down into grades 1-5; U.S. No. 1 is the most desirable.

Grade specifications are a response to the durum wheat millers' requirements. These grades are a measurement of quality based upon the test weight, and other physical characteristics of a durum wheat sample such as percent contrasting wheat classes, damaged kernels, defects, dockage, foreign material, heat damaged kernels, other grains, and shrunken and broken kernels (USDA, 1985). Cultivar characteristics, cultivation and management practices, weather conditions, growing location, harvest conditions, storage conditions and transport handling are all factors which can influence the final assigned grade or subclass designation of the durum sample (Dick and Youngs, 1988).

Before a wheat sample is graded, both dockage and moisture are determined. Moisture content determination not only provides a basis for comparison of grading factors such as test weight, but it is important for practical and economic reasons. If the grain moisture content is above 14%, it is more likely to heat up in the storage bin and/or undergo bacterial contamination and insect infestation. A safe moisture level at which to harvest is from 10-12.5%. Moisture is also an important factor in selling the wheat by weight. Economically, millers do not want to pay for water, thus, they will typically not accept durum wheat with moisture levels above 13 or 13.5% (Pitz, 1992).

Test weight, Contrasting Classes of Wheat and Wheat of Other Classes are important factors in grading durum wheat due to their use as predictors of semolina quality. To be designated U.S. No. 1, the minimum test weight for durum wheat is 77.2 kg/hl (60 lb/bu) (USDA, 1985). Both test weight and 1000 kernel weight (not a grading factor) are strongly correlated with semolina yield (Dexter et al., 1987; Pitz, 1992). The acceptable 1000 kernel weight is between 35 and 40 g/1000 kernels (Pitz, 1992). Any factors affecting seed size or shape, such as drought, frost, heat stress, or disease will also affect the test weight and 1000 kernel weight. Any shrunken, thin, or otherwise damaged kernels can result in a reduced semolina yield and an increased amount of speckiness (Dexter and Matsuo, 1981). Plump kernels tend to have high 1000 kernel weights and yield more semolina. These kernels also contribute to a high test weight because they may be packed more tightly into the container used to weigh the seed. A uniform size distribution of kernels is desirable because the rolls on the mill used to extract semolina are set a certain distance apart according to the average kernel size (Pitz, 1992). Contrasting classes of wheat tend to produce more flour and less coarse semolina because other wheat classes are usually too soft (Feillet and Dexter, 1996). Contaminated durum wheat may also have an inferior color and reduced cooking quality (Dexter et al., 1983b).

Kernel Vitreousness

As mentioned previously, the three official subclasses of durum wheat in the United States, Hard Amber Durum, Amber Durum and Durum wheat, are based upon the grain vitreousness. Kernel vitreousness is a measure of the kernel protein level, color and semolina granulation. Vitreous kernels have a shiny, translucent appearance, a good protein level (>12%), and coarse semolina granulation (Pitz, 1992). The opaque color of starchy, nonvitreous kernels has lead to use of the term "yellow berry" for these undesirable kernels. In the U.S., whole yellow berry kernels in a designated weight of wheat are identified by visual inspection, then separated and weighed. Percent kernel vitreousness is then expressed as the ratio of the weight of vitreous kernels to the total sample weight. Unfortunately, a major constraint of using kernel vitreousness as a grading factor is that it is a very subjective measurement (Pitz, 1992). Millers often use kernel vitreousness as a predictor of semolina yield and quality. Yellow berries pulverize easily into durum flour; thus it seems to follow that kernel vitreousness would be associated with semolina yield (Gooding and Davies, 1997). Starchy kernels or yellow berries may also produce white specks in the dried pasta (Matveef, 1963 as cited in Feillet and Dexter, 1996). The more vitreous areas of the kernel are higher in protein than starchy, or yellow berry, areas in the kernel (McDermott and Pace, 1960). High protein levels are desirable for both nutritional value and improved cooking quality. The occurence of yellow berries will increase in low protein environments (Gooding and Davies, 1997). While vitreousness has remained an important milling parameter, there is an increasing realization that vitreousness may not be as important now that trends have turned to finer semolina granulation (Menger, 1971 as cited in Feillet and Dexter, 1996).

Preharvest Sprouting

Durum wheat is extremely susceptible to preharvest sprouting when there is extended moisture during harvest. Sprout damaged kernels may reduce the grade of the durum wheat sample. Several methods for detection of preharvest sprouting have been developed based on enzymes that are produced or activated with seed sprouting. Assays that detect the presence of alpha-amylase activity (an enzyme that breaks down starch to maltose and glucose), and therefore preharvest sprouting, include nephelometric, colorimetric, gel diffusion and dextrinogenic techniques. Falling number and amylograph tests detect changes in the viscosity of gelatinized starch preparations due to alpha-amylase activity. The falling number test is most commonly used to detect preharvest sprouting due to its ease, simplicity, reproducibility and low cost. Pregermination may also be detected using the property of lipase (a product of pregermination) to fluoresce when combined with fluorescein dibutyrate (FD) (Pitz, 1992).

Marketability and kernel vitreousness of durum grain are affected by the amount of preharvest sprouting in a sample (Dick et al., 1974). The effect preharvest sprouting has on the quality and performance of the wheat has not yet been conclusively determined. According to Dexter et al. (1990) sprout damage itself does not affect the semolina milling potential or spaghetti color. However, the presence of some fungi often associated with preharvest sprouting may detract from the appearance of the semolina or pasta. *Cladosporium*, a mildew fungus, causes specks in the semolina and dull spaghetti (Dexter and Matsuo, 1982). Blackpoint (*Alternaria alternata)* and smudge (*Helminthosporium sativum)* fungi may detract from the appearance of semolina and pasta by giving them a black or dark brown color. None of these fungi seem to adversely affect spaghetti cooking quality (Dexter and Matsuo, 1982). Although there is not conclusive evidence of the negative effects of preharvest sprouting on spaghetti cooking quality, negative effects have been reported by pasta producers who have used wheat with low falling numbers. These negative effects include uneven extrusion, strand stretching, difficulty drying and poor storage stability (Donnelly, 1980). High α-amylase activity, an enzyme synthesized when the grain germinates, increases dough stickiness (Gooding and Davies, 1997) and sequesters lysine, reducing the nutritional quality (Kent and Evers, 1994). For this reason, a minimum acceptable falling number is usually designated for durum.

Severe sprout damage can result in a slight reduction in spaghetti firmness and an increase in the cooking loss, but even severe sprouting has little effect on semolina yield or spaghetti color (Matsuo et al., 1982a, Grant et al., 1993). Sprouting also has little effect on overall spaghetti cooking quality. During pasta processing, the low moisture content of pasta dough and the rapid decrease in moisture during drying help to prevent the α-amylase from degrading starch (Dexter et al., 1990). Furthermore, during cooking, the boiling water denatures the α-amylase, reducing the amount of damage (Kruger and Matsuo, 1982).

Initially, it was thought that genes for the control of preharvest sprouting could be introduced into the durum population by crossing with common wheat. However, genetic variation for preharvest sprouting within the durum gene pool has recently been discovered. Reducing the risk of preharvest sprouting by selecting for parents and cultivars within the durum class therefore is a promising possibility (Clarke, et al., 1994).

Chemical Characteristics

Pasta Quality

Durum wheat is the most suitable wheat for high quality pasta products because of its high protein content, excellent amber color, kernel hardness, granular semolina, and superior cooking quality. Dough produced from durum wheat is good for pasta products because of its bright yellow color, stiffness and ability to retain its shape (not get soft and mushy) (Dexter and Matsuo, 1977). Spaghetti, linguini and other long goods are made from the highest quality durum wheat, U.S. No. 1 Hard Amber Durum, while elbows, twists and other short goods may be produced from blends with other high protein bread wheat (NDSU, 1992).

Milling produces the raw materials used to make pasta. Without quality raw materials (semolina), it is difficult to produce quality end products (pasta). Dalbon et al. (1996) describe pasta making as the transformation of loose granules of semolina into a homogeneous structure stabilized by drying. The semolina must be able to be shaped through a die and produce a strong, flexible, dry finished product with acceptable packaging tolerance and storage stability. The dry, finished product should be translucent, without specks, and possess a bright, amber yellow color. The cooked product should be firm and non-sticky, with a pleasing taste and aroma. Furthermore, the end product should make a significant contribution to a balanced diet (Feillet and Dexter, 1996).

Semolina Quality

The objective of milling durum wheat is to obtain a high yield of brightly colored semolina by first separating the bran from the endosperm, then granulating the endosperm into semolina. Milling extracts 65-75% semolina from the durum wheat kernel (Feillet and Dexter, 1996). In addition to semolina, some durum flour is produced upon milling. Semolina granules may be greater than 500 μm, while the maximum granulation for flour is 150 μm (Kruger et al., 1996). Semolina is more expensive than flour, so it tends to be consumed in areas where the people are more quality conscious (Kruger et al., 1996). Semolina is used to make high quality pasta such as spaghetti noodles, and the durum flour is primarily used for noodles and some breads (Fabriani and Lintas, 1988).

Semolina Granulation

The granulation, or particle size distribution, of semolina is important because it affects the rate and amount of water absorption, as well as the semolina color. Fine semolina particles hydrate more rapidly than coarse particles, leaving coarse particles dehydrated. These unhydrated particles show up as white specks in the final pasta product and detract from its appearance (Pitz, 1992). It has become increasingly necessary to produce smaller, more uniform semolina particles in order to produce homogenous, translucent pasta using the new automatic continuous processing (Dalbon et al., 1996). However, if the semolina is milled too finely, starch damage will occur, increasing the potential cooking loss (Pitz, 1992). Semolina granulation will also affect the color. The finer the granulation, the paler it appears. This characteristic has been measured and verified with colorimeters (Irvine, 1971; Symons and Dexter, 1991).

Wheat Pigment Content

While research has not shown any direct link between color and pasta quality, a bright yellow color has been traditionally associated with high quality pasta. Pasta color is affected by several factors, including the wheat characteristics, milling conditions, and pasta processing**.** Generally, the best colored macaroni is obtained from cultivars with high carotenoid pigment levels, low polyphenol oxidase and lipoxygenase activity levels. A high level of lipoxygenase is undesirable since this enyzme oxidatively destroys yellow pigments. Certain processing conditions can also destroy the yellow pigment by catalyzing the lypoxygenase enzyme. The macaroni pigment content is correlated to wheat pigment content (Irvine and Anderson, 1953). Therefore, spaghetti color may be determined by testing the color of dry durum semolina. Semolina color is determined by the presence and concentration of carotenoid pigments, xanthophylls and lutein (Pitz, 1992). The desirable bright yellow coloring of semolina is attributable primarily to xanthophyll (Irvine, 1971). The presence of these pigments is greatly affected by genotype. The relationship between the yellow pigment and protein content of semolina varies among cultivars of durum (Dexter et al., 1977). Some durum lines form a complex between carotenoids and proteins, which helps to prevent oxidation and subsequent color loss (Mkhitaryan et al., 1974, as cited in Feillet and Dexter, 1996). Higher protein samples also tend to be browner in color (Alause and Feillet, 1970 as cited in Feillet and Dexter, 1996).

Common methods for determining the color of semolina are: visual comparison with standards, reflectance spectrophotometry, or chemical extraction of pigments and subsequent spectrophotometry. The Hunter Color Difference Meter, the Photovolt reflectance meter and the Densichron reflectance meter are all suitable instruments for color determination (Walsh, 1969, as cited in Feillet and Dexter, 1996). Saturated n-butyl alcohol may be utilized for chemical extraction of pigments in wheat, semolina and ground macaroni, but the process is tedious and n-butanol is a noxious, flammable solvent (Irvine and Anderson, 1953). Colorimeters are often more rapid indicators of semolina color than pigment extraction methods. The Judd-Hunter tristimulus coordinates, L*(brightness) and b*(yellow-blue chromaticity), in particular are used to determine the yellowness and browness of semolina samples (Francis, 1983).

Pasta Appearance

In addition to pigments, other factors can affect the overall appearance of pasta. Improper cleaning of the equipment, improper mill setting, or damaged kernels, can all result in specks in the pasta. White specks or streaks in the pasta may be the result of nonuniform hydration due to insufficient water, poor mixing and extrusion, or semolina derived from especially starchy or contaminated wheat. Brown specks can be created by higher extraction rates or starchy wheat (Feillet and Dexter, 1996). Diseases such as black point and smudge often result in black or dark brown specks in the semolina, thus millers consider grain affected by these diseases to have a serious defect (Dexter and Matsuo, 1982). Finally, the drying stage may affect pasta appearance as most pigment loss occurs during this stage of pasta processing (Matsuo et al., 1970).

Protein Content

Protein content is one of the most important qualities to be considered in durum production. Test weight, 1000 kernel weight and kernel vitreousness are all affected by protein content. Pasta quality is principally determined by protein content and gluten strength. Durum wheat protein content usually ranges from 9-18% (Feillet, 1988). A price premium is paid for durum wheat with a higher amount of protein. Protein content is directly related to spaghetti cooking quality (Matsuo et al., 1972). As protein content increases, the rheological properties of durum wheat and the overcooking tolerance of the pasta are also often improved (Dexter and Matsuo, 1977). A grain protein content greater than 13% is commonly desired for high quality pasta (Gooding and Davies, 1997), while protein levels below 11% produce pasta of inferior quality (Pitz, 1992). On the other hand, protein levels greater than 16% are often associated with a lower test weight, which may reduce market value (Fabriani and Lintas, 1988).

Protein content may be measured by wet chemistry methods, such as the Kjeldahl method or the Udy Dye Binding method, by near-infrared reflectance spectrophotometry (NIR) (Osborne and Fearn, 1983), or by oxidative combustion (Wilson, 1990).

Improving Protein Content

Grain protein is developed during the fruiting period, while starch is produced later, closer to maturity. During the early development stages, albumins and globulins are synthesized. As protein content increases, the proportion of albumins and globulins (cytoplasmic proteins) decreases (Dexter and Matsuo, 1977). Once the cytoplasmic protein requirement has been met, any further protein synthesis is of storage proteins, which determine pasta quality (Lásztity, 1996). Protein content is influenced more by the environment than by the genotype. Crop rotations, especially with legumes, nitrogen fertilizers, and selection of higher-protein cultivars are helpful for improving the protein content of durum wheat (Pitz, 1992). Nitrogen may be applied to raise both yields and protein content. Low protein cultivars will not necessarily be more responsive to nitrogen applications than high protein cultivars. The distribution of high and low molecular weight fractions change with changes in available nitrogen. High protein bread wheats as well as high protein durum cultivars are useful in the development of higher-protein durum cultivars. The *Triticum diccoides* 6B chromosome, for example, has been shown to be a valuable substitution in durum wheat for improving protein content in higher yielding cultivars, with no negative effects on pasta cooking quality (Kovacs et al., 1998).

Protein Quality

Protein quality is just as important as protein quantity in producing durum wheat; however, it is not easily predictable and is poorly understood (Bénétrix et al., 1994). The durum protein quality determines both the cooking performance and the quality of the cooked spaghetti (Pitz, 1992). When the semolina dough is rinsed in an excess of water or dilute salt solution, most of the starch and the soluble material is removed. The rubbery part which remains is the gluten. The gluten forming portions of the wheat protein complex, are the low molecular weight (LMW) storage proteins (gliadins) and the high molecular weight (HMW) storage proteins (glutenins). These gluten proteins are associated with protein quality, thus protein quality is equivalent to gluten quality. It is the gluten quality and not the quantity that is the major contributor to pasta quality when traditional drying processes are employed (Kovacs et al., 1998). Cooking quality is also strongly affected by the nature of the gluten proteins (Sheu et al., 1967). In particular, a high glutenin to gliadin ratio has been associated with superior cooking quality (Dexter and Matsuo, 1977). However, a high glutenin to gliadin ratio is not a guarantee of superior quality, and the specific composition of each of these fractions is important. Durum wheat that produces high quality pasta tends to have a higher ratio of low molecular weight glutenin subunits than intermediate molecular weight subunits (Brunori et al., 1990).

The size and composition of large protein aggregates, which are strongly influenced by the environment, determine the protein quality of wheat (Kackowski et al., 1987, as cited in Bénétrix et al., 1994). The amount of protein aggregates and the proportion of proteins increases during periods of grain dehydration (Bénétrix et al., 1994). High temperature stress seems to favor gliadin production over glutenin production, resulting in a drop in quality (Blumenthal et al., 1993). Glutenin production is decreased at higher temperatures, while gliadin production is reduced with low relative humidity (Graybosch et al., 1995). In addition, gluten content increases under saline growing conditions (Gooding and Davies, 1997). Increases in protein content seem to improve overall gluten characteristics, but the specific effect on the gliadins within the gluten complex seem to vary according to cultivar (Dexter and Matsuo, 1977).

Protein quality is determined by the genotype, the environment and their interaction. An analysis of durum wheat landraces grown in northern Syria suggests that durum wheat quality may be more heritable than initially thought (Pecetti and Annicchiarico, 1993). Studies of northern Syrian and Spanish durum wheat landraces have found a wide array of genetic variation for gluten strength among available landraces (Smith, 1995; Pecetti and Annicchiarico, 1993). Durum lines with increased protein quantity and quality may also be derived from crosses with strong gluten common bread wheat parents (Kovacs et al., 1998).

There are several useful methods for determining gluten quality. For very small samples, using the washed gluten test often provides the most information about the sample quality (Pitz, 1992). Gluten strength may also be measured by the Berliner method for gluten swelling (Dexter and Matsuo, 1977), the mixograph (Leisle and Baker, 1973), the extensigraph (Kruger et al., 1996), the Chopin alveograph, the Pelshenke test, electrophoretic and chromatographic techniques, protein solubility and specific absorbance (Pitz, 1992), the Zeleny sedimentation test and the SDS sedimentation test (Gooding and Davies, 1997).

One test that serves as a good measure of gluten quality is the sodium dodecyl sulfate (SDS) sedimentation test. The SDS sedimentation test was first used in 1979 to screen samples for gluten strength by both breeders and industry (McDonald, 1985). There are a few variables that warrant consideration when performing this test. The protein content of the sample and the operator's techniques both have a large bearing on the results. Temperature at which the test is run also may affect sedimentation volumes. The extent of this temperature dependence varies with genotype. Temperature correction is not required in a constant temperature laboratory or in a constant temperature water bath (McDonald, 1985). The environmental conditions during wheat growth also affect sedimentation volumes. Sedimentation volumes are negatively correlated with the number of hours of temperature greater than 32°C and the number of hours of less than 40% relative humidity during grain fill (Graybosch et al., 1995).

Despite the necessity for the above precautions, the results of the SDS sedimentation test are very useful in predicting gluten quality. A study comparing the merits of the mixograph and the SDS sedimentation test, found that the SDS sedimentation test was able to detect differences in gluten strength to a higher resolution, and thus more accurately predicts spaghetti cooking quality (Dexter et al., 1980). Furthermore, the SDS sedimentation test is more reliable for screening early generation durum lines for gluten strength (Dexter et al., 1980). Additionally, this test is less complex, requires only a small amount of sample and samples do not need to be milled.

Gliadins and Quality

Most of the early quality studies focused on gliadins because they are easier to extract than glutenins by gel electrophoresis. The gliadin fraction is not affected by protein content, growth conditions, sprouting, dusting or grain fumigation, or heat treatment that is great enough to destroy baking quality (Lásztity, 1996). Environmental factors, such as location and weather conditions, have no qualitative effect on gliadin electrophoregrams, making electrophoregrams especially helpful for cultivar identification and screening (Kosmolak et al., 1980). Using gel isoelectric focusing and electrophoresis, the gliadin fraction of the endosperm may be separated into 46 components (Lásztity, 1996). Damidaux et al. (1978, as cited in Bénétrix et al., 1994) determined that γ-gliadin band 45 is associated with strong gluten, while γ-gliadin band 42 is associated with weak gluten. Further studies have found cultivars with relative mobility γ-gliadin band 45 to have superior viscoelastic properties compared to those with γ-gliadin band 42. Kosmolak et al. (1980) extensively studied the charactersistics of cultivars with either γ-gliadin band 42 or band 45. Cultivars with neither band demonstrated less than optimum viscoelastic properties, while cultivars possessing both γ-gliadin bands 42 and 45 tended to have superior viscoelastic properties. Cultivars with only band 42 demonstrated lower sodium dodecyl sulfate sedimentation values, lower mixograph mixing times, lower gluten breaking strengths and lower cooking quality.

Cooking quality is not as well predicted by the gliadin bands as by the gluten strength tests. Cooking quality is primarily influenced by protein content, while gluten strength is more influenced by protein composition. Variation in a particular cultivar's cooking quality may be seen from location to location due to differing protein content and grain endosperm composition (Feillet,1988; Kosmolak et al., 1980). While protein content does not affect the gliadin bands, selection for band 45, a marker for gluten strength, may be helpful in increasing the selection for superior cooking quality. It is worth mentioning that buff-colored glumes seemed to be associated with polyacrylamide gel electrophoresis (PAGE) band 42 and weak gluten; whereas, white glumes tend to be associated with PAGE band 45 and strong gluten (Pitz, 1992). Autran and Galterio (1989) reported an inverse relationship between γ-gliadin band 42 and 1000 kernel weight and protein content, and a direct correlation between γ-gliadin band 45 and the same traits. Milling qualities and pasta stickiness have not been associated with protein markers (Autran and Galterio, 1989).

The relationship between the presence or absence of gliadin bands and quality was first suggested to be a functional relationship, but this was complicated by cultivars possessing both γ-gliadin bands 42 and 45 (Kosmolak et al., 1980). Genetic linkage between traits controlling quality and gliadin patterns is a more likely explanation. In more recent years, it has been discovered that γ-gliadin band 45 is a genetic marker for low molecular weight subunit glutenins (LMW-SG). The LMW-SG aid in the formation of the proteins that give the pasta its viscoelastic properties (Feillet et al., 1996). Gamma gliadin bands 45 and 42 are genetically closely linked to the presence or absence of LMW-1 and LMW-2 glutenins, respectively (Payne et al., 1984). According to Pogna et al. (1988) the benefit of γ-gliadin band 45 originates from aggregate subunits of glutenin of the Glu-B3 locus, genetically linked with the Gli-B1 locus.

Noting that cultivars with γ-gliadin band 42, but without the d_4 ω-gliadin band, possessed good cooking quality, Hussain and Lukow (1993) suggested that perhaps the d_4 ω-gliadin band was a better screen for poor quality attributes. The d_4 ω-gliadin band was present only in cultivars possessing the γ-gliadin band 42, but not all of these γ-gliadin band 42 cultivars possessed the d_4 ω-gliadin band. The d_4 and d_5 (another band in the same study) ω-gliadin bands are not associated with the γ-gliadin bands 42 and 45 in aluminum lactate-polyacrylamide gel electrophoresis (A-PAGE), but appear higher up on the gel, in the ω region. On A-PAGE, d_5 was reported to have a relative mobility of 35, while d_4 separated into two bands with a relative mobility of 33 and 38. The mobility of either band is not affected by SDS, pH, reduction or alkylation treatment (Hussain and Lukow, 1993).

The procedure often used to isolate γ-gliadin band 45 is aluminum lactate polyacrylamide gel electrophoresis (A-PAGE). In 1989, monoclonal antibodies were used instead of PAGE to screen for γ-gliadin band 45 (Howes et al., 1989). The isolation of ω-gliadins may be done using a two-step process, first A-PAGE, then SDS-PAGE (Branlard et al., 1992). The use of SDS-PAGE to screen for the d_4 ω-gliadin band, as suggested by Hussain and Lukow (1993) would greatly simplify the quality screening process. Advantages to using ω-gliadin d_4 as a screen for end product quality are the ease of extraction and the clearer visualization.

Dough Rheology

Dough rheology is the study of dough strength, thus it is often utilized to estimate the suitability of dough for a desired end product. The resistance of a dough to mixing is determined by the rheological properties (Bloksma, 1984). Medium gluten strength (short, inextensible gluten) is optimum for pasta production (Matsuo and Irvine, 1970; Matsuo, 1978). Dough strength is a function of the molecular weight distribution of gluten proteins. The quantity and quality of the protein components in the gluten complex and the interactions between the protein fractions determine the rheological properties of the dough. The ratio of LMW to HMW fractions in the protein matrix plays a key role in the control of dough rheology. The most commonly held view is that a 1:1 ratio is best; however, recent studies have found that both solubility and molecular weight distribution of the gluten proteins are important determining factors for gluten quality. The insoluble HMW (glutenin) fraction, in particular, has many positive effects on gluten quality. Glutenins are composed of both HMW and LMW subunits. A high content of LMW glutenin subunits is responsible for the good cooking quality of the end product (Autran et al., 1987; Bénétrix et al., 1994). The HMW glutenin subunits play a lesser role in the gluten quality, yet there exists an optimal level of HMW concentration (Autran and Galterio, 1989). At very high levels of HMW concentration, the dough actually begins to weaken, and in breads, loaf volume drops (Lásztity, 1996).

Cooking Quality

Pasta cooking quality is based on the cooking time, water uptake during cooking, texture, surface condition, aroma and taste (Feillet, 1984). Differences in cooking quality among cultivars are primarily due to protein content and composition of the grain endosperm (Matsuo et al., 1982b; Feillet, 1988). Before conducting pasta cooking-quality tests, the optimum cooking time must be determined. Cooking time is described in several phases. Minimum cooking time is the time until the starch has gelatinized. Optimum cooking time is the time required to give pasta the desired texture, usually depicted by the disappearance of the center white core. The typical optimum cooking time for spaghetti noodles is about 12 minutes (D'Egidio and Nardi, 1996; Dexter and Matsuo, 1977). Maximum cooking time is the time beyond which the pasta will disintegrate. Overcooking time is usually the normal, or optimum, cooking time plus 10-12 minutes (D'Egidio and Nardi, 1996).

Semolina gluten proteins form a matrix, held together by disulfide, hydrogen and hydrophobic bonds, that give the dough its viscoelastic properties. The matrix entraps other molecules, such as starch. High amounts of low molecular weight glutenins are desirable since the aggregation of these molecules forms a good protein matrix, thus improving viscoelastic properties. Upon cooking, this matrix begins to disintegrate at a rate depending on the character of the semolina and processing conditions (Feillet and Dexter, 1996). Cooking loss provides an overall measure of the how much this matrix, and therefore the spaghetti, breaks down during cooking. Even for durum genotypes of highly different spaghetti making quality, the solubility changes of the semolina proteins do not significantly differ during the spaghetti processing, suggesting that spaghetti quality is due to the ability of the proteins to withstand boiling water during cooking (Matsuo et al., 1978). Rinsing the noodles after cooking washes off the starch responsible for the stickiness. The weight of the residue in the cooking water and the rinse water may be measured after evaporation or freeze drying to determine the amount of cooking loss (AACC, 1984). Matsuo et al. (1992) suggest using a colorimetric method that measures the iodine-amylose complex absorption in cooking water to determine cooking loss. Water hardness is thought to affect cooking loss as well as end product quality. However, there are only a few studies specifying desirable chemical or physical characteristics of water for good dough production. Generally, it is thought that water containing large amounts of sodium chloride, magnesium chloride or iron salts is undesirable, due to the unpleasant flavor and color it will impart on the end product (Dalbon et al., 1996). Percent cooking loss is correlated to sensory evaluation for stickiness (D'Egidio et al., 1982). The swelling of the noodles while cooking is measured by weighing the noodles before and after cooking. Generally, 100 g of dry spaghetti will increase in weight to 160-180 g during cooking (Feillet, 1984).

The pasta consumer prefers a spaghetti noodle with firmness, or bite ("al dente"), and without stickiness. Spaghetti firmness is the resistance of the spaghetti to biting, or the force necessary to cut the spaghetti with teeth. Dexter and Matsuo (1979) have shown pasta firmness and resilience are positively correlated to the starch amylose content. However, the amylose content in durum does not vary to a great extent, so further investigation into the source of spaghetti firmness would be useful. In a pasta sample that is not sticky, a continuous protein network surrounds each starch granule, whereas in a poor quality sample, the protein reticulation is overcome by the starch gelatinization (Resmini et al., 1983). Water hardness and time the pasta is allowed to sit after draining may also affect stickiness (Dexter et al., 1983b). Other textural considerations are cohesiveness and elasticity. The cohesiveness of the noodles describes how well the internal bonds hold the pasta together, the opposite is compressibility. Recovery of the noodles to return to original shape when a force is removed is called the elasticity of the noodles (D'Egidio and Nardi, 1996). Samples with good cooking quality are firm with good elasticity, a low tenderness index, low compressibility and a high recovery (Dexter and Matsuo, 1977).

Cooking conditions which may affect the results obtained in texture tests include the length of time for cooking, the pasta to water ratio, the hardness of the water, the water pH, and the time between pasta drainage and testing (Menger, 1979, as cited in Dalbon et al., 1996). Stickiness has been tested with the Instron, but it only relates to sensory ratings before eating (Voisey et al., 1978). To test the firmness of the spaghetti, a simulated bite test using a plexiglass tooth was developed by Matsuo and Irvine in 1969 (Matsuo and Irvine, 1969). The test involved taking spaghetti strands immediately after cooking (to reduce water loss) and recording the movement of a cutting edge as it moved through the spaghetti. The force required to shear a cooked spaghetti noodle (firmness) by a plexiglass tooth using an Instron Universal Tester is correlated to sensory firmness (D'Egidio and Nardi, 1996). Matsuo and Irvine (1969) developed a Grain Research Laboratory Tenderness Tester (GRL) in 1969. This instrument recorded the rate of movement of the cutting edge under increasing force through cooked spaghetti. The GRL was used to relate spaghetti stickiness to consumer evaluation (Dexter et al., 1983a). Noodle texture and firmness have also been tested using a compression cell. In these tests, low compressibility and stickiness ratings and high recovery ratings were associated with good taste by sensory panel evaluations (D'Egidio and Nardi, 1996). Softer samples take less time to cut, but factors such as spaghetti diameter and time after cooking can alter the reading (Matsuo and Irvine, 1969).

Poor quality durum may produce pasta with one or more of the following detriments detracting from the overall pasta appearance: cracks in the finished product, poor packaging tolerance, poor drying characteristics, and low protein content. Poor coloration or appearance may be caused by problems inherent to the wheat even before it comes to the pasta plant, such as low protein content or high α-amylase activity. Problems at the plant itself, such as storage in an environment with unstable relative humidity, may also reduce the quality of the finished product

(Feillet and Abecassis, 1976). Thus, high quality pasta products must start with quality durum seed and production practices.

Chapter III

Winter Durum Wheat Yield Evaluations at Various Virginia Physiographic Locations

Abstract

Durum wheat (*Triticum durum* Desf.) produced in the United States is primarily of spring growth habit and is grown in the Northern Great Plains and the Pacific Southwest. The objective of this study was to determine the feasibility of winter durum production in Virginia, typically a soft red winter wheat region. The adaptation and the yield potential of available winter durum lines were assessed from 1993-1998, over three different physiographic regions in Virginia, the piedmont plateau, the ridge and valley, and the coastal plain. Durum lines were planted along with soft red winter wheat in late September to early October and harvested in late June to early July, depending on location. Yields and test weights were determined at harvest. The head date of most durum lines was later ($P<0.05$) than FFR 555W, which is a late heading soft red winter wheat cultivar. In addition, most durum lines were shorter ($P<0.05$) than FFR 555W. Climate was the major factor affecting durum production. Field trials showed that durum is particularly susceptible to disease, such as *Fusarium* head blight, under wet, humid conditions, resulting in suppressed yields and low test weights. Overall, winter durum lines from the Ukraine were best adapted to the Virginia climate. Generally, winter durum yields averaged 1600-2800 kg/ha less than soft red winter wheat. The highest average durum yields were observed in Orange County, in the northern piedmont plateau, while soft red winter wheat had the lowest yield advantage at Richmond County, in the northern coastal plain. Test weights of most durum lines met the required minimum for grade U.S. No. 2 or better in 1994, 1996 and 1997. Based on average durum yield data, and assuming the grain meets U.S. No. 2 Hard Amber Durum standards, durum production in Virginia would have had an economic advantage over soft red winter wheat production in 1994 and 1997. The field trials showed that durum production in Virginia is possible, however, the observed inconsistencies in yield and test weight indicate that durum may be a relatively high risk alternative to soft red winter wheat production.

Introduction

Durum wheat in the United States is primarily grown in the Northern Great Plains (Montana, North Dakota, South Dakota) and in the Pacific Southwest (Arizona and California) (Wrigley, 1995). The Northern Great Plains accounts for at least 75% of the durum production in the United States (U.S. Wheat Associates, 1997). Interest in producing durum wheat in Virginia, typically a soft red winter wheat region, began in 1993. A milling company in Winchester, Virginia, prompted extension agents in Shenandoah, Frederick, Clarke, and Page Counties to request an investigation into the possibility of growing durum wheat in Virginia. At the time, the milling company was importing approximately a million bushels of durum wheat by rail from North Dakota. Speculation was that if durum wheat could be successfully produced in Virginia, the reduction in transportation costs and generally higher price for durum would translate into increased income for Virginia wheat producers. To be considered successful, the durum produced in Virginia must produce sufficient yields and adequate quality to be an economically feasible alternative to soft red winter wheat production. The first part of this equation, durum yields, is discussed in this chapter. The objectives of this study were:

1. To assess the adaptation of available winter durum lines to Virginia,
2. To determine the yield potential of winter durum wheat in Virginia, and
3. To estimate the profitability of durum production in comparison to soft red winter wheat production.

Materials and Methods

Field studies were conducted from 1993-1998 at different locations within the three main physiographic regions of Virginia (Fig. 1). For the first year of the field trials, two locations in the Virginia ridge and valley (Montgomery County and Shenandoah County) and one location in the northern piedmont plateau (Orange County) were selected. The northern ridge and valley test site was moved from Shenandoah County to Clarke County in 1995. The Montgomery County, Orange County, and Shenandoah County locations were used for the field trials in 1995 and 1996. An additional location, Richmond County, in the northern coastal plain, was included in 1996. To better cover the physiographic regions of Virginia, the 1997 field trials were conducted at two locations within each region. Locations in 1997 included Montgomery County and Shenandoah County (ridge and valley), Orange County and Nottoway County (piedmont plateau), and Richmond County and Suffolk (coastal plain). Soil types for each region are shown in Table 1.

The field study initiated in 1993 included 55 durum wheat lines and five soft red winter wheat cultivars (Table 2). The soft red winter cultivars were selected based on their yield potential, agronomic performance and adaptation to Virginia. Durum wheat lines were obtained from Romania, Syria, Ukraine, France, Turkey, the International Center for Maize and Wheat Improvement (CIMMYT) in Mexico, and several states in the U.S. Three Hungarian winter durum wheat cultivars (Basa, Minaret and Pannondur) were obtained from Ohio, where similar field trials were performed. Western Plant Breeders of Phoenix, Arizona, contributed 38 experimental winter durum wheat lines, identified in the Virginia field trials by the prefix ‘BZ’. The breeding program at Oregon State University also supplied several durum lines. Lines previously tested in Oregon are referred to here under an experimental number with the prefix ‘OR’. The identities and origins of these lines are shown in Table 3. Based upon observations during the 1993-1994 growing season, it was determined that several of the original 55 durum lines did not possess sufficient winter hardiness to be grown in Virginia. These and other lines with poor yield performance were dropped from subsequent field trials. Only 29 winter durum wheat lines and six soft red winter wheat lines were planted in 1994. Six new lines from the Ukraine were obtained in 1995. These lines are referred to as the ‘Odessa’ lines during the Virginia field trials; however, the actual line designation for these lines may be found in Table 3.

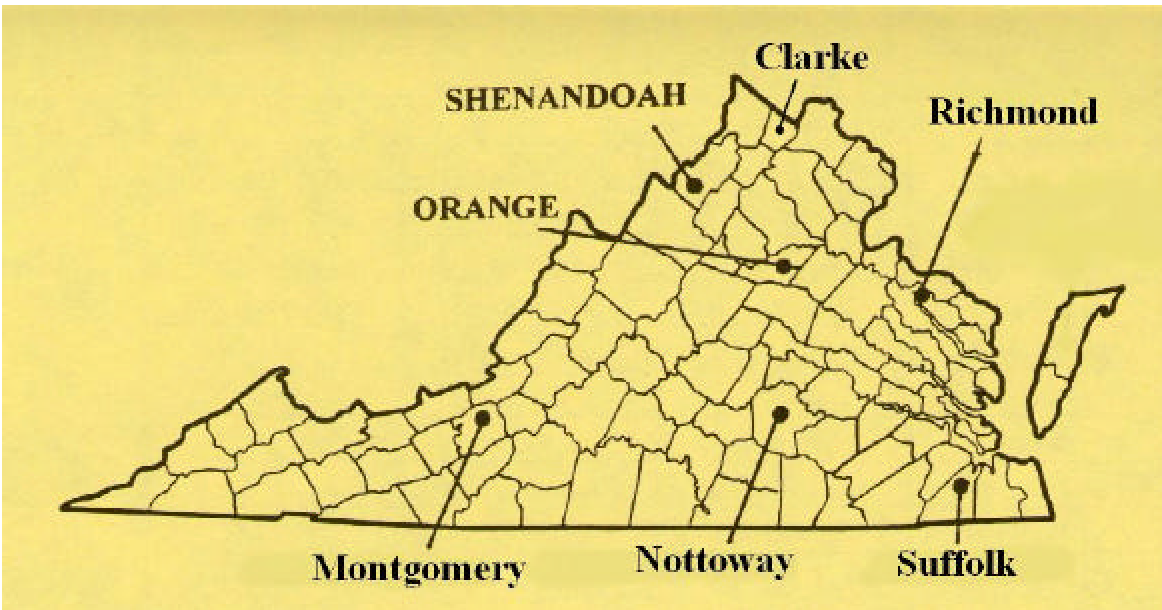


Fig. 1. Locations of the Virginia durum field trials, 1993-1998.

Table 1. Regions, years, and soil types utilized for the Virginia durum wheat trials.

Location By Region	Year	Soil Type	Soil Family
Southern Ridge and Valley	1993-1998	Hayter fine loam	Fine loamy, mixed mesic ultic,Hapludalfs
Northern Piedmont Plateau	1993-1994	Starr silty clay loam	Fine loamy, mixed, thermic fluvenitic, Dystrochrepts
	1994-1995, 1996-1997	Davidson/ Rabun silty clay loam	Silty clay loam
	1997-1998	Starr/Dyke silty clay loam	Fine loamy, mixed, thermic fluvenitic, Dystrochrepts
Northern Coastal Plain	1996-1998	Kempsville sandy loam	Fine loamy, siliceous, thermic typic, Hapludults
Northern Ridge and Valley	1993-1996, 1997-1998	Frederick poplimento	Silt loam
	1996-1997	Nicholson-duffield	Silt loam
Southern Coastal Plain	1997-1998	Emporia fine loam *and* Nansemond coarse loam	Fine loamy, siliceous, thermic typic Hapludult; Coarse loamy, siliceous, thermic Aquic Hapludult
Southern Piedmont Plateau	1997-1998	Mayodan sandy loam	Clayey, kaolinitic, thermic typic Hapludult

Table 2. Durum and soft red winter wheat lines planted in Virginia field trials, by growing season.

		Growing Season				
Line	Origin	1993-1994	1994-1995	1995-1996	1996-1997	1997-1998
COKER 9803[1]	South Carolina	*	*	*	*	
COKER 9835[1]	South Carolina		*	*	*	
FFR 555W[1]	Virginia	*	*	*	*	*
MASSEY[1]	Virginia	*	*	*	*	
PIONEER 2548[1]	Indiana	*	*	*	*	
WAKEFIELD[1]	Virginia	*	*	*	*	
BASA	Hungary	*	*	*	*	*
BZ8289-6	Arizona	*				
BZ8W90-2	Arizona	*				
BZ8W90-27	Arizona	*	*	*	*	*
BZ8W90-29	Arizona	*				
BZ8W90-33	Arizona	*				
BZ8W90-7	Arizona	*				
BZ8W90-8	Arizona	*				
BZ8W91-1	Arizona	*	*	*	*	
BZ8W91-2	Arizona	*	*	*	*	
BZ8W91-4	Arizona	*	*	*	*	
BZ8W91-7	Arizona	*	*	*	*	
BZ8W91-8	Arizona	*	*	*	*	*
BZ8W92-1	Arizona	*				
BZ8W92-10	Arizona	*	*	*	*	*
BZ8W92-11	Arizona	*				
BZ8W92-12	Arizona	*				
BZ8W92-13	Arizona	*				
BZ8W92-14	Arizona	*				
BZ8W92-15	Arizona	*				
BZ8W92-16	Arizona	*				
BZ8W92-17	Arizona	*				
BZ8W92-18	Arizona	*				
BZ8W92-19	Arizona	*				
BZ8W92-2	Arizona	*	*	*	*	*
BZ8W92-20	Arizona	*				
BZ8W92-21	Arizona	*				
BZ8W92-22	Arizona	*				
BZ8W92-3	Arizona	*	*	*	*	

[1]soft red winter wheat

Table 2 (continued). Durum and soft red winter wheat lines planted in Virginia field trials, by growing season.

Line	Origin	Growing Season 1993-1994	1994-1995	1995-1996	1996-1997	1997-1998
BZ8W92-4	Arizona	*				
BZ8W92-5	Arizona	*				
BZ8W92-6	Arizona	*	*	*	*	
BZ8W92-7	Arizona	*				
BZ8W92-8	Arizona	*	*	*	*	*
BZ8W92-9	Arizona	*	*	*	*	
BZ90-7	Arizona			*	*	
BZ92-13	Arizona			*	*	
ELBURZ	Arizona	*				
ELBURZ-1	Syria	*				
HAD-6	Syria	*				
KORALL	Colorado	*		*	*	*
MINARET	Hungary	*	*	*	*	*
ODESSA #63	Ukraine			*	*	*
ODESSA #64	Ukraine			*	*	
ODESSA #65	Ukraine			*	*	*
ODESSA #66	Ukraine			*	*	*
ODESSA #67	Ukraine			*	*	
ODESSA #69	Ukraine			*	*	*
OR3880015	CIMMYT	*				
OR3880152	CIMMYT	*	*	*	*	*
OR3880158	CIMMYT	*	*	*	*	*
OR3880181	Ukraine	*	*	*	*	*
OR3910084	Romania	*	*	*	*	*
OR3910085	France	*	*	*	*	*
OR3910106	Turkey	*	*	*	*	
OR3910214	Romania	*	*	*	*	*
OR3910246	France	*				
OR3910258	France	*				
OR916121	Oregon	*	*	*	*	*
PANNONDUR	Hungary	*	*	*	*	*
THHA	Arizona	*				
TOMA	Arizona	*				
TOURUS-1	Syria	*				

Table 3. Pedigree and further information regarding lines tested in the Virginia durum field trials.

Virginia Line	Actual Line	Origin	Pedigree
ODESSA #63	N1291/86	Ukraine	(Kandikans 91/60 x Novomichyrinka) x Novinka x Parus
ODESSA #64	N1589/86	Ukraine	Korall x 873/77 (LR-I x Leukurum 504/87x Kharkovskaya)
ODESSA #65	N1013/84	Ukraine	(Kharovskaya I x Krasnod. Karlik I)
ODESSA #66	N1439/83	Ukraine	(F1 Kharkovskaya I x Odesskaya yubileinaya) x Oviachik 65 x Kharkovskaya I
ODESSA #67	N913/85	Ukraine	539/79 (Kharkovskaya I x Odesskaya yubilejnaya) x Oviachik 65 x Zernogradskaya 2087/76
ODESSA #69	N736/89	Ukraine	Chernomor x 367/78 (Kharkovskaya I x Odesskaya yubilejnaya) x Oviachik 65 x Kharkovskaya I
OR3880015	H7092-60	CIMMYT	Not Available
OR3880152		CIMMYT	UVY162/61.130//73.44//OVI65/3/BERK/OVI65/4 /C.BUG1018//BR180
OR3880158		CIMMYT	UVY162/61.130//73.44//OVI65/3/BERK/OVI65/4 /C.BUG1018//BR180
OR3880181	PARUS	Ukraine	Not Available
OR3910084	DF 38-86	Romania	Not Available
OR3910085	AMBRAL	France	Not Available
OR3910106	TKCB 66	Turkey	Not Available
OR3910214	DF 222-95	Romania	Not Available
OR3910246	D.127-11	France	Not Available
OR3910258	D.142-17	France	Not Available
OR3920036		Oregon	7-5/VALGERARDO//EDMORE///TOPAZ
OR3950055		Oregon	FLD87050/H7092-50
OR916121		Oregon	H7092-11/WPB 881
OR936773		Oregon	AMBRAL///VALNOVA/VALDUR//7-5
OR948578		Oregon	WALLY855692/H7092-59//H7092-3/ALTAR 84
OR948612		Oregon	ZY81090/H7092-49//H7092-53/ALTAR 84
OR948763		Oregon	H7092-52/ALTAR 84/4/UVY162/61.130 //HC6654/3/A
OR948927		Oregon	H7092-11/WPB 881
OR948948		Oregon	H7092-54/ALTAR 84
OR949024		Oregon	CALVIN/EDMORE//H7092-59
OREXP#10		Oregon	UVY162/61.130/HC6654/3/AKB/OVI65 /4/WPB 881
OREXP#11		Oregon	UVY162/61.130//HC6654/3/AKB/OVI65 /4/WPB 881
OREXP#12		Oregon	BRINDUR/DF 38-86
OREXP#13		Oregon	DF 900-83/WPB 881
OREXP#14		Oregon	D.130-16/4/UVY 162/61.130//HC6654/3/AKB /OVI65

Thirty-two winter durum wheat lines and six soft red winter wheat lines were planted in 1995 and 1996 (Table 2). Based on data from previous years, the number of lines planted in 1997 was narrowed to the 19 best performing winter durums and one soft red winter wheat line (Table 2). Twenty new lines from Romania and Oregon were also grown in Richmond County in 1997 (Table 4).

The experimental design was a randomized complete block design with three to four replications, depending on location. Durum in Richmond County and Montgomery County was planted in six 18 cm (7 in) rows, in plots 1.52 m (5 ft) wide and 2.74 m (9 ft) long for a total size of 484.2 m^2 (45 ft^2). Durum at all other locations was planted in seven 18 cm (7 in) rows, in plots 1.71 m (5.64 ft) wide and 2.74 m (9 ft) long, for a total area of 546.6 m^2 (50.8 ft^2). Planting occurred in late-September to early October, depending on location. Seeding rates were calculated based upon kernel weight. Due to limited seed the first year, 1993-1994, seeding rates were approximately 72.4 seeds/m drill row (22 seeds/ft drill row). The seeding rate all other growing seasons was 78.9 seeds/m drill row (24 seeds/ ft drill row).

Plots at each location were fertilized according to soil test recommendations. Specific management practices by location may be found in Appendix A. Typically, about 672 kg 10-10-10 (N-P-K) fertilizer was applied per hectare (600 lb/acre) in the fall prior to planting. In addition to the fall fertilization, approximately 44.8 kg/ha (40 lb/acre) of 25-0-0-3 (N-P-K-S), depending on location, was applied just after green up, at Zadoks growth stage 25 in both the 1993-1994 and 1994-1995 growing seasons. For the 1995-1996 growing season, a second nitrogen application of approximately 56 kg/ha (50 lb/acre) of 25-0-0-3 (N-P-K-S) was applied when 6.4 mm (0.25 in) of the hollow stem in the main stem was visible (Zadoks growth stage 30). In the 1996-1997 and 1997-1998 growing seasons, another nitrogen application, in addition to the pre-planting fertilization and nitrogen applied at Zadoks growth stages 25 and 30, was made at a later stage to boost grain protein. Around Zadoks growth stage 37, flag leaf stage, approximately 16.8 kg N/ha (15 lb N/acre) was applied, made from 14 kg (30 lb) granular urea dissolved in 20-25 gal of water.

Seeds were treated with Baytan® (34 ml/45.4 kg) and captan (59 ml/45.4 kg) to reduce powdery mildew (*Erysiphe graminis*) and multiple diseases, in 1993 and 1994. In 1995, and

Table 4. Durum lines grown only in Richmond County, VA (northern coastal plain): 1997-1998.

Line	Origin
ACADUR	Romania
AGEDUR	Romania
ALIDUR	Romania
AMADUR	Romania
OR3920036	Oregon
OR3950055	Oregon
OR936773	Oregon
OR948578	Oregon
OR948612	Oregon
OR948763	Oregon
OR948927	Oregon
OR948948	Oregon
OR949024	Oregon
OREXP#10	Oregon
OREXP#11	Oregon
OREXP#12	Oregon
OREXP#13	Oregon
OREXP#14	Oregon
PANDUR	Romania
RODUR	Romania

subsequent growing seasons, seeds were also treated with Gaucho® (44 ml/45.4 kg) to control insects, especially aphids. Beginning at Zadoks growth stage 25, in early spring, plots were scouted for diseases, especially powdery mildew. In all years, at all locations, fungicide was applied on a 14 day schedule or as needed based on visual assessment, to restrict disease development, and therefore, losses in yield and quality (Table 5). In the 1997-1998 field trials, using a split block design, three additional replicates of the 19 lines and one soft red winter wheat check were grown with limited, or restricted, fungicide applications at the sites in Montgomery, Orange, Shenandoah, Suffolk, and Richmond Counties. The application of fungicide to these plots was limited to no more than two applications, applied according to recommended disease thresholds. Usually this meant the application of a fungicide, such as Tilt, to control mildew, rust and Septoria prior to Zadoks growth stage 37. Another fungicide, such as Bayleton, was applied if needed, either before or after the application of Tilt, depending on location and disease pressure.

Plots were visually assessed for disease, heading date, plant height, lodging, and winter survival. The crop was permitted to completely dry down, according to the latest maturing line, before harvest. Depending on location, crop maturity, and weather conditions, plots were harvested in late June to early July. Yield, moisture and test weight for each plot were measured after harvest.

Data Analysis

Data from all locations and years were analyzed by analysis of variance using SAS software (SAS Inst., 1991). In cases where the data was unbalanced due to limited availability of grain, the general linear model (GLM) procedure was employed (SAS Inst., 1991). Effect of replication, location, line and all interactions were tested. In 1998, the effect of restricting fungicide applications for the appropriate locations was also tested. Mean separations were performed by line and/or location, if the ANOVA F-statistic indicated significant effect at the 0.05 level (SAS Inst., 1991).

Table 5. Guidelines for disease control in the 1993-1998 Virginia winter durum wheat field trials.

Begin to Treat at this Growth Stage	**Disease**	**Threshold[1]**	**Suggested Fungicide**	**Rate**
Zadoks Growth Stage 30 (stem elongation)	Powdery mildew	Upper leaves have ≥5% leaf area infected	Bayleton	4 oz/acre
Zadoks Growth Stage 37 (flag leaf just visible)	Leaf rust	Upper leaves have 3-9 pustules/leaf	Tilt or Bayleton	4 oz/acre
Zadoks Growth Stage 37 (flag leaf just visible)	Septoria	1 out 4 leaves has 1 lesion	Tilt or Bayleton	4 oz/acre

[1]Stromberg, E.L., P.M. Phipps, A.P. Grybauskas, and R.P. Mulrooney. 1994. Diseases and Nematodes. p. 73-111. *In* 1994 Pest Management Guide for Field Crops. Virginia Cooperative Extension, Blacksburg, VA.

Results

Overall, average grain yields of the durum wheat grown in Virginia were lower ($P<0.05$) than average yields of soft red winter wheat from 1993-1998. Region, line, and the interaction between region and line all had an effect ($P<0.05$) on yield each year. Due to differences in soil type, environment, precipitation, and disease pressure, it is not surprising that the location of the field trials was a large factor in determining the amount of grain each line produced. Since the durum lines tested originated in, and thus were adapted to, several different regions around the world, the adaptation of each line to Virginia was expected to vary. Furthermore, the specific region within Virginia where the lines were grown also affected grain yields, as some lines performed well at one location, but poorly at another location.

Yield and Test Weight: 1993-1994

The poor yields and, in some cases, severe winter kill of several durum lines in the 1993-1994 field trials indicated that those lines were either facultative-type durums (exhibiting both spring- and winter-type traits) or did not possess sufficient winter hardiness to survive the cold Virginia winters. Precipitation and temperature data for the 1993-1994 growing season are presented in Figs. 2 and 3. Durum yields were highest in Orange County, in the northern piedmont plateau, where the average yield was 33% less than the average soft red winter wheat yield at the same location (Table 6). Seven durum lines at this location produced yields that were not different ($P>0.05$) from the average soft red winter wheat yield, which was 5052 kg/ha (75 bu/acre). A line from Arizona, BZ8W92-15, the top yielding durum at this location, yielded more grain than four of the five soft red winter wheat checks, and only 8% less than the highest yielding soft red winter wheat line (FFR 555W).

The gap between durum and soft red winter wheat yields was greater in Shenandoah County, in the northern ridge and valley region. On average, the durum yield in Shenandoah County was 40% less than the soft red winter wheat yield (Table 7). The highest durum yield at this location was produced by the French line OR3910085, with a mean yield 21% less than that of the top performing soft red winter wheat (Pioneer 2548). Although the gap between the two classes of wheat appeared to be greater at this location than in Orange County, ten of the durum

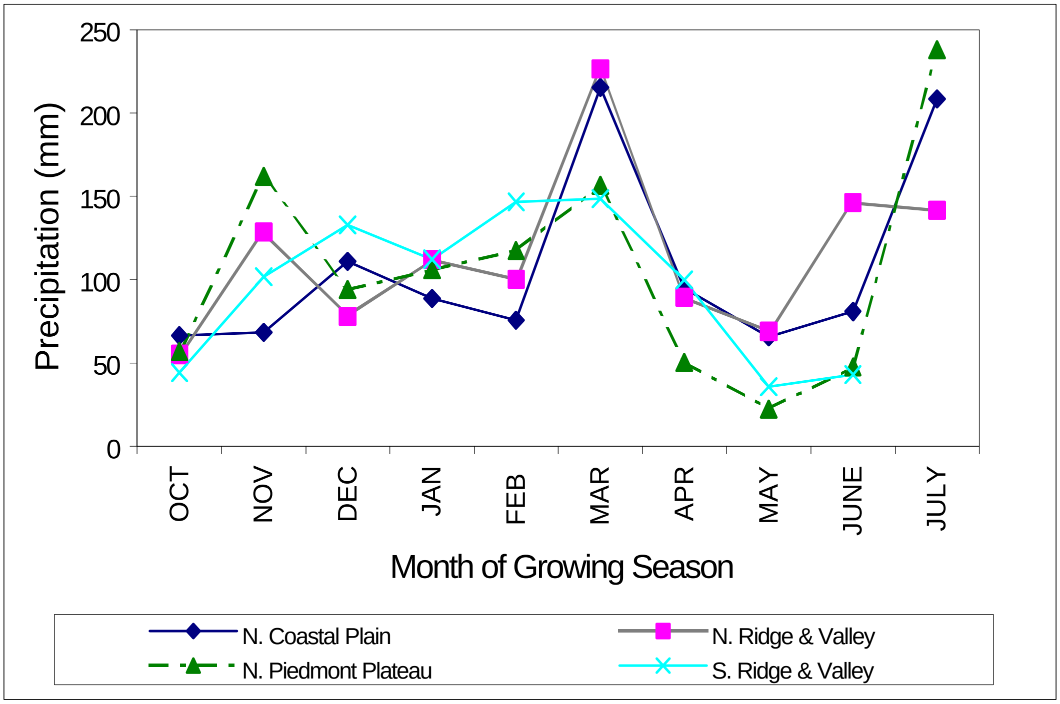


Fig. 2. 1993-1994 Precipitation at the sites of durum field trials.
(Dept. of Commerce, 1993-1994)

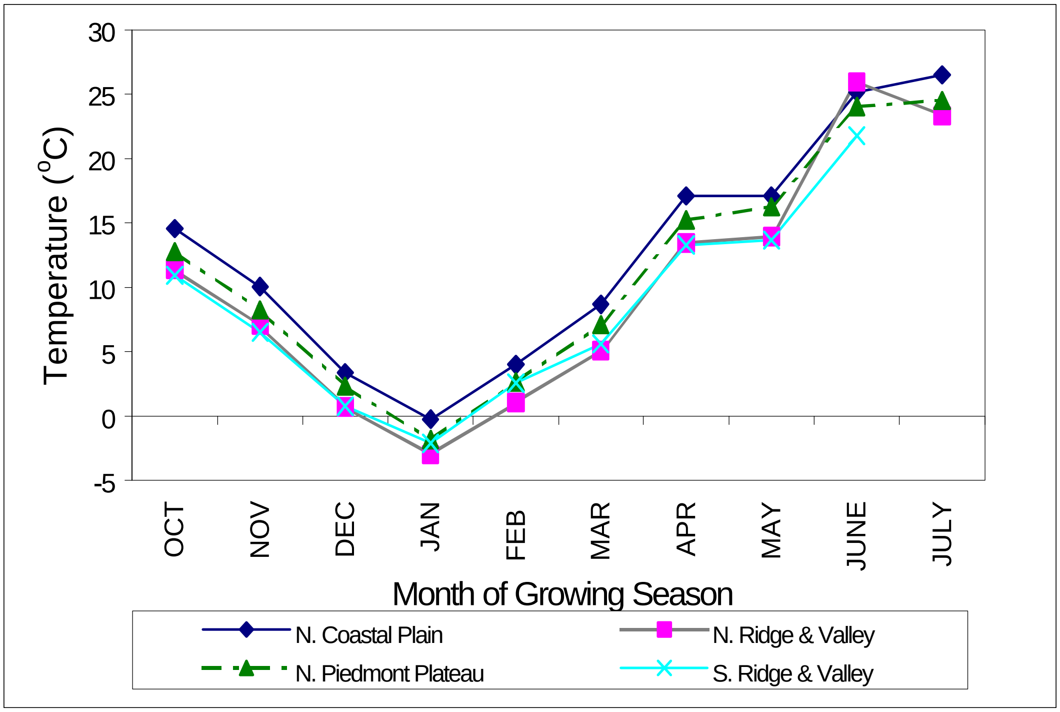


Fig. 3. 1993-1994 Temperature at the sites of durum field trials.
(Dept. of Commerce, 1993-1994)

Table 6. Average grain yield and test weight of durum grown in Orange County, VA (northern piedmont plateau): 1993-1994.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**	**Rank**[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	5958	76.7	31	TOURUS-1	3427	77.6
2	BZ8W92-15	5532	78.1	32	OR3910084	3404	75.8
3	PIONEER 2548[2]	5196	77.9	33	BZ8W92-7	3270	78.1
4	WAKEFIELD[2]	5106	77.8	34	BZ8W90-33	3270	76.7
5	OR3880181	4479	78.6	35	BZ8W92-4	3248	75.6
6	MASSEY[2]	4479	77.2	36	BZ8W92-20	3225	76.0
7	COKER 9803[2]	4479	78.6	37	OR3910258	3203	81.1
8	BZ8W92-6	4255	76.7	38	BZ8W91-4	3203	74.3
9	OR3880152	4233	80.1	39	OR3880015	3158	77.6
10	BZ8W92-9	4211	76.4	40	BASA	3113	78.3
11	OR3910214	4188	78.8	41	BZ8W92-22	3091	76.4
12	BZ8W92-10	4166	79.1	42	BZ8W92-11	3046	77.6
13	OR916121	4031	77.3	43	BZ8W92-12	3024	74.7
14	OR3910085	3964	76.9	44	ELBURZ-1	2979	78.9
15	OR3880158	3964	79.8	45	BZ8W92-19	2979	75.5
16	BZ8W91-7	3942	77.6	46	BZ8W91-2	2979	72.4
17	OR3910106	3919	75.7	47	BZ8W90-7	2979	80.4
18	MINARET	3740	77.5	48	HAD-6	2934	77.6
19	BZ8W91-8	3718	76.2	49	BZ8W92-18	2889	77.6
20	BZ8W90-27	3718	77.2	50	BZ8W92-1	2889	75.9
21	BZ8W92-2	3695	78.7	51	ELBURZ	2867	78.9
22	BZ8W90-2	3695	78.8	52	BZ8289-6	2844	78.0
23	PANNONDUR	3628	81.4	53	KORALL	2822	79.0
24	THHA	3583	79.8	54	BZ8W92-16	2777	75.9
25	BZ8W92-3	3583	76.1	55	OR3910246	2732	78.2
26	BZ8W92-8	3561	78.8	56	BZ8W92-17	2598	77.5
27	BZ8W90-8	3561	80.1	57	BZ8W92-21	2531	76.7
28	TOMA	3494	78.5	58	BZ8W92-14	2441	75.9
29	BZ8W92-13	3494	76.0	59	BZ8W92-5	2307	76.7
30	BZ8W91-1	3494	77.0	60	BZ8W90-29	1814	79.7
LSD (0.05)		964	1.3				
C.V.		16.9	1.0				
Durum Test Average		3380	77.5				
SRWW Advantage[3]		1664					

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 7. Average grain yield and test weight of durum grown in Shenandoah County, VA (northern ridge and valley): 1993-1994.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**	**Rank[1]**	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	PIONEER 2548[2]	5353	74.2	31	BZ8W92-19	3068	75.2
2	FFR 555W[2]	5308	73.0	32	BZ8289-6	3046	76.2
3	WAKEFIELD[2]	4950	74.6	33	BZ8W91-1	2979	76.6
4	MASSEY[2]	4457	75.9	34	BZ8W92-3	2956	74.0
5	COKER 9803[2]	4412	77.1	35	BZ8W92-1	2956	71.0
6	OR3910085	4255	74.5	36	BZ8W91-2	2912	68.7
7	OR3910106	4143	71.3	37	BZ8W92-11	2889	76.1
8	OR3880181	3852	76.3	38	BZ8W92-5	2867	75.0
9	OR3910084	3785	72.3	39	BZ8W90-33	2844	74.7
10	BZ8W90-27	3718	75.5	40	BZ8W92-7	2844	74.9
11	OR3910214	3695	75.4	41	THHA	2800	77.7
12	OR3880152	3695	77.9	42	BZ8W92-22	2800	73.6
13	BZ8W91-8	3651	73.6	43	BZ8W92-21	2732	74.4
14	TOMA	3628	74.2	44	BZ8W92-18	2710	75.2
15	PANNONDUR	3539	78.9	45	BZ8W92-15	2688	74.9
16	BZ8W92-2	3449	74.6	46	BZ8W92-6	2531	73.5
17	BZ8W92-10	3449	77.4	47	BZ8W92-4	2486	73.4
18	OR3880158	3404	78.7	48	BZ8W92-16	2464	74.5
19	MINARET	3404	74.2	49	BZ8W92-14	2464	73.3
20	OR916121	3382	74.6	50	BZ8W92-13	2441	70.9
21	BZ8W90-8	3337	80.1	51	BZ8W90-7	2419	52.6
22	BZ8W91-7	3270	75.4	52	OR3910258	2150	52.4
23	BZ8W91-4	3225	73.1	53	BZ8W92-17	2105	50.5
24	OR3880015	3203	73.5	54	BZ8W92-9	2016	50.0
25	KORALL	3180	73.9	55	OR3910246	1949	51.0
26	ELBURZ	3180	75.9	56	TOURUS-1	1837	49.6
27	BZ8W90-2	3180	78.4	57	BZ8W90-29	1837	52.2
28	BASA	3180	76.4	58	BZ8W92-12	1792	48.7
29	BZ8W92-8	3113	77.0	59	HAD-6	1725	50.0
30	ELBURZ-1	3091	78.9	60	BZ8W92-20	1635	50.3
LSD (0.05)		1325	28.7				
C.V.		26.4	25.0				
Durum Test Average		2945	70.6				
SRWW Advantage[3]		1951					

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

lines produced yields that were not different ($P>0.05$) from that of the average soft red winter wheat yield, which was 4905 kg/ha (73 bu/acre) (Table 7). Furthermore, yields of both OR3910085 and OR3910106 were not different ($P>0.05$) from the highest yielding soft red winter wheat cultivar (FFR 555W).

Yield differences between soft red winter wheat and durum were broader still in Montgomery County, where the average soft red winter wheat yield advantage was 49% (Table 8). The top yielding durum at this location was a Romanian line, OR3910084. The mean yield of OR3910084 was 32% less than the mean yield of the top yielding soft red winter wheat (Pioneer 2548) at the same location. All of the durum yields in Montgomery County were less ($P<0.05$) than both the top yielding soft red winter wheat and the average soft red winter wheat yield.

Test weight did not differ ($P>0.05$) from region to region in the 1993-1994 growing season, suggesting that the conditions affecting test weight did not differ greatly between regions (Table 9). However, test weights between durum lines varied widely ($P<0.001$). Six lines met the minimum requirement of 77.2 kg/hl (60.0 lb/bu) to be assigned grade U.S. No. 1, and 16 additional lines met the minimum required test weight of 74.6 kg/hl (58.0 lb/bu) for grade U.S. No. 2. The average test weight, from the 1989-1998 Virginia state wheat tests, of the soft red winter wheat line FFR 555W is 73.8 kg/hl (57.3 lb/bu). Since this line is well adapted to Virginia and was grown in all of the durum field trials, it is helpful to consider the performance of this particular line. In the 1993-1994 growing season, the test weight of FFR 555W (73.9 kg/hl) was average, suggesting that the environmental effects on test weight that year were representative of Virginia conditions.

Yield and Test Weight: 1994-1995

Early in the 1994-1995 growing season exceptional disease pressure, aggravated by excessive moisture, destroyed much of the durum crop. Scab (*Fusarium graminearum*), a disease for which there is currently no known resistance in durum cultivars, was the primary pathogen responsible for the extensive damage. At the end of the 1994-1995 growing season, unseasonable rainfall covered most of Virginia, resulting in an excessive amount of preharvest sprouting (Figs. 4 and 5). From June 22 to July 7, a record 29.2 cm (11.5 in) of rain fell in one region alone, Orange County (the northern piedmont plateau), with damp weather and cloud cover for 14 out 16 days. Due to these adverse conditions, grain yields, often less than the seed amount planted,

Table 8. Average grain yield and test weight of durum grown in Montgomery County, VA (southern ridge and valley): 1993-1994.

Rank	Line	Yield (kg/ha)	Test Weight (kg/hl)	Rank[1]	Line	Yield (kg/ha)	Test Weight (kg/hl)
1	PIONEER 2548[2]	7369	71.6	31	OR916121	3583	71.6
2	WAKEFIELD[2]	7010	73.7	32	OR3910106	3561	67.3
3	FFR 555W[2]	6697	71.9	33	BZ8W92-1	3539	71.0
4	MASSEY[2]	6137	74.4	34	TOURUS-1	3516	71.0
5	COKER 9803[2]	6047	75.1	35	BZ8W92-12	3494	69.2
6	OR3910084	5017	71.5	36	OR3880152	3449	75.4
7	BZ8W92-8	4838	74.7	37	BZ8W92-9	3427	70.0
8	BZ8W91-8	4748	71.1	38	BZ8W90-8	3360	74.9
9	BZ8W92-10	4726	74.0	39	BZ8W92-17	3315	73.6
10	BZ8W91-7	4591	69.6	40	BZ8W92-4	3292	71.7
11	OR3880158	4479	76.1	41	OR3880015	3248	69.8
12	MINARET	4457	71.0	42	BZ8W92-16	3225	69.5
13	OR3910214	4435	73.2	43	BZ8W90-33	3225	70.7
14	OR3880181	4435	72.7	44	BZ8289-6	3225	73.2
15	PANNONDUR	4323	75.9	45	BZ8W90-7	3203	75.3
16	BZ8W91-4	4300	68.7	46	THHA	3068	74.4
17	BZ8W92-11	4009	72.4	47	OR3910085	3046	70.8
18	BZ8W92-22	3987	73.0	48	BZ8W92-19	2867	69.2
19	BZ8W92-13	3987	68.8	49	BZ8W92-14	2844	71.6
20	BZ8W92-3	3919	72.7	50	BZ8W92-20	2665	69.6
21	BZ8W91-1	3875	73.5	51	BZ8W92-18	2576	74.0
22	KORALL	3830	73.9	52	BZ8W92-21	2531	71.1
23	BZ8W92-7	3830	74.0	53	TOMA	2464	73.2
24	BZ8W91-2	3807	61.9	54	ELBURZ	2374	73.3
25	BASA	3785	74.1	55	BZ8W92-15	2240	68.5
26	BZ8W92-6	3695	72.7	56	HAD-6	2016	73.1
27	BZ8W90-27	3673	73.7	57	BZ8W92-5	1881	73.4
28	BZ8W92-2	3651	73.0	58	OR3910258	1814	74.7
29	BZ8W90-29	3651	74.7	59	OR3910246	1254	70.3
30	BZ8W90-2	3606	74.4	60	ELBURZ-1	963	72.2
LSD (0.05)		770	1.8				
C.V.		13.0	1.5				
Durum Test Average		3435	72.1				
SRWW Advantage[3]		3217					

[1] Rank according to yield
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 9. Average test weight of durum grown at three locations in Virginia: 1993-1994.

Line	Test Weight (kg/hl)	Line	Test Weight (kg/hl)
PANNONDUR	78.8	MINARET	74.3
BZ8W90-8	78.4	BZ8W91-7	74.3
OR3880158	78.2	BZ8W92-21	74.1
OR3880152	77.7	OR3910085	74.1
THHA	77.2	BZ8W90-33	74.0
BZ8W90-2	77.2	ELBURZ-1	73.9
COKER 9803[1]	77.0	FFR 555W[1]	73.9
BZ8W92-10	76.8	BZ8W92-15	73.9
BZ8W92-8	76.8	OR3880015	73.6
ELBURZ	76.6	BZ8W91-8	73.6
BASA	76.3	BZ8W92-14	73.6
MASSEY[1]	75.8	BZ8W92-4	73.6
OR3880181	75.8	BZ8W92-16	73.4
BZ8289-6	75.8	BZ8W92-19	73.4
OR3910214	75.8	OR3910084	73.2
BZ8W91-1	75.7	BZ8W92-1	72.6
BZ8W92-7	75.7	BZ8W91-4	72.1
BZ8W92-18	75.7	BZ8W92-13	71.9
KORALL	75.5	OR3910106	71.4
BZ8W90-27	75.4	BZ8W90-7	69.4
BZ8W92-2	75.4	OR3910258	69.4
WAKEFIELD[1]	75.4	BZ8W90-29	68.9
BZ8W92-11	75.4	BZ8W91-2	67.7
TOMA	75.3	BZ8W92-17	67.2
BZ8W92-5	75.0	HAD-6	66.9
PIONEER 2548[1]	74.5	OR3910246	66.5
OR916121	74.5	TOURUS-1	66.2
BZ8W92-6	74.4	BZ8W92-9	65.5
BZ8W92-22	74.3	BZ8W92-20	65.4
BZ8W92-3	74.3	BZ8W92-12	64.2
LSD (0.05)	9.5		
C.V.	14.0		
Durum Average	73.4		

[1] Soft red winter wheat

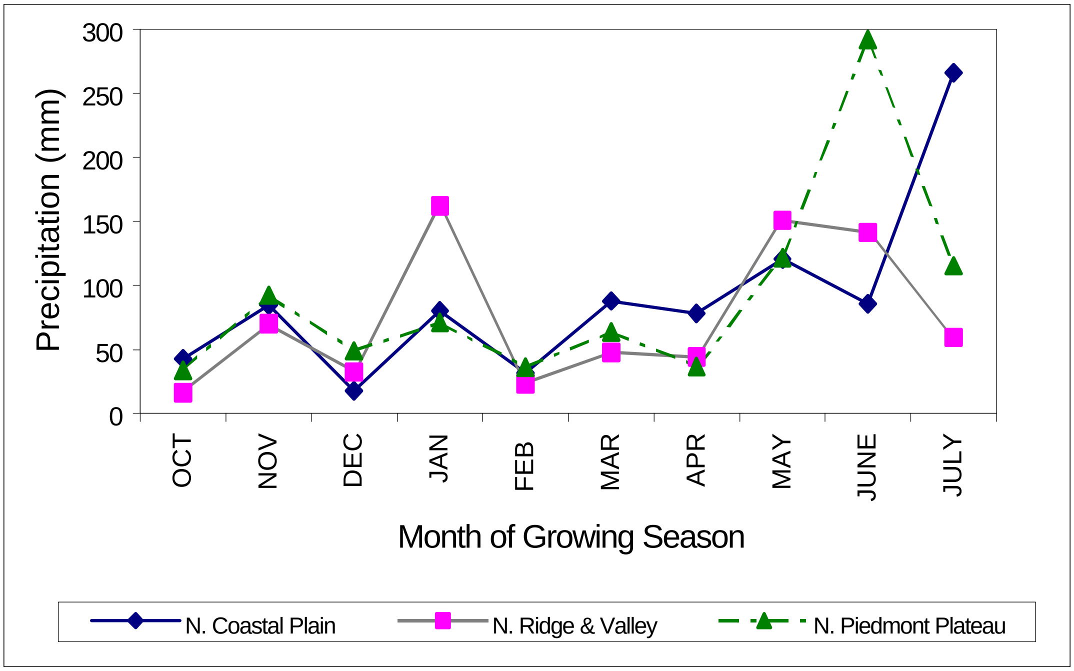


Fig. 4. 1994-1995 Precipitation at the sites of durum field trials.
(Dept. of Commerce, 1994-1995)

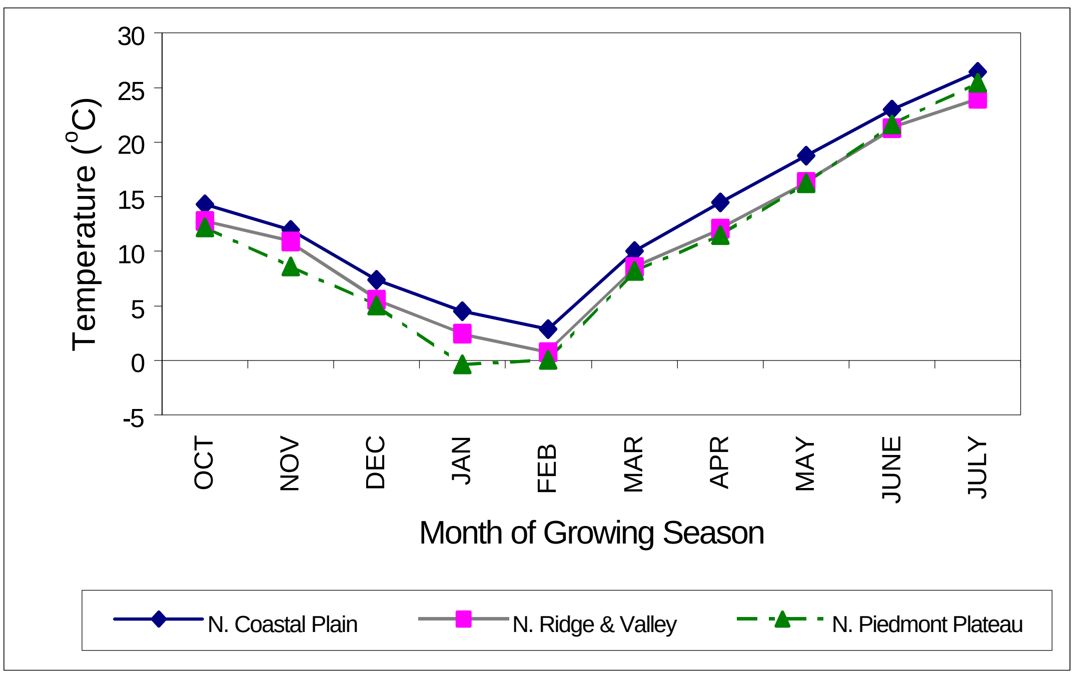


Fig. 5. 1994-1995 Temperature at the sites of durum field trials.
(Dept. of Commerce, 1994-1995)

and quality were severely reduced. As a result, data from the 1994-1995 field trials were not available and/or suitable for analysis.

Yield and Test Weight: 1995-1996

As in the 1993-1994 growing season, durum yields were again highest in Orange County, in the northern piedmont plateau. While the average durum yield was 35% less than the average soft red winter wheat yield, several of the durum lines proved to be competitive with the soft red winter wheat (Table 10). Yields of four durum lines, Odessa #65, Odessa #63, Odessa #69 and BZ8W91-8, did not differ ($P>0.05$) from the two lowest yielding soft red winter wheat lines, Massey and Coker 9835. The mean yield of the highest yielding durum line, Odessa #65, was not significantly different from mean yields of Massey, Coker 9835 or Wakefield, three of the five soft red winter wheat lines tested. Odessa #65 yielded 2093 kg/ha (31 bu/acre) less than the best yielding soft red winter wheat line (FFR 555W) at Orange, and 1008 kg/ha (15 bu/acre) less than the average soft red winter wheat yield.

The average winter durum yield in Montgomery County was 3842 kg/ha (51 bu/acre), which was 43% less than the average soft red winter wheat yield (Table 11). As at the Orange County location, Odessa #65 was the best yielding durum line. The mean yield of Odessa #65 was not different ($P>0.05$) from the mean yield of Massey, the lowest yielding soft red winter wheat line tested. Odessa #65 yielded 2137 kg/ha (32 bu/acre) less than the best yielding soft red winter wheat line (Wakefield), and 1488 kg/ha (22 bu/acre) less than the average soft red winter wheat. Yields of all other durum lines at this location were less ($P<0.05$) than the yields of the soft red winter wheat lines.

For the 1995-1996 growing season, the average durum yield was the lowest at the Clarke County location, in the northern ridge and valley region. The mean soft red winter wheat yield was 54% more than the average durum yield (Table 12). A line from Romania, OR3910214, the top yielding durum line in this region, produced 2499 kg/ha (37 bu/acre) less than the best yielding soft red winter wheat (Wakefield) and 1681 kg/ha (25 bu/acre) less than the average soft red winter wheat yield. All of the lines at this location produced yields less ($P<0.05$) than the soft red winter wheat yields (Table 12).

In the 1995-1996 growing seasons, both region and durum line had a great effect ($P<0.0001$) on test weight. None of the durum lines met the minimum test weight (77.2 kg/hl)

Table 10. Average grain yield and test weight of durum grown in Orange County, VA (northern piedmont plateau): 1995-1996.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	8515	74.0
2	PIONEER 2548[2]	8086	74.3
3	COKER 9803[2]	7463	76.7
4	WAKEFIELD[2]	7265	74.2
5	MASSEY[2]	7016	74.5
6	ODESSA #65	6422	74.1
7	COKER 9835[2]	6235	73.1
8	BZ8W91-8	6059	69.6
9	ODESSA #63	6027	73.8
10	ODESSA #69	5988	74.3
11	ODESSA #67	5810	66.7
12	ODESSA #64	5577	72.3
13	OR3910214	5513	73.5
14	OR3910084	5372	68.7
15	KORALL	5187	72.8
16	OR3910085	5115	72.4
17	BASA	4975	73.3
18	OR3880181	4962	67.2
19	OR3880152	4938	67.6
20	PANNONDUR	4844	75.3
21	OR916121	4841	70.0
22	ODESSA #66	4781	74.4
23	BZ8W90-27	4707	67.1
24	BZ90-7	4535	74.0
25	MINARET	4505	67.9
26	OR3880158	4490	68.3
27	BZ8W92-8	4461	71.0
28	BZ8W92-2	4441	69.6
29	OR3910106	4419	70.0
30	BZ8W91-4	4393	70.5
31	BZ8W92-10	4382	72.6
32	BZ8W91-1	4214	70.8
33	BZ8W92-3	4208	70.4
34	BZ8W92-9	4188	66.8
35	BZ8W91-7	4035	68.7
36	BZ92-13	3830	64.3
37	BZ8W91-2	3763	65.1
38	BZ8W92-6	3615	68.1
LSD (0.05)		1060	2.3
C.V.		14.4	2.3
Durum Test Average		4831	71.0
SRWW Yield Advantage[3]		2599	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 11. Average grain yield and test weight of durum grown in Montgomery County, VA (southern ridge and valley): 1995-1996.

Rank[1]	Line	Yield (kg/ha)	Test Weight (kg/hl)
1	WAKEFIELD[2]	6634	69.9
2	PIONEER 2548[2]	6610	69.3
3	COKER 9835[2]	6251	69.0
4	FFR 555W[2]	6038	69.0
5	COKER 9803[2]	5384	71.7
6	MASSEY[2]	4990	71.5
7	ODESSA #65	4497	69.5
8	ODESSA #69	4386	67.7
9	ODESSA #64	4372	71.1
10	ODESSA #63	4262	68.3
11	ODESSA #67	4249	69.0
12	OR3880158	4030	69.6
13	KORALL	4029	71.9
14	ODESSA #66	3854	70.6
15	OR3910214	3720	67.0
16	OR3880152	3717	70.2
17	PANNONDUR	3708	74.7
18	BZ8W90-27	3573	70.1
19	BASA	3550	71.7
20	MINARET	3513	66.7
21	OR3910106	3428	62.3
22	BZ8W92-2	3396	66.7
23	OR3910084	3305	62.8
24	BZ8W91-8	3298	63.0
25	OR3910085	3293	66.4
26	BZ8W91-1	3285	65.5
27	BZ8W92-3	3276	68.1
28	OR916121	3243	68.6
29	BZ8W92-9	3207	63.9
30	BZ8W91-4	3206	63.9
31	OR3880181	3201	64.7
32	BZ8W92-10	3199	64.6
33	BZ8W92-8	3175	68.5
34	BZ8W92-6	2764	67.3
35	BZ92-13	2540	63.9
36	BZ90-7	2537	72.3
37	BZ8W91-7	2228	59.9
38	BZ8W91-2	2042	56.8
LSD (0.05)		589	3.9
C.V.		10.9	4.1
Durum Test Average		3842	67.6
SRWW Advantage[3]		2143	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 12. Average grain yield and test weight of durum grown in Clarke County, VA (northern ridge and valley): 1995-1996.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	WAKEFIELD[2]	5847	72.8
2	PIONEER 2548[2]	5468	70.5
3	FFR 555W[2]	5140	71.3
4	MASSEY[2]	4986	73.2
5	COKER 9835[2]	4461	68.6
6	COKER 9803[2]	4270	75.0
7	OR3910214	3348	64.5
8	ODESSA #65	2916	67.2
9	ODESSA #67	2873	65.3
10	MINARET	2813	65.7
11	ODESSA #69	2796	65.8
12	BASA	2771	63.8
13	OR3880152	2743	61.3
14	BZ8W91-8	2713	59.6
15	KORALL	2697	65.1
16	BZ8W90-27	2678	63.2
17	ODESSA #63	2598	67.7
18	OR3910084	2522	63.3
19	OR3880158	2447	61.6
20	ODESSA #66	2427	67.0
21	BZ8W92-3	2382	63.2
22	ODESSA #64	2311	64.2
23	BZ8W92-6	2295	62.5
24	BZ8W92-2	2288	58.8
25	BZ8W91-4	2271	61.8
26	BZ90-7	2187	68.0
27	OR916121	2163	57.8
28	OR3910085	2079	62.7
29	OR3910106	2070	56.4
30	BZ92-13	2024	59.6
31	PANNONDUR	1745	64.4
32	BZ8W91-1	1732	60.1
33	BZ8W92-9	1712	62.5
34	BZ8W91-7	1660	59.7
35	BZ8W92-10	1632	60.1
36	OR3880181	1611	58.2
37	BZ8W91-2	1592	54.2
38	BZ8W92-8	1105	57.3
LSD (0.05)		825	5.1
C.V.		18.7	5.0
Durum Test Average		2288	63.8
SRWW Yield Advantage[3]		2741	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

requirement necessary for grade U.S. No. 1 (Tables 10-12). The highest average durum test weight was produced in Orange, while the lowest average test weight this growing season was produced in Clarke County. Only Pannondur, at two locations, Orange County and Montgomery County, met the minimum test weight (74.6 kg/hl) requirement for grade U.S. No. 2. Similar to the durum lines, the highest test weight (74.0 kg/hl) for the soft red winter wheat line FFR 555W was produced in Orange County, which was very close to its 10 year average test weight (73.8 kg/hl). The test weight of FFR 555W was below average at the other locations, with its lowest test weight resulting from Clarke County.

Yield and Test Weight: 1996-1997

As in previous years, durum wheat yields were the highest at the Orange County location. At this location, the average durum wheat yield was only 317 kg/ha (5 bu/acre), or 5%, less than the average soft red winter wheat yield (Table 13). Several durum lines yielded as much as, or more than, the five soft red winter wheat lines grown in Orange County. Yields of thirteen durum lines were not different (P>0.05) from the highest yielding soft red winter wheat (FFR 555W). The top two durum lines, Odessa #65 and Odessa #69, yielded 6659 kg/ha (99 bu/acre) and 6644 kg/ha (99 bu/acre). Therefore, yields were only 271 kg/ha (4 bu/acre) and 286 kg/ha (4 bu/acre) less than the highest yielding soft red winter wheat, FFR 555W.

At the southern ridge and valley location, Montgomery County, one durum line, Odessa #63, actually yielded 3% more than the average soft red winter wheat yield (Table 14). Two durum lines produced yields that were not different (P>0.05) from that of the highest yielding soft red winter wheat at this location. Yields of Odessa #63 and Odessa #69 were only 3% and 10%, respectively, less than that of Coker 9803. Overall, however, durum yields in the southern ridge and valley region were 26% less than soft red winter wheat yields.

While the average durum yield in Richmond County was not as high as at either the Orange County or Montgomery County locations, several durum lines in Richmond County out-yielded the soft red winter wheat. Three durum lines, BZ8W92-10, BZ8W92-2, and Odessa #65, yielded more grain than the top soft red winter wheat line, Coker 9835, and eight durum lines produced yields greater than the average soft red winter wheat yield (Table 15). Overall, the yields of eleven durum lines were not different (P>0.05) from the yield of Coker 9835.

Table 13. Average grain yield and test weight of durum grown in Orange County, VA (northern piedmont plateau): 1996-1997.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	6930	71.6
2	ODESSA #65	6659	76.5
3	ODESSA #69	6644	76.5
4	PIONEER 2548[2]	6625	74.1
5	BZ8W91-8	6578	74.0
6	OR3910084	6491	74.5
7	OR3910085	6298	76.8
8	OR3880152	6268	77.1
9	ODESSA #67	6219	75.6
10	ODESSA #66	6167	77.5
11	OR3880181	6123	74.7
12	OR3910106	6119	72.8
13	ODESSA #63	6095	76.5
14	BZ8W92-6	6085	75.1
15	BZ8W92-2	6052	74.6
16	COKER 9835[2]	6039	72.6
17	OR3880158	5939	77.5
18	BZ8W91-4	5935	72.4
19	MINARET	5843	74.7
20	WAKEFIELD[2]	5811	74.2
21	MASSEY[2]	5753	75.4
22	COKER 9803[2]	5751	75.9
23	BZ8W92-3	5734	74.5
24	OR3910214	5688	75.2
25	BZ8W92-9	5630	71.6
26	BZ8W91-1	5626	75.4
27	PANNONDUR	5625	76.7
28	BASA	5579	75.5
29	BZ8W92-10	5578	75.3
30	ODESSA #64	5551	77.9
31	BZ90-7	5501	77.6
32	BZ8W90-27	5491	76.7
33	BZ8W91-7	5317	73.2
34	OR916121	5308	74.1
35	BZ8W91-2	5285	67.0
36	KORALL	5219	77.5
37	BZ92-13	5190	71.1
38	BZ8W92-8	4975	75.1
LSD (0.05)		1025	1.9
C.V.		10.7	11.5
Durum Test Average		5835	74.9
SRWW Yield Advantage[3]		317	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 14. Average grain yield and test weight of durum grown in Montgomery County, VA (southern ridge and valley): 1996-1997.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	COKER 9803[2]	6410	74.3
2	FFR 555W[2]	6339	71.7
3	ODESSA #63	6156	72.2
4	PIONEER 2548[2]	6110	70.8
5	WAKEFIELD[2]	5929	71.0
6	ODESSA #69	5701	71.0
7	MASSEY[2]	5580	71.3
8	COKER 9835[2]	5573	69.2
9	MINARET	5508	70.2
10	ODESSA #64	5444	71.3
11	OR3880152	5321	70.5
12	OR3910214	5251	71.8
13	BASA	5213	73.2
14	PANNONDUR	5155	73.7
15	ODESSA #66	5149	72.6
16	ODESSA #65	5063	70.3
17	ODESSA #67	5022	67.7
18	OR3880158	4987	71.0
19	OR3910084	4847	69.0
20	BZ8W92-6	4845	69.8
21	OR916121	4709	69.4
22	BZ8W91-8	4603	67.1
23	OR3880181	4433	69.5
24	BZ8W92-10	4397	71.4
25	OR3910085	4133	68.3
26	BZ8W91-1	4072	65.4
27	BZ8W92-9	4057	65.8
28	KORALL	4045	71.7
29	OR3910106	3992	67.3
30	BZ8W90-27	3885	66.2
31	BZ8W91-4	3750	63.8
32	BZ90-7	3711	72.3
33	BZ8W91-7	3511	67.1
34	BZ92-13	3388	62.0
35	BZ8W92-2	3358	67.1
36	BZ8W92-8	3119	66.8
37	BZ8W91-2	2778	57.7
38	BZ8W92-3	2758	63.8
LSD (0.05)		953	3.5
C.V.		12.9	3.1
Durum Test Average		4449	69.1
SRWW Yield Advantage[3]		1541	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 15. Average grain yield and test weight of durum grown in Richmond County, VA (northern coastal plain): 1996-1997.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	BZ8W92-10	5324	80.2
2	BZ8W92-2	5169	78.2
3	ODESSA #65	5141	81.1
4	COKER 9835[2]	5132	79.4
5	OR3880181	5098	80.1
6	ODESSA #67	5094	76.5
7	ODESSA #63	5004	81.3
8	ODESSA #69	4966	80.6
9	OR3910084	4962	78.4
10	WAKEFIELD[2]	4895	78.2
11	FFR 555W[2]	4894	79.6
12	MASSEY[2]	4766	79.0
13	BZ8W92-8	4765	80.7
14	COKER 9803[2]	4699	81.8
15	ODESSA #66	4617	81.0
16	PANNONDUR	4571	83.2
17	BZ8W91-8	4550	78.0
18	OR3910085	4490	80.2
19	BZ8W90-27	4441	78.2
20	PIONEER 2548[2]	4336	79.9
21	OR3880158	3963	75.3
22	OR3880152	3908	76.7
23	BZ8W91-4	3806	75.2
24	BZ90-7	3772	80.1
25	MINARET	3733	78.1
26	ODESSA #64	3732	78.3
27	BZ8W92-3	3686	79.2
28	KORALL	3614	78.7
29	OR3910214	3588	79.7
30	BASA	3142	80.1
31	BZ8W92-9	3095	75.5
32	OR3910106	3070	77.0
33	OR916121	3016	76.1
34	BZ8W92-6	2985	77.5
35	BZ92-13	2840	73.1
36	BZ8W91-1	2778	77.5
37	BZ8W91-7	2622	77.5
38	BZ8W91-2	2248	72.6
LSD (0.05)		627	1.6
C.V.		9.4	1.3
Durum Test Average		3993	78.5
SRWW Yield Advantage[3]		794	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 16. Average grain yield and test weight of durum grown in Clarke County, VA (northern ridge and valley): 1996-1997.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	6169	71.6
2	COKER 9803[2]	5524	76.4
3	COKER 9835[2]	5511	75.4
4	PIONEER 2548[2]	5424	75.4
5	WAKEFIELD[2]	5401	75.0
6	MASSEY[2]	5133	71.9
7	ODESSA #65	4561	77.2
8	ODESSA #69	4449	70.6
9	BZ8W91-1	4330	75.8
10	BZ8W92-8	4277	78.4
11	OR3880158	4128	73.2
12	KORALL	3994	76.6
13	BZ8W92-10	3929	64.0
14	BZ92-13	3900	72.3
15	ODESSA #67	3820	71.9
16	OR3880152	3667	67.3
17	ODESSA #63	3647	73.5
18	BZ8W91-7	3642	74.2
19	PANNONDUR	3595	76.8
20	BZ8W92-9	3522	75.1
21	ODESSA #66	3511	75.4
22	OR3910084	3452	65.3
23	OR3880181	3430	76.7
24	BZ8W92-6	3422	70.2
25	BZ8W91-8	3386	75.1
26	ODESSA #64	3343	75.9
27	BZ8W91-2	3201	70.4
28	OR3910214	3078	72.8
29	BZ8W90-27	3075	74.3
30	BZ8W92-2	2940	74.9
31	BZ90-7	2896	70.8
32	OR916121	2742	71.5
33	BZ8W91-4	2719	74.0
34	OR3910085	2706	72.8
35	BASA	2634	73.0
36	BZ8W92-3	2445	70.1
37	MINARET	2287	73.4
38	OR3910106	2048	65.7
LSD (0.05)		1213	8.3
C.V.		20.3	7.0
Durum Test Average		3399	73.0
SRWW Yield Advantage[3]		2128	

[1] Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

For the 1996-1997 growing season, durum wheat yields were the lowest at the Clarke County location in the northern ridge and valley. Average soft red winter wheat yield was 39% greater than the average durum wheat yield (Table 16). However, the yields of four durum lines (Odessa #65, Odessa #69, BZ8W91-1, and BZ8W92-8) were not different ($P>0.05$) from four of the five tested soft red winter lines. The yield of the top soft red winter wheat line, FFR 555W, was different from all of the durum lines ($P<0.05$) in Clarke County.

Region was again highly significant ($P<0.0001$) in regard to test weight for the 1996-1997 season. The effect of line was highly significant ($P<0.0001$) in all regions, except in the northern ridge and valley at the Clarke County location (Tables 13-16). The test weights in Clarke County were all around 73.0 kg/hl (56.7 lb/bu). The test weight (77.2 kg/hl) requirement for grade U.S. No. 1 was met in only two counties, Richmond County and Orange County. A test weight of 77.2 kg/hl (60.0 lb/bu) or greater was met by 24 durum lines in Richmond County and 5 durum lines in Orange County. The highest average test weights were produced in Richmond County, while the lowest were found in Montgomery County. In addition, the minimum necessary test weight (74.6 kg/hl) for grade U.S. No. 2 was met by six lines in Richmond County and 17 lines in Orange County. While the durum test weights tended to be higher during the 1996-1997 growing season, the test weight of FFR 555W was less than its 1989-1998 average of 73.8 kg/hl at most locations, despite this line’s high yields. The test weight of FFR 555W (79.6 kg/hl) was well above average in Richmond County.

Yield and Test Weight: 1997-1998

Although the field trials in 1997-1998 called for two different disease control practices, as-needed and restricted fungicide treatments, all of the plots in both Montgomery County and Orange County received the same fungicide treatment regime, as in previous years. Durum lines grown at the Richmond County, Suffolk and Shenandoah County locations, however, were subject to both disease control practices. For the 1997-1998 growing season, restricting the number of fungicide applications affected ($P<0.05$) yields and test weights at both the Suffolk and Shenandoah County locations. However, the difference in disease control measures did not affect either yields or test weights in Richmond County. For all regions and disease control measures, the yield of the soft red winter wheat line FFR 555W was consistently higher ($P<0.05$)

than the average durum yields. In all three counties where different disease control measures were practiced, the treatment affected ($P<0.05$) test weight.

The highest average durum wheat yields were observed in Orange County and Shenandoah County. In Orange County, average durum yields were 43% less than that of FFR 555W, the only soft red winter wheat check grown in 1997-1998 (Table 17). The highest yielding durum line, Odessa #66, produced grain yields 28% less than the soft red winter wheat. The mean durum yield at the Nottoway County location, was 53% less than the soft red winter wheat yield (Appendix B). The highest yielding durum line at this location was OR3910084, which produced grain yields 42% less than the soft red winter wheat check (Appendix B). The soft red winter wheat check held a 54% advantage over the average durum yield in Montgomery County (Table 19). The top yielding durum line at this location, Odessa #66, produced grain yields that were 37% less than the soft red winter wheat.

At Suffolk, the difference in yield between soft red winter wheat and durum wheat, grown under the apply-as-needed fungicide treatment, was only slightly better than at Montgomery County, with a 49% yield advantage for soft red winter wheat (Table 20). OR3910214, the best yielding durum line at this location, produced 36% less grain than FFR 555W. Under restricted fungicide treatment, the yield advantage of the soft red winter wheat check in the southern coastal plain location was 62% more than that of the average durum line (Table 20). Under these management practices, Odessa #66 was the best producing durum line, with a mean yield 37% less than the soft red winter wheat yield.

In Shenandoah County, under the same disease control practices as used in previous years, FFR 555W yielded 51% more than the mean durum wheat yield (Table 18). The highest yielding durum line in this region, Korall, a later maturing line, produced grain yields 36% less than the soft red winter wheat. Under the restricted fungicide treatment, the grain yield of the soft red winter wheat check was 54% higher than the average durum line and 22% more than the highest yielding durum line, Korall (Table 18).

As mentioned previously, differences in disease control practices did not affect ($P>0.05$) yields in Richmond County. The average durum wheat yield was 54% less than the soft red winter wheat yield (Table 21). Several of the newly acquired lines performed well, with five of the lines producing the highest durum yields in this region. In fact, the highest yielding durum line in this region, Amadur, produced only 14% less than the soft red winter wheat. Of the 19

Table 17. Average grain yield and test weight of durum grown in Orange County, VA (northern piedmont plateau): 1997-1998.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	6494	72.4
2	ODESSA #66	4712	71.8
3	BZ8W91-8	4315	67.2
4	ODESSA #69	4213	70.2
5	ODESSA #65	4177	69.6
6	PANNONDUR	4140	72.9
7	OR3910084	4082	65.4
8	OR3910214	4019	67.7
9	ODESSA #63	4013	71.3
10	KORALL	4011	69.3
11	BZ8W90-27	3673	70.4
12	MINARET	3669	66.2
13	OR3880181	3499	62.9
14	OR3910085	3487	66.2
15	OR3880152	3472	69.4
16	OR3880158	3334	69.7
17	BASA	3300	68.2
18	BZ8W92-8	2918	66.7
19	BZ8W92-10	2802	65.5
20	BZ8W92-2	2210	66.8
LSD (0.05)		685	4.0
C.V.		10.9	3.5
Durum Test Average		3686	68.3
SRWW Yield Advantage[3]		2808	

[1]Rank according to yield.
[2] Soft red winter wheat
[3](SRWW Test Average)-(Durum Test Average)

Table 18. Average grain yield and test weight of durum grown in Shenandoah County, VA (northern ridge and valley): 1997-1998.

Rank[1]	Line	Yield (kg/ha)			Test Weight (kg/hl)		
		As Needed Fungicide	Restricted Fungicide	Difference	As Needed Fungicide	Restricted Fungicide	Difference
1	FFR 555W[2]	7609	6303	1306	71.4	70.6	0.8
2	KORALL	5143	4911	232	73.4	72.4	1.0
3	OR3910084	4881	3966	915	64.7	65.1	-0.4
4	BASA	4630	3214	1416	69.1	64.4	4.7
5	MINARET	4505	3563	942	68.0	66.5	1.5
6	BZ8W91-8	4237	2936	1301	66.3	63.6	2.7
7	ODESSA #66	4043	3768	275	64.3	67.2	-2.9
8	ODESSA #63	4031	3203	828	64.9	63.7	1.2
9	ODESSA #69	3812	3148	670	64.8	62.8	2.0
10	BZ8W92-2	3806	3001	805	67.4	64.6	2.8
11	BZ8W92-10	3660	1914	1746	66.7	58.0	8.7
12	BZ8W92-8	3645	1765	1880	66.8	57.8	9.0
13	ODESSA #65	3587	3058	529	64.0	62.5	1.5
14	BZ8W90-27	3502	2686	816	68.0	65.7	2.3
15	OR3910214	3307	3561	-254	64.1	64.0	0.1
16	OR3880158	3246	1871	1375	68.5	63.7	4.8
17	OR3880152	3177	1908	1269	67.1	60.6	6.5
18	OR3910085	3110	2179	931	65.3	63.4	1.9
19	PANNONDUR	2409	2329	80	63.7	61.5	2.2
20	OR3880181	1593	1346	247	57.2	54.7	2.5
LSD (0.05)		423	423		1.7	1.7	
C.V.		10.6	10.6		2.2	2.2	
Durum Test Average		3701	2859		66.3	63.6	
SRWW Yield Advantage[3]		3908	3443				

[1]Rank according to as needed yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 19. Average grain yield and test weight of durum grown in Montgomery County, VA (southern ridge and valley): 1997-1998.

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	5630	67.2
2	ODESSA #66	3556	67.3
3	ODESSA #65	3354	65.9
4	ODESSA #63	3204	63.4
5	ODESSA #69	3189	64.9
6	KORALL	3054	69.8
7	PANNONDUR	3052	70.9
8	OR3910214	2801	62.8
9	BZ8W91-8	2778	63.7
10	OR3880181	2773	62.0
11	OR3910084	2722	62.8
12	BASA	2627	68.0
13	MINARET	2446	62.7
14	OR3910085	2386	59.8
15	BZ8W92-8	2305	62.7
16	OR3880158	2175	66.0
17	OR3880152	2043	65.3
18	BZ8W92-10	1996	60.5
19	BZ8W90-27	1811	60.6
20	BZ8W92-2	1525	59.5
LSD (0.05)		477	2.8
C.V.		10.4	2.7
Durum Test Average		2621	64.3
SRWW Yield Advantage[3]		3009	

[1]Rank according to yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 20. Average grain yield and test weight of durum grown in Suffolk, VA (southern coastal plain): 1997-1998.

Rank[1]	Line	Yield (kg/ha)			Test Weight (kg/hl)		
		As Needed Fungicide	**Restricted Fungicide**	**Difference**	**As Needed Fungicide**	**Restricted Fungicide**	**Difference**
1	FFR 555W[2]	4878	4005	873	62.0	70.7	-8.7
2	OR3910214	3149	2229	920	71.0	65.4	5.6
3	ODESSA #69	3133	1375	1758	68.8	65.1	3.7
4	ODESSA #66	3128	2526	6020	72.5	70.6	1.9
5	PANNONDUR	3029	1968	1061	73.8	67.6	6.2
6	ODESSA #63	2960	1971	989	70.7	65.9	4.8
7	OR3910085	2918	1546	1372	66.1	54.6	11.5
8	ODESSA #65	2814	2118	696	71.9	66.3	5.6
9	MINARET	2803	1566	1237	68.8	59.0	9.8
10	OR3910084	2790	2082	708	67.3	62.6	4.7
11	OR3880181	2732	1098	1634	70.0	59.8	10.2
12	BASA	2327	1372	955	69.4	63.1	6.3
13	OR3880158	2299	1267	1032	67.8	64.0	3.8
14	BZ8W91-8	2290	1026	1264	67.8	58.6	9.2
15	OR3880152	2052	1448	604	64.4	65.7	-1.3
16	BZ8W92-8	2016	1026	990	68.8	59.2	9.6
17	BZ8W90-27	1814	1057	757	66.0	57.8	8.2
18	BZ8W92-10	1706	942	764	65.5	61.4	4.1
19	BZ8W92-2	1606	742	864	66.8	59.7	7.1
20	KORALL	1479	909	570	66.5	64.3	2.2
LSD (0.05)		417	417		3.0	3.0	
C.V.		16.9	16.9		3.8	3.8	
Durum Test Average		2476	1488		68.3	63.1	
SRWW Yield Advantage[3]		2402	2517				

[1]Rank according to as needed yield.
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 21. Average grain yield of durum grown in Richmond County, VA (northern coastal plain): 1997-1998.

Rank	Line	Yield (kg/ha)	Rank	Line	Yield (kg/ha)
1	FFR 555W[2]	4663	21	OR3880158	1857
2	AMADUR	3999	22	OR3910085	1840
3	ALIDUR	3360	23	OR949024	1800
4	OREXP#13	3360	24	BZ8W91-8	1758
5	AGEDUR	3244	25	KORALL	1719
6	OREXP#12	2943	26	BZ8W92-8	1653
7	ODESSA #66	2821	27	OR948927	1659
8	OR3880181	2724	28	OREXP#11	1698
9	OR3910214	2598	29	BASA	1638
10	ODESSA #65	2561	30	BZ8W92-10	1615
11	OR3910084	2548	31	OR3880152	1574
12	ODESSA #69	2480	32	OREXP #10	1523
13	RODUR	2497	33	BZ8W92-2	1440
14	OR948763	2396	34	MINARET	1379
15	ODESSA #63	2336	35	OR936773	1409
16	OR948612	2256	36	OR948578	1349
17	PANNONDUR	2200	37	BZ8W90-27	1256
18	ACADUR	2173	38	OR3950055	1015
19	OREXP#14	2056	39	OR3920036	959
20	PANDUR	2045	40	OR948948	616

LSD (0.05)	437
C.V.	12.3
Durum Average	2128
SRWW Yield Advantage[3]	2535

[1]Rank according to yield
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

lines grown at all locations, Odessa #66 produced the most grain in the northern coastal plain, but was 40% less than soft red winter wheat.

The highest average durum test weight was produced in Orange County, while the lowest average durum test weight grown was produced at Montgomery County (Tables 17 and 19). None of the lines at any of the locations met the minimum test weight necessary for either grade U.S. No. 1 (77.2 kg/hl) or grade U.S. No. 2 (74.6 kg/hl). As mentioned previously, restricting the fungicide treatments did not affect test weights in Richmond County (Table 22). While the difference in disease control measures in Shenandoah County and Suffolk had an effect ($P<0.05$) on test weight, the average test weight at both locations was around 63.0 kg/hl (49.0 lb/bu) (Tables 18 and 20). Similar to the durum test weights, the test weight of the soft red winter wheat check was low in comparison to previous years. The test weight of the soft red winter wheat line FFR 555W was below its 1989-1998 average (73.8 kg/hl) at all locations, with its highest test weight that season resulting from Orange County.

Table 22. Average test weight of durum grown in Richmond County, VA (northern coastal plain): 1997-1998.

Line	**Test Weight (kg/hl)**	**Line**	**Test Weight (kg/hl)**
ALIDUR	72.1	BASA	64.8
RODUR	70.9	OREXP #10	64.8
ODESSA #66	70.7	ODESSA #65	64.7
FFR 555W[2]	69.8	OR3880152	64.5
PANNONDUR	69.8	OR948612	64.4
OREXP#13	69.4	BZ8W91-8	64.3
KORALL	68.0	BZ8W92-10	63.5
OR948763	67.7	OREXP#11	63.3
AGEDUR	67.4	OR948927	63.2
OREXP#14	66.9	OR3910085	62.4
AMADUR	66.5	OR948578	61.9
OREXP#12	66.4	OR3910084	61.7
OR3880158	66.2	BZ8W92-2	61.1
OR3910214	65.7	BZ8W90-27	60.4
ODESSA #69	65.7	OR3920036[1]	60.3
PANDUR	65.7	MINARET	60.1
BZ8W92-8	65.6	OR949024	59.8
ACADUR	65.2	OR936773	59.4
ODESSA #63	65.1	OR3950055	56.7
OR3880181	64.8	OR948948[1]	51.9
LSD (0.05)	2.6		
C.V.	2.4		
Durum Test Average	64.4		

[1]Excluded from statistical analysis due to limited grain, thus lack of replications for these lines.
[2]Soft red winter wheat

Discussion and Conclusions

Effect of Climate

Durum wheat is well adapted to regions with hot, dry days and cool nights with winter rains and dry summers (Bozinni, 1988). The mild and often humid Virginia climate is somewhat different from many of the regions around the world where durum is typically grown. The Virginia climate affected durum yield and test weight as much as, if not more than, other factors, such as soil type.

The poor yields and winter kill of several durum lines in the 1993-1994 growing season indicated that these lines were either facultative-type durums or did not possess sufficient winter hardiness to survive Virginia winters. This prompted the decision to grow only durum lines with good winter hardiness, or winter type durum in subsequent field trials. An advantage to growing winter versus spring or facultative-type durum is that winter type wheat typically yields more than spring type wheat (Berzonsky and Lafever, 1993). The average temperature in Virginia in January is 2°C (36°F); however, this average does not reflect that each winter temperatures drop below –7°C (20°F) each winter for several days to several weeks (Dept. of Commerce, 1993-1998). Spring type durum is grown in colder areas of the U.S., such as North Dakota, where the average temperature drops to -17°C (2°F) in January (ND State Government, 1999). However, in areas such as North Dakota, spring type durum is planted in April or early May, while durum in Virginia was planted in early October of 1993.

Although North Dakota experiences colder winters, the average temperature in July for North Dakota and Virginia is similar. The average July temperature rises to 24°C (75°F) and 23°C (73°F) in Virginia and North Dakota, respectively (VA State Government, 1997; ND State Government, 1999). In July, however, durum in North Dakota is still in the field, whereas durum in Virginia has already been harvested. During grain maturation and ripening, the temperatures in Virginia are warmer, around 22°C (72°F), than the average temperature, 19°C (67°F), during the same growth stage in North Dakota (Dept. of Commerce, 1998; North Dakota Extension Service, 1997). Although the warmer weather in Virginia may initially seem to be suitable for durum production, it is important to also consider the amount of precipitation during growing season.

The best durum production occurs under an annual rainfall of between 50-70 cm (20-28 in) (Bozinni, 1988). North Dakota, the highest durum producing state in the U.S., has a sub-humid continental climate, with an annual mean precipitation of 33 cm (13 in) in the northwest and 51 cm (20 in) in the southeast (ND State Government, 1999). In contrast, Virginia receives an annual average precipitation of 109 cm (43 in) (VA State Government, 1997). During grain maturation and ripening, the normal precipitation in North Dakota is approximately 5 cm (2 in), while that in Virginia is around 9 cm (3.5 in) (Dept. of Commerce, 1993-1998; North Dakota Extension Service, 1997). The high amount of precipitation in Virginia and warm temperatures create a humid climate during grain ripening, which strongly influenced both the yields and test weights of durum lines grown in the Virginia field trials.

The humid, often wet, weather in Virginia provides favorable conditions for the spread of several wheat pathogens to spread. In 1994-1995, record amounts of rainfall and severe disease pressure destroyed the crop, casting doubt on the adaptation of durum to Virginia (Figs. 4 and 5). Cold, wet weather marked the 1995-1996 growing season, but devastating effects such as those observed the previous year, did not occur (Figs. 6 and 7). The cold spring weather delayed the date of heading for many durum lines, but the soft red winter wheat lines appeared to have been affected similarly. Average rainfall and temperature were both slightly higher in Orange County than at the other test sites in the 1995-1996 growing season. The below average test weight of the soft red winter wheat check FFR 555W and the generally lower durum test weights at both the Clarke and Montgomery County locations reflected the cold temperatures and excessive moisture during the vegetative and grain fill periods. The 1996-1997 growing season conditions were excellent for both soft red winter and durum wheat production (Figs. 8 and 9). The favorable, drier conditions were reflected in the low incidence of disease and in high yields and test weights. Over all years of the durum field trials, average durum yields were highest and the yield advantage of soft red winter wheat was lowest in the 1996-1997 growing season. In contrast to the favorable conditions in 1996-1997, during the 1997-1998 growing season, there was too much rainfall from planting until almost June (Fig. 10). Extensive grain weathering before harvest and high disease pressure greatly reduced grain yields and test weights. The excessive rain combined with elevated temperatures created a humid environment, which was ideal for the spread of fungal head diseases, such as scab (*Fusarium graminearum*) and glume

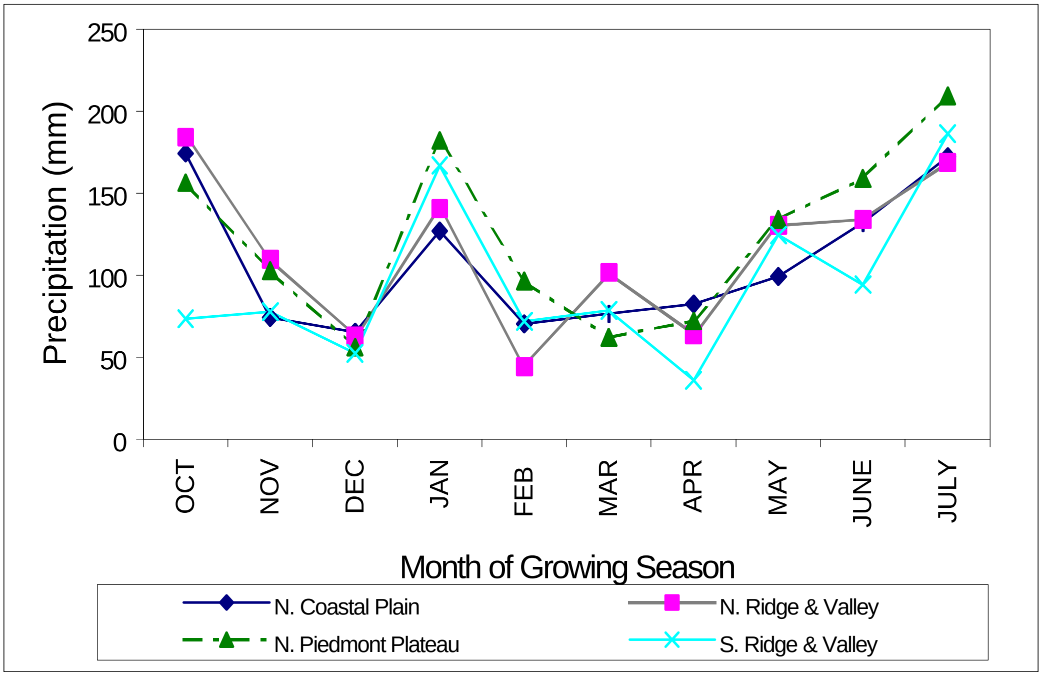


Fig. 6. 1995-1996 Precipitation at the sites of durum field trials[1].
(Dept. of Commerce, 1995-1996)

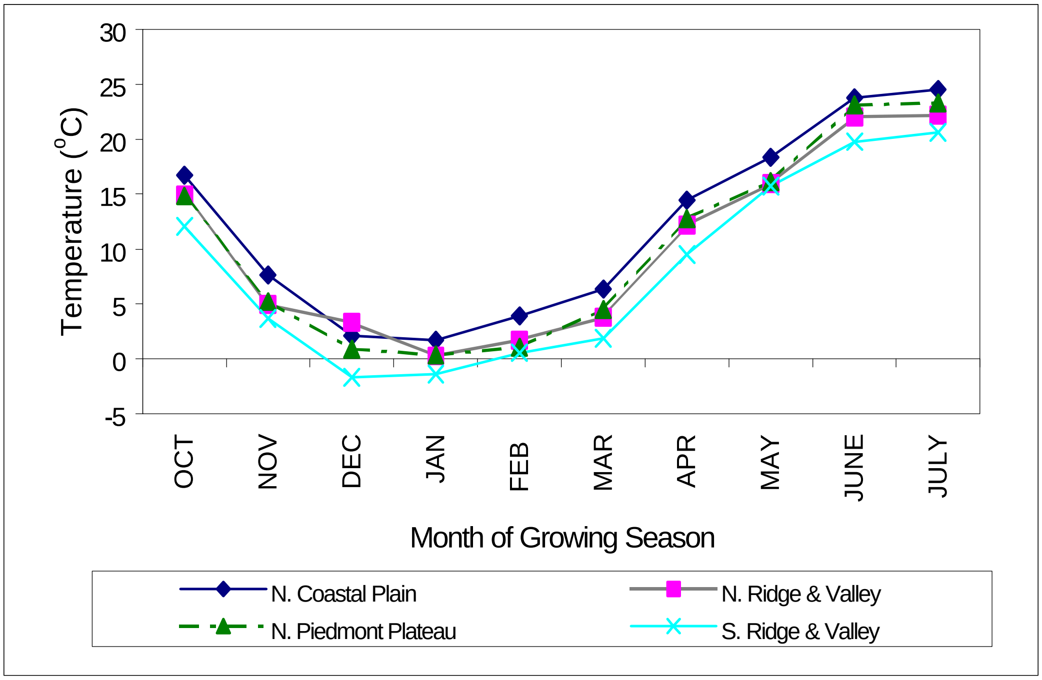


Fig. 7. 1995-1996 Temperature at the sites of durum field trials[1].
(Dept. of Commerce, 1995-1996)

[1]Northern ridge and valley temperature and precipitation for December are based on monthly averages over 4 years.

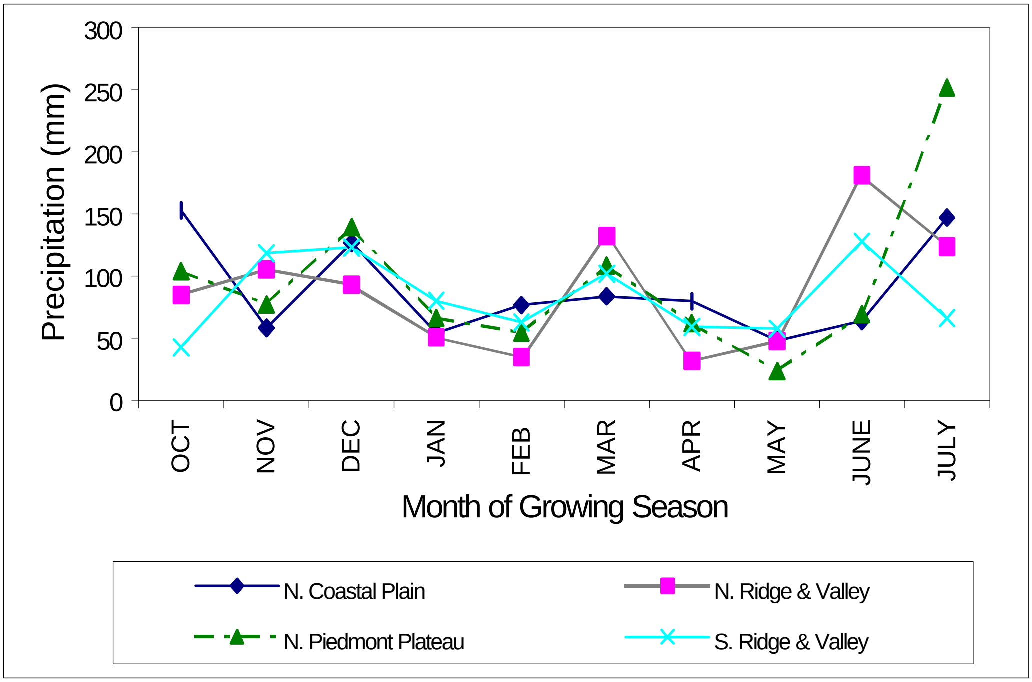


Fig. 8. 1996-1997 Precipitation at the sites of durum field trials[1]. (Dept. of Commerce, 1996-1997)

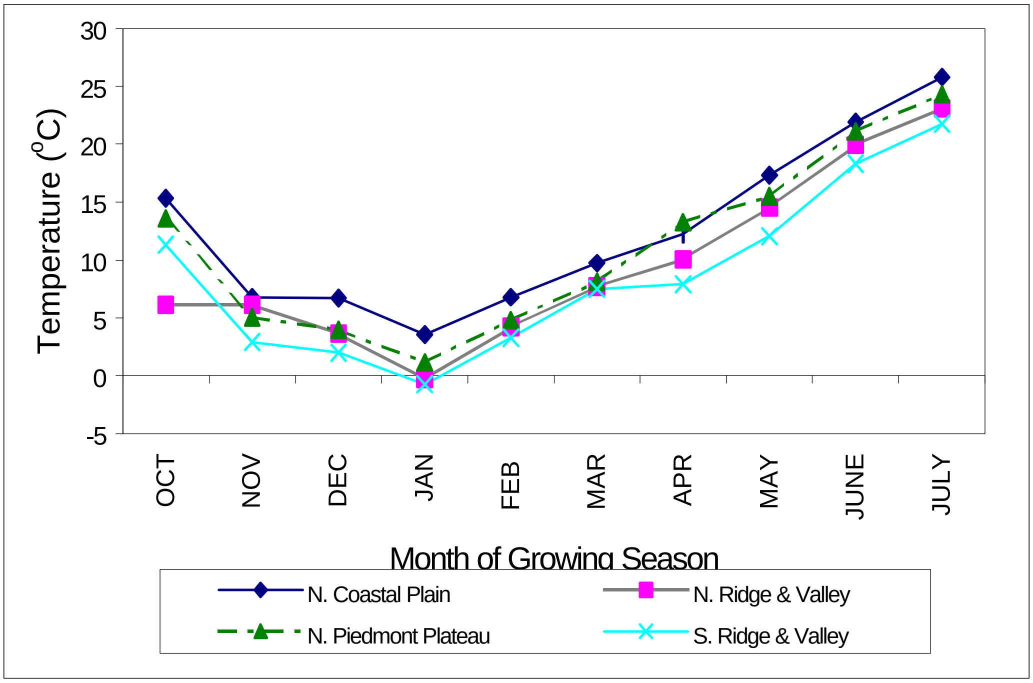
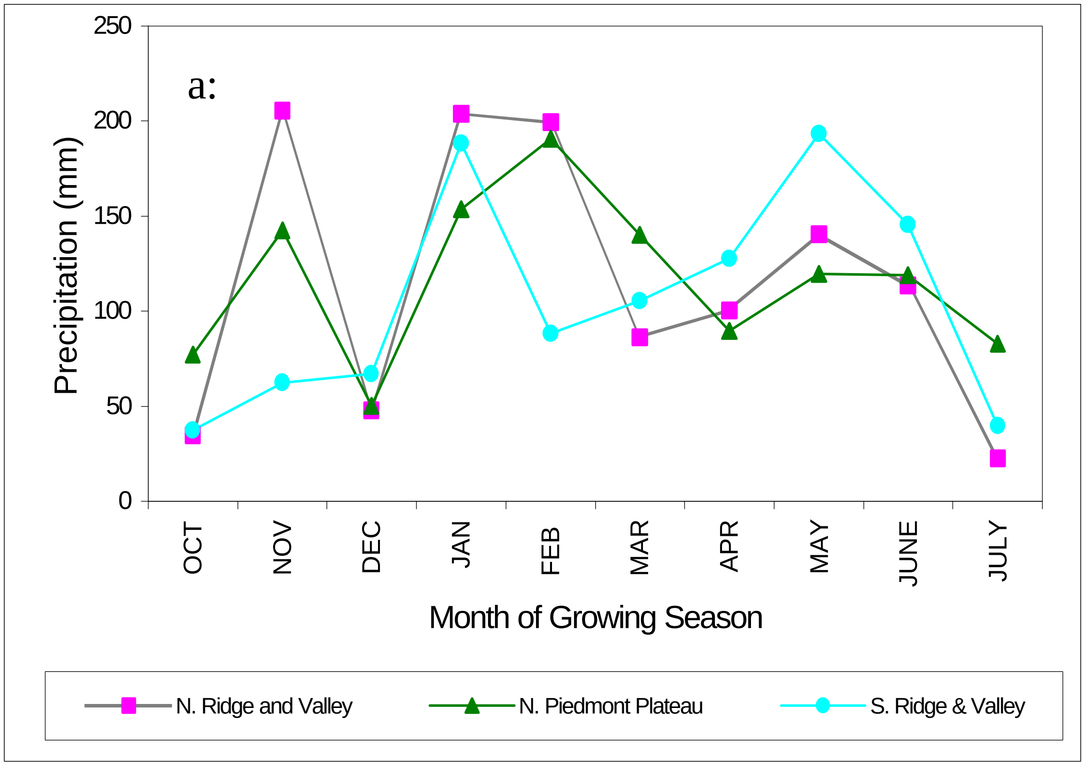


Fig. 9. 1996-1997 Temperature at the sites of durum field trials[1] . (Dept. of Commerce, 1996-1997)

[1]Northern piedmont plateau temperature and precipitation for April are based on monthly averages over 4 years.



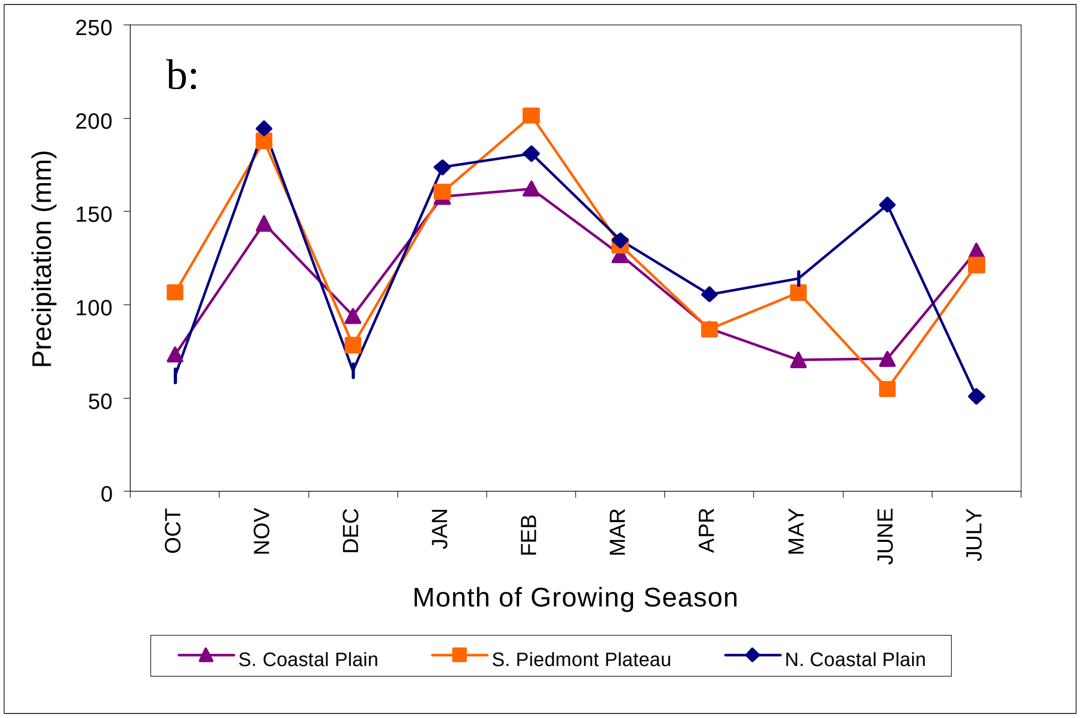
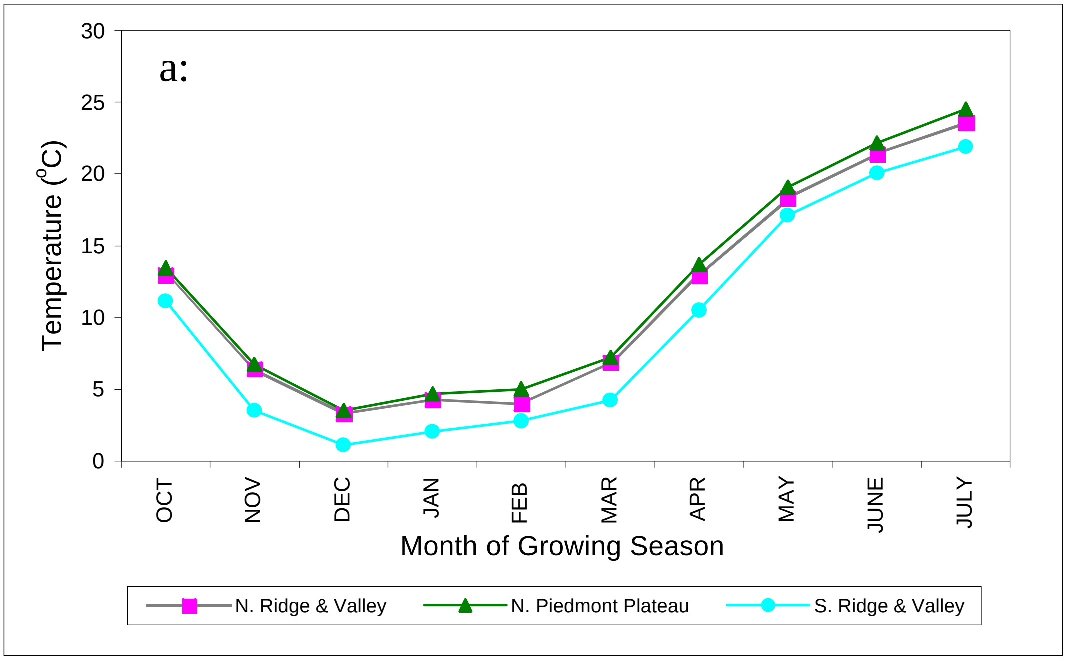


Fig. 10. 1997-1998 Precipitation at the sites of durum field trials. (Dept. of Commerce, 1997-1998)

blotch (*Stagonospora nodorum*), and leaf diseases, such as leaf rust (*Puccinia recondita*) and powdery mildew (*Erysiphe graminis*) (Fig. 11). Although the higher yields and test weights (P<0.05) of plots sprayed with an additional application of fungicide at the Shenandoah County and Suffolk locations (1997-1998) suggested that some of the fungicide applications were helpful in reducing the crop loss, the high disease pressure in combination with the extreme susceptibility of durum to scab resulted in overall low yields and test weights. The reduction in both yield and quality due to the scab epidemic was also seen in the soft red winter wheat, which had a state average of 3024 kg/ha (45 bu/acre) in 1998 compared to 4502 kg/ha (67 bu/acre) in 1997 (VA Agricultural Statistics Service, 1999). Furthermore, the test weight of the only soft red winter wheat check, FFR 555W, grown in the 1997-1998 was well below its 10 year average (73.8 kg/hl) at all locations.

Disease

The effect of management practices in controlling durum diseases were evaluated in the 1997-1998 growing season. As mentioned previously, conditions in the northern piedmont plateau (Orange County) and the southern ridge and valley (Montgomery County) did not necessitate more than two fungicide applications during the growing season. While this suggests that durum may be produced in these regions, generally characterized by lower disease severity, without excess fungicide applications, it also indicates that low yields in these regions were attributable to some factor other than those controlled by fungicide. Reasons include climatic conditions, as previously discussed, as well as other factors such as poor adaptation of durum genotypes tested, soil type, and diseases not controlled by fungicides, such as scab. Additionally, when comparing soft red winter wheat yields to those of durum, it is important to realize that the low protein (9-11%) soft red winter wheat inherently produces much higher yields than the high protein durum wheat. In fact, soft red winter wheat yields are much higher than other classes of wheat, such as hard red spring and hard red winter wheats. In North Dakota, from 1994-1998, average yields of 1901 kg/ha (28.3 bu/acre), 2016 kg/ha (30.0 bu/acre), and 1996 kg/ha (29.7 bu/acre), were reported for durum, hard red winter, and hard red spring wheats, respectively (ND Agricultural Statistics Service, 1999). In comparison, the average Virginia soft red winter wheat yield from 1994-1998 was 3830 kg/ha (57.0 bu/acre) (VA Agricultural Statistics Service, 1999). Based upon this data, the five year average yield of



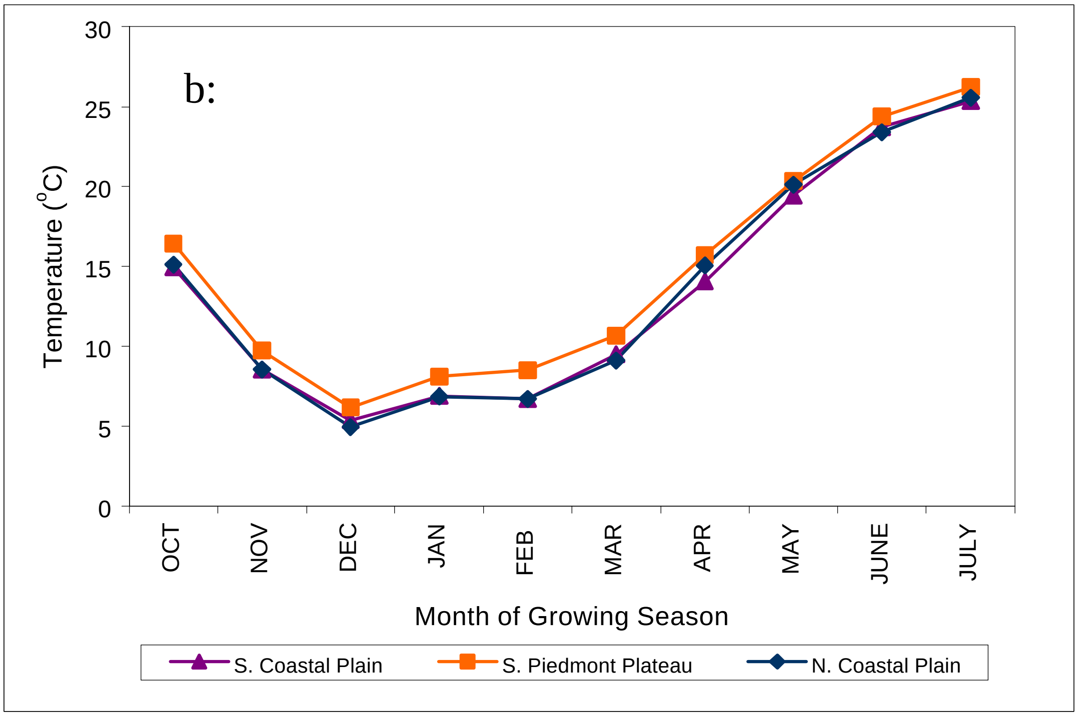


Fig.11. 1997-1998 Temperature at the sites of durum field trials.
(Dept. of Commerce, 1997-1998)

Virginia soft red winter wheat is 50% higher than North Dakota grown durum. Additionally, the average yield of durum wheat is lower than the average yields of hard red spring and hard red winter wheat.

In the 1997-1998 growing season, the difference in disease control practices affected ($P<0.05$) both yields and test weights at the Shenandoah County and Suffolk locations. However, the difference in disease control practices had no effect ($P>0.05$) in Richmond County, which experienced a high level of disease pressure. The 1997-1998 growing season was characterized by particularly wet weather until June, which created favorable conditions for the spread of disease through the durum plots. In fact, in Richmond County, some areas of the field intermittently contained sitting water. Under these poor conditions, disease management practices are nearly ineffective. Leaf rust infection was evident on several durum lines in the durum field trials in 1997-1998. The largest disease problem, however, was from scab (*Fusarium* head blight). Currently, there are no known durum cultivars resistant to scab, nor are there effective fungicides. Scab was observed in the durum plots in all regions, although it was the most prevalent in Richmond County. The high incidence of scab at this location, in comparison to that at the Shenandoah County and Suffolk locations, may partly explain the lack of an effect of different disease control practices at the Richmond County location.

Powdery mildew is one of the most important wheat diseases in the eastern United States, especially in humid regions such as Virginia. During the first year of the field trials, 1993-1994, the amount of powdery mildew in the durum plots was scored in Orange County the last week in April, one week before the first fungicide application (Appendix C). For most of the durum lines, powdery mildew was not a problem. A few of the lines with a powdery mildew score of six or greater (on a scale of 0-9, with 9 being the most severe) were dropped in subsequent field trials. During the dry, favorable growing conditions in 1996-1997, no powdery mildew was detected in the Orange County field plots (Appendix C). In 1997-1998, the amount of powdery mildew was scored at a different location, Richmond County, 20 days after the first fungicide application. Both the 20 additional lines and the 19 durum lines (grown under restricted fungicide treatment) were assessed (Appendix C). Despite the wet growing conditions, powdery mildew was generally not a problem for the 19 durum lines, and all had a lower ($P<0.05$) incidence of powdery mildew than the soft red winter wheat check FFR 555W, which is moderately susceptible to powdery mildew (Appendix C). The preliminary data gathered for the

20 new durum lines suggests that powdery mildew will not be a significant problem for most of those durum lines. Based upon this limited data, it appears possible that some of the durum lines possess some tolerance to powdery mildew. Additionally, fungicides such as Bayleton were effective in limiting the occurrence of powdery mildew.

Pests were typically not a large problem in the durum plots, although limited cereal leaf beetle damage was observed. In 1997-1998, both locations in the piedmont plateau (Orange and Nottoway Counties) experienced some cereal leaf beetle (*Oulema melanopa*) damage. In the 1996-1997 growing season, the seed treatment Gaucho® was first employed to control insects, especially aphids, which are vectors for the barley yellow dwarf virus. In the 1996-1997 durum plots, the incidence of barley yellow dwarf virus was not detected in Orange County and was minimal in Montgomery County (Appendix C).

General Agronomic Characteristics

The soft red winter wheat check, FFR 555W, grown in all of the field trials from 1993-1998 is considered a late heading variety. Both heading date and height of the plants varied slightly by region, with lines tending to head later and grow taller in the wet, cool spring of the southern ridge and valley (Montgomery County). Most of the durum lines headed later ($P<0.05$) and were shorter ($P<0.05$) than FFR 555W (Appendix C). One line, OR3910214, typically headed at or near the same time as FFR 555W. Preliminary heading notes for the 20 new lines tested indicate a wide range of heading dates, from three days earlier than FFR 555W to 12 days later than FFR 555W. Height of most of the durum lines was under 101.6 cm (40 in), with the exception of the Colorado line Korall, which grew up to as much as 124.5 cm (49 in) (Appendix C).

Over all years, lodging was not a major problem in the durum field trials. Actual amount of lodging varied by region, weather and disease damage. During the wet 1997-1998 growing season, hard rains contributed to the lodging observed at the Richmond, Orange, and Montgomery County locations (Appendix C). Twelve durum lines experienced lodging at both the Richmond and Montgomery County locations. One line, OR3910214, experienced lodging in Montgomery, Orange, and Richmond Counties.

Effect of Soil Type Differences Between Regions

Differences in durum performance between locations are the result of several environmental factors, such as temperature, moisture, and disease pressure, and the interaction between these factors and genotype. As previously discussed, climatic factors greatly influence not only durum yield and test weight, but also general straw-strength characteristics. In addition to the aforementioned environmental factors, differences in soil type between each Virginia region affected the success of the durum at each location.

Durum wheat performs best in well-drained clay or clay loam soils, while it performs poorly in sandy soils (Impiglia and Anderson, 1998). The soil type varied from region to region (Table 1). The coastal plain region is primarily flat, and soils are comprised of fluvial and marine sediments. Most of the soils are sandy, but there are areas within the region with clay or loam soils. The piedmont plateau, as its name suggests, is higher in elevation than the coastal plain. In contrast to the coastal plain, soils in this region are usually highly weathered, deep clays. The ridge and valley soils vary widely. The ridges have been formed primarily from sandstone or conglomerate strata outcrops, while the valleys are made up of limestone, dolomite and shale. Soils along a ridge may be stony, with sandy or loamy soils, which are often not very fertile. Agricultural productivity of the soils in the valleys varies, depending on the parent material. Limestone valleys can be productive, while shale valleys can be too acidic for vegetative growth.

The highest average durum wheat yields were consistently produced on silty clay loam soils at the Orange County location in the northern piedmont plateau, from 1995-1998. In the 1993-1994 growing season, the highest average durum yield was observed on a fine, loamy soil in the southern ridge and valley region at Montgomery County. However, the durum yield average, 3380 kg/ha (50 bu/acre), at Orange County was only slightly less than the average durum yield produced in Montgomery County, 3842 kg/ha (51 bu/acre) (Tables 7 and 9). The average durum yield was the lowest in the northern ridge and valley from 1993-1997. The soil type at all of the locations tested in this region was a silt loam. The difference in productivity between the northern and southern areas of this region serves as a reminder of the wide differences in soil types even within a single region. During the 1997-1998 growing season, average durum yields were the lowest on the sandy loam soil in the northern coastal plain region (Richmond County) and the loamy southern coastal plain soils at Suffolk. Recall that in Richmond County, some water pooled in the field, which not only hindered plant growth, but also encouraged the spread of disease. Since this region is flat, often the rainfall cannot properly drain off low lying areas in the fields. Average durum yields in Richmond County were also lower than those in Orange County or Montgomery County in the 1996-1997 growing season. However, although soil type may be important, climatic factors are more likely responsible for the differences in durum performance among locations.

Best Yielding Durum Lines

During the 1993-1994 growing season, no single durum line excelled in all of the regions across Virginia. In the 1995-1996 and 1996-1997 growing seasons, a Ukrainian line, Odessa #65, consistently produced relatively high durum yields across Virginia. In the 1995-1996 growing season, Odessa #65 was the highest yielding durum line at Montgomery County and Orange County and second highest at Clarke County. In 1996-1997, this same line was the top producer at Orange County and Clarke County and second highest in Richmond County. Another Ukrainian line, Odessa #69, was consistently the second highest yielding durum line in the 1996-1997 growing season at the Clarke, Montgomery and Orange County locations.

The adaptation of the Ukrainian Odessa lines to Virginia was further demonstrated during the 1997-1998 growing season. Odessa #66 was the highest yielding durum line in Montgomery and Orange Counties, as well as at Suffolk under restricted fungicide disease management. Among the 19 previously tested durum lines, Odessa #66 had the highest yield at Warsaw as well. Since the winter of 1997-1998 was wet across Virginia, and the growing season was marked by high disease pressure, the performance of Odessa #66 suggests that this line has a higher tolerance to adverse growing conditions than many of the other lines tested. In Shenandoah County, Korall was the top yielding line under both disease control practices. In Richmond County, a new line from Romania, Amadur, was the top durum line in terms of yield, with Odessa #66 falling behind five of the new lines tested that year. A Romanian line, tested as OR3910084, produced the highest durum yield at the experimental site in Nottoway County in 1997-1998. The same line also produced the best durum yield in the 1993-1994 growing season at the Montgomery County location.

The highest durum yield produced in any single region or year was 6659 kg/ha (99 bu/acre) by Odessa #65, at the northern piedmont plateau location (Orange) in 1996-1997 (Table 13). The best soft red winter wheat, FFR 555W, at the same location yielded only slightly higher, 6930 kg/ha (103 bu/acre). Average durum yields were also highest in 1996-1997. Over all locations in 1996-1997, the highest average durum yield was 5835 kg/ha (87 bu/acre), occurring in Orange County (Table 13). The same year, the highest yielding durum line in Richmond County, in the northern coastal plain, actually produced 3.7% more grain than the best producing soft red winter wheat line in the same region (Table 15). The yield advantage of soft red winter wheat was also the lowest during the 1996-1997 growing season. For instance, the average durum wheat yield was only 3.9% less than the average soft red winter wheat yield at Orange County (Table 13). The success of the durum crop during the 1996-1997 growing season was largely due to the optimal, drier, growing conditions during that year.

Since weather conditions can vary widely from year to year, it is often useful to consider the performance of the durum lines over all locations and years, as well as the performance of each line over all years within locations. Considering the data shown in Tables 23-26, the highest average durum wheat yields and test weights were produced in the northern piedmont plateau (Orange County), while the lowest average durum yields and test weights were produced in the northern ridge and valley (Clarke County and Shenandoah County). In both the northern piedmont plateau (Orange County) and the northern coastal plain (Richmond County), the highest durum yields over all years were produced by Odessa #65. Another Ukrainian line, Odessa #63, was the top durum producer over all years at the southern ridge and valley location, Montgomery County. However, in the northern ridge and valley region (Clarke County and Shenandoah County) Korall, a line from Colorado, was the top performing durum line. The average yield of this line, however, is lower than that of the top yielding durum lines on average, over all years, at the other locations. The Ukrainian line, Odessa #69, was the second highest durum producer in the northern ridge and valley. Looking at the results of the individual regions, it comes as no surprise that the top four durum producers over all regions, averaged over all years are the Odessa lines from the Ukraine (Table 27).

Table 23. Grain yield and test weight of winter durum lines from the 1996-1998 crops at Montgomery County, VA (southern ridge and valley).

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	6036	69.5
2	ODESSA #63	4662	68.4
3	ODESSA #69	4538	68.1
4	ODESSA #65	4391	68.8
5	ODESSA #66	4244	70.4
6	PANNONDUR	4055	73.3
7	OR3910214	4026	67.6
8	MINARET	3947	66.9
9	BASA	3903	71.3
10	OR3880158	3872	69.1
11	KORALL	3769	71.3
12	OR3910084	3707	65.1
13	OR3880152	3696	68.8
14	BZ8W91-8	3631	64.7
15	OR3880181	3442	65.3
16	OR3910085	3351	65.3
17	BZ8W92-10	3307	66.0
18	BZ8W90-27	3206	66.1
19	BZ8W92-8	2917	66.3
20	BZ8W92-2	2872	64.9
Durum Average		3765	67.8
SRWW Yield Advantage[3]		2271	

[1] Rank according to yield
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 24. Grain yield and test weight of winter durum lines for the 1996-1998 crops, in Orange County, VA (northern piedmont plateau).

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	7388	72.7
2	ODESSA #65	5896	73.7
3	BZ8W91-8	5772	70.5
4	ODESSA #69	5742	74.0
5	ODESSA #63	5503	74.1
6	OR3910084	5427	69.9
7	ODESSA #66	5266	74.8
8	OR3910214	5117	72.3
9	OR3910085	5101	72.3
10	OR3880152	5022	71.5
11	PANNONDUR	4936	75.1
12	KORALL	4878	73.5
13	MINARET	4763	69.9
14	BASA	4738	72.7
15	BZ8W90-27	4710	71.5
16	OR3880158	4702	72.0
17	BZ8W92-2	4418	70.7
18	BZ8W92-10	4386	71.7
19	OR3880181	4335	65.3
20	BZ8W92-8	4152	70.9
Durum Average		4993	71.9
SRWW Yield Advantage[3]		2395	

[1] Rank according to yield
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 25. Grain yield and test weight of winter durum lines for the 1996-1997 crops in Clarke County and the 1997-1998 crop in Shenandoah County, VA (northern ridge and valley).

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	6192	71.4
2	KORALL	3836	71.5
3	ODESSA #69	3597	66.9
4	OR3910084	3509	64.3
5	ODESSA #65	3505	68.4
6	BZ8W91-8	3372	66.3
7	OR3910214	3343	68.6
8	ODESSA #63	3287	68.2
9	OR3880152	3245	67.1
10	BASA	3237	68.7
11	OR3880158	3191	67.1
12	ODESSA #66	3163	68.7
13	MINARET	3150	64.8
14	BZ8W90-27	3044	68.0
15	BZ8W92-2	2939	66.2
16	BZ8W92-10	2819	63.1
17	OR3910085	2819	66.4
18	BZ8W92-8	2576	66.5
19	PANNONDUR	2499	67.9
20	OR3880181	1403	57.8
Durum Average		3081	66.7
SRWW Yield Advantage[3]		3111	

[1] Rank according to yield
[2] Soft red winter wheat
[3] (SRWW Test Average)-(Durum Test Average)

Table 26. Grain yield and test weight of winter durum lines for the 1997-1998 crops in Richmond County, VA (northern coastal plain).

Rank[1]	Line	Yield (kg/ha)	Test Weight (kg/hl)
1	FFR 555W[2]	4845	75.4
2	ODESSA #65	4045	74.1
3	OR3910084	3931	71.2
4	ODESSA #69	3926	74.2
5	ODESSA #66	3883	76.6
6	ODESSA #63	3817	74.4
7	BZ8W92-10	3736	73.1
8	PANNONDUR	3590	77.4
9	OR3910085	3524	73.5
10	BZ8W92-8	3457	74.2
11	BZ8W92-2	3328	69.6
12	BZ8W91-8	3264	71.1
13	OR3910214	3159	73.7
14	OR3880158	3106	71.4
15	BZ8W90-27	3084	70.6
16	OR3880152	2923	71.5
17	KORALL	2724	74.1
18	OR3880181	2716	64.8
19	MINARET	2678	70.4
20	BASA	2480	73.5
Durum Average		3335	72.6
SRWW Yield Advantage[3]		1510	

[1] Rank according to yield

[2] Soft red winter wheat

[3] (SRWW Test Average)-(Durum Test Average)

Table 27. Grain yield and test weight of winter durum lines from 1996-1998, over Virginia field trials in Orange County, Richmond County[3], Montgomery County, Clarke County, and Shenandoah County .

Rank[1]	Line	Yield (kg/ha)	Test Weight (kg/hl)
1	FFR 555W[2]	6115	72.2
2	ODESSA #65	4459	71.2
3	ODESSA #69	4451	70.8
4	ODESSA #63	4331	71.4
5	ODESSA #66	4157	72.6
6	OR3910084	4143	67.6
7	BZ8W91-8	4010	68.2
8	OR3910214	3887	70.2
9	KORALL	3802	72.6
10	PANNONDUR	3770	73.5
11	OR3880158	3718	69.9
12	OR3880152	3698	69.2
13	OR3910085	3638	69.4
14	MINARET	3638	69.0
15	BASA	3602	71.4
16	BZ8W92-10	3562	68.5
17	BZ8W90-27	3511	69.0
18	BZ8W92-2	3389	67.9
19	BZ8W92-8	3336	69.5
20	OR3880181	2974	63.3
Durum Average		3793	69.7
SRWW Yield Advantage[4]		2322	

[1] Rank according to yield

[2] Soft red winter wheat

[3] Averaged over 1997-1998

[4] (SRWW Test Average)-(Durum Test Average)

Inherent Adaptation

The yield data indicates that most of the high yielding durum lines in the Virginia field trials originated from the Ukraine. In particular, the Odessa lines seem better suited to Virginia than many of the other lines tested. By considering the climate of the place of origin of these lines, some understanding is gained concerning their successful adaptation to Virginia. The Odessa oblast region of the Ukraine has short summers and long winters. The climate is dry, with low spring precipitation and hot, dry summers. A high amount of rainfall in April and May helps to promote winter plant growth. In comparison to Virginia, the region receives slightly more than half as much rainfall, about 40-60 cm (16-24 in) of precipitation annually. However, the temperature range is within a few degrees of the average temperature range in Virginia, with temperatures around -1.91 °C in January, and reaching highs in July of around 22.10 °C (Desai, 1986).

Comparing the climate of the Odessa oblast in the Ukraine to that of Virginia, it becomes apparent that an important difference between the two areas of the world is the amount of precipitation. The high amount of precipitation in Virginia is the primary limiting factor in the production of durum in this state. Years such as 1996-1997 proved that it is possible for durum yields to be competitive with soft red winter wheat, but such favorable, relatively dry, growing conditions are the exception rather than the rule in Virginia. It is not only that durum inherently performs better in drier environments, but the indirect effects of too much precipitation and enhanced disease development also reduced durum yields in Virginia. As seen in 1997-1998, wet weather late into the growing season not only results in weathered kernels, but also creates ideal conditions for the spread of diseases, such as scab and glume blotch. Furthermore, if the weather is too wet near harvest, as in 1995, the durum is likely to sprout. Plots were harvested in a timely manner, but the durum was allowed to dry down before harvest, according to the latest maturing line. Adjustments in the harvesting date may improve durum production and reduce the risk of losses due to sprouting. For durum yields to be consistently high in Virginia, it is apparent that not only good cultivars and management practices, but also drier weather, especially during grain maturation, are keys to a successful crop. Since weather conditions are beyond human control, producing stable, high durum yields in Virginia, will require durum lines with a higher tolerance to wet conditions and increased levels of disease resistance, such as was demonstrated by several of the Romanian lines tested in Richmond County in 1997-1998.

Test Weight

There is no truly acceptable substitute for durum in premium pasta production, so the durum market is highly sensitive to changes in quality from year to year (ND Wheat Commission, 1999). Price premiums and discounts received for durum wheat are highly sensitive to quality factors such as percent vitreous kernels and test weight. Therefore, a durum test weight that is at least 77.2 kg/hl (60.0 lb/bu), the minimum test weight for grade U.S. No. 1, is very desirable. The price is discounted for lower test weight durum, although it may be acceptable for lesser quality noodles, such as elbows and twists (Fabriani and Lintas, 1988). The situation is different in soft red winter wheat production, where a test weight of at least 74.6 kg/hl (58.0 lb/bu) is acceptable to most producers, due to the lack of a price premium for higher test weight soft red winter wheat.

Over all, the average durum test weight of Virginia grown durum tended to be less than this requirement. Performance of the durum lines varied from year to year and from region to region, however; several individual lines surpassed the average Virginia test weight. Although test weight is often affected by the environment, durum test weights essentially did not differ from region to region in the 1993-1994 growing season, suggesting that the conditions affecting test weight did not differ greatly between regions. The cold, wet weather, combined with weathering prior to harvest and some scab infection, was partly responsible for the low test weights observed in the 1995-1996 growing season. As mentioned previously, any factor that might result in shriveled, or otherwise damaged grain, typically reduces the test weight. During the 1996-1997 growing season, test weight averages increased in every region, due to the more favorable, drier growing conditions. In 1998, high disease pressure and wet weather were major factors resulting in low test weights, which were well below the minimum requirement for grade No. 1. At the Suffolk and Shenandoah County locations, the average test weight of durum grown under the restricted fungicide treatment was lower than the average test weight of durum treated as in previous years. This suggests that the extra fungicide applications reduced the amount of kernel damage resulting from disease.

As with yield, the highest average durum test weights were consistently produced in the northern piedmont plateau, at the Orange County location. This offers further support for the suitability of this particular Virginia region for durum production. While the over all average durum test weight, both within locations and across locations, from 1996-1998, is less than 77.2 kg/hl (60.0 lb/bu), the performance of several individual lines offers promise of a successful durum crop (Tables 23-27). Consideration of the average test weight over several years is useful in assessing the durum lines, as conditions vary from year to year, and a single poor year may be the exception rather than the rule. Over all of the three physiographic regions in Virginia, Pannondur had the highest average test weight from 1996-1998. None of the lines met the test weight requirements for U.S. No. 2, across all years and locations. Within locations, two durum lines met the minimum test weight requirement for grade U.S. No. 2, which is 74.6 kg/hl (58.0 lb/bu), over the 1995-1996 and 1996-1997 growing seasons. In Richmond County, Odessa #66, and in Orange County, Odessa #66 and Pannondur had an average test weight of at least 74.6 kg/hl (58.0 lb/bu). Additionally, the over all average test weight for Pannondur in Richmond County is acceptable for grade U.S. No. 1. In summary, Pannondur, Odessa #66 and Korall consistently produced higher test weights than the other durums, and often there was no difference ($P>0.05$), within years and location, between the test weights of these three lines. Based on test weight results, it appears that durum grown in Virginia, at specific locations (Richmond and Orange Counties) has the potential to meet the minimum test weight requirements for grade U.S. No.2 in most years, and U.S. No. 1 in a few years. However, as with yield, the test weight of the durum lines varies from year to year, and is sensitive to environmental conditions.

Cost Comparison Based on Yield Performance

The Virginia winter durum field trials demonstrated that winter durum yields are approximately 62% less than soft red winter wheat yields. As mentioned previously, it is expected that soft red winter wheat will produce a much higher yield than durum wheat. Despite the lower yields, durum production in Virginia could still have an economic advantage over soft red winter wheat due to the higher price per bushel for durum wheat versus soft red winter wheat. To estimate the potential economic advantage of durum production over soft red winter wheat production, a cost comparison using the yield data from the Virginia field trials was performed. The potential price per acre for durum and soft red winter wheat was determined utilizing the marketing year average prices received by states, published by the Agriculture Statistics Board (1993-1999). In this economic analysis the price per bushel of soft red winter wheat was the price received by Virginia producers (Table 28). For durum, the price per bushel was that received by North Dakota producers. The marketing year average prices for each state were determined by weighting the monthly prices by the estimated percentage of market sales during that year. These prices reflect the average price received for all grades of wheat sold in each state. Therefore, it is helpful to consider the average quality of the durum and soft red winter wheat. The average quality of durum wheat in North Dakota is grade U.S. No. 2 Hard Amber Durum (ND Wheat Commission, 1999). The average quality of soft red winter wheat in Virginia is grade U.S. No. 2 Soft Red Winter Wheat. As a result, the following price comparison makes the assumption that the durum grown in Virginia is grade U.S. No. 2 Hard Amber Durum, with a minimum test weight of 74.6 kg/hl (58.0 lb/bu), and the soft red winter wheat is grade U.S. No. 2 Soft Red Winter Wheat.

In the 1993-1994 growing season, the yield of the top producing durum wheat in each of the three regions was high enough, relative to the best producing soft red winter wheat, to make durum production more profitable. Furthermore, the same year, the average durum yield in the northern piedmont plateau (Orange) and the northern ridge and valley (Shenandoah County) were high enough that durum production would have been more profitable than soft red winter wheat production (Fig. 12). In stark contrast, durum production would have been much less profitable than soft red winter wheat in both the 1994-1995 and the 1995-1996 growing seasons (Fig. 12). The situation turned around in 1996-1997, with an excellent growing season. Due to the drier conditions, durum yields were higher than in previous years. On average, soft red winter wheat had only a narrow yield advantage, and the higher price paid for durum would have made durum exceptionally profitable at Orange, Montgomery and Richmond Counties (Fig. 12). In addition, the top producing durum lines in all regions would have brought in more money than the top producing soft red winter wheat lines at the same locations. The 1997-1998 growing season, however, was not as successful for durum production in Virginia. None of the locations produced average durum yields of an acceptable level. Only the top producing durum line in Shenandoah County, grown under restricted fungicide treatment, and a new Romanian line (Amadur) grown in Richmond County yielded enough to have a slight economic advantage.

Table 28. Marketing year average prices received by state[1].

Growing Season	Durum Wheat: (U.S. No. 2 HAD) North Dakota ($/bu)	Soft Red Winter Wheat: (U.S. No. 2 SRWW) Virginia ($/bu)
1993-1994	4.68	2.70
1995-1996	4.53	4.15
1996-1997	4.91	3.05
1997-1998	3.20	2.40

[1]Prices received may be found in NASS. 1994-1999. Agricultural Prices. National Agriculture Statistics Board, USDA, Washington D.C.

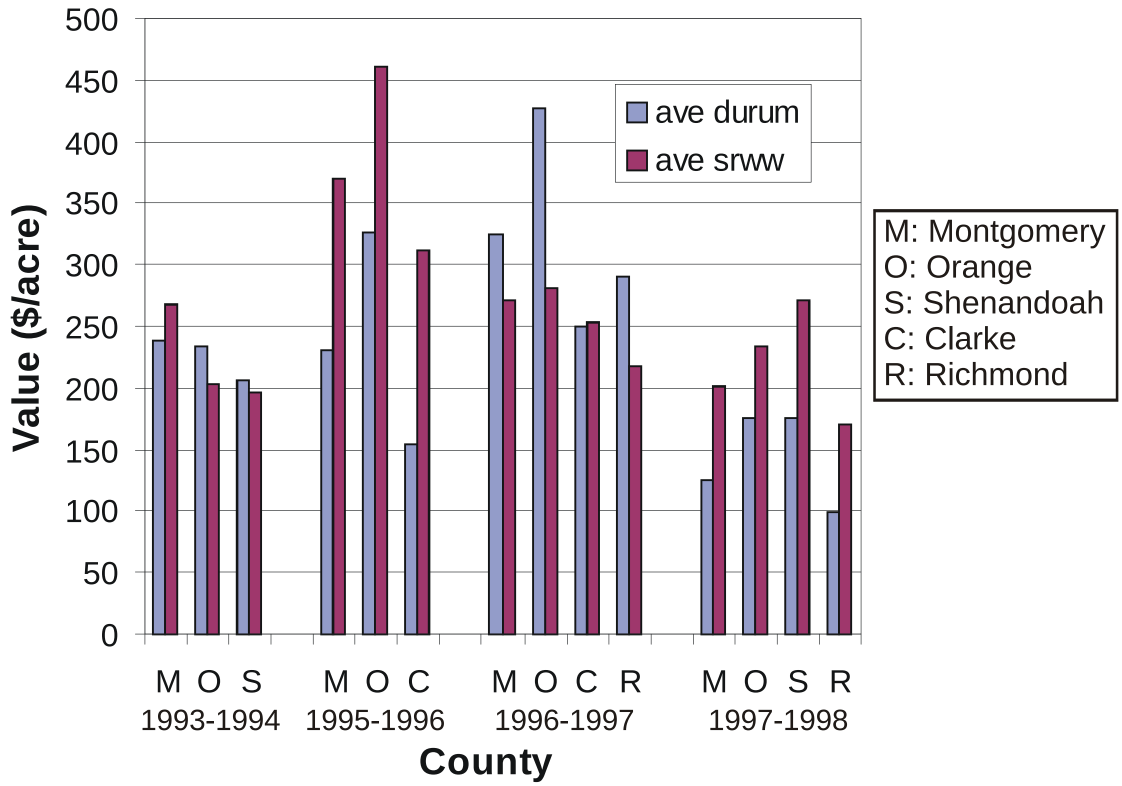


Fig. 12. Value of durum production vs. soft red winter wheat production in Virginia based upon average yields at each location.

The variation in the top producing durum line in each region creates a risky situation for the producer deciding to grow durum in Virginia. In order for durum to be the most profitable in regions where soft red winter wheat is typically grown, it is important that the yield advantage of soft red winter wheat is very small, or nonexistent, and that the durum production is consistent over years. The average yield advantage of soft red winter wheat was lowest on average in both 1997 and 1998 in the northern coastal plain (Richmond County). However, consideration should be given to the fact that soft red winter wheat typically yields less at the Richmond County location than at the Orange or Montgomery County test sites. The highest average durum yields in Virginia were produced in the northern piedmont plateau (Orange County).

The field trials conducted in Virginia have shown that durum wheat production can have an economic advantage over soft red winter wheat, as in 1994 and 1997. However, this economic advantage did not exist for all years. There was little or no economic advantage to durum production over soft red winter wheat in 1996 and 1998. Furthermore, soft red winter wheat fared better than durum in the 1994-1995 growing season when the entire crop of durum wheat was lost. Since durum is less adapted to high rainfall regions and appears to be more susceptible to disease than soft red winter wheat, it is important to consider the disease pressure at each growing location. Government fungicide restrictions may limit the number of fungicide applications, which can adversely affect durum yield and quality in certain growing conditions.

Conclusions

Results of this field study indicate that the most successful Virginia durum crop, in terms of yield and test weight, was grown in the northern piedmont plateau in Orange County. Lines such as Odessa #66, with relatively good yield and test weight, demonstrate that both of these qualities may be produced in Virginia grown durum. Additionally, results from the 1997-1998 growing season suggest that some of the new Romanian lines may surpass the durum lines tested in previous years. The greatest hindrance to durum yield and test weight in Virginia was the wet, humid climate. It is possible that with intensive wheat management practices and the development of scab resistant durum lines, future durum production will be more consistent in terms of yield and test weight. Since the feasibility of producing durum in Virginia is largely dependent on the price premium received for high quality durum, test weight, and other factors that have an effect on the durum marketability, will be discussed in the following chapter.

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Chapter IV
Physical and Chemical Quality Aspects of Winter Durum Wheat Grown in Virginia

Abstract

Durum wheat (*Triticum durum* Desf.) is primarily used to produce high quality pasta products, such as spaghetti and linguini. Field studies in Virginia demonstrated that yields of available winter durum wheat lines are less than those of soft red winter wheat. This difference in yield may be compensated for by a price premium received for high quality durum wheat. The 19 top performing winter durum lines evaluated from 1996-1998 were selected for physical and chemical quality analyses. The objectives of these analyses were to determine the marketability of the grain, its suitability for pasta, and general characteristics of the end product. Kernel vitreousness of most lines over all years was less than 75%. In 1996 and 1997, 42% of the durum lines were assigned grade U.S. No. 2 or better. High quality standards for 1000 kernel weight, falling number, and protein content were met by the Virginia grown durum lines. Protein quality was assessed by gel electrophoresis, SDS-sedimentation test and farinograph test. Twelve of the 19 lines tested possessed γ-gliadin band 45, an indicator of good cooking quality. Protein quality and viscoelastic properties were acceptable for several lines, based on SDS-sedimentation volumes and farinograms. Pasta produced from Virginia grown durum largely appears to be comparable to pasta produced from commercially available semolina, in terms of color, firmness and cooking loss. While no single line excelled for all of the quality traits, several lines performed well in specific quality tests. These lines may be useful in the future development of good quality durum lines with increased adaptation to the wet, humid Virginia climate and greater disease resistance.

Introduction

Durum wheat quality is defined by both physical and chemical characteristics. Physical characteristics are those traits of the wheat kernel that affect the semolina, milling or processing. The potential suitability of durum for milling and processing is determined by considering the grade, test weight, 1000 kernel weight, falling number, and kernel vitreousness of each durum line. Grade is the most important criteria to millers, as it offers an overall assessment of the physical quality characteristics of durum wheat. Grades 1-5 reflect those characteristics which affect milling or end product quality, such as test weight, damaged kernels, percent contrasting wheat classes, damaged kernels, defects, foreign material, heat damaged kernels, other grains and shrunken and broken kernels (USDA, 1985).

Durum wheat quality is also defined in terms of chemical attributes, which include those innate properties of the wheat that affect the end product quality. Protein content and protein quality, in particular, strongly influence the end product quality. The protein content of durum wheat is a principle factor in determining pasta cooking quality (Feillet and Dexter, 1996). For pasta with good cooking performance and quality, the wheat protein content should be between 12-16% (14% moisture content) (Pitz, 1992). Good gluten strength, or protein quality, is also important in durum wheat, since the dough must be extended without breaking during spaghetti processing. These factors, protein quantity and protein quality, also affect consumer acceptance of the end product, as they influence the stickiness and the firmness of the noodles. Consumer acceptance of the finished product is also influenced by the color of the finished product. Dough produced from durum wheat is ideal for pasta products since it has a bright, yellow color and the ability to retain its shape (Dexter and Matsuo, 1977).

As indicated by field trials, durum wheat grown in Virginia typically yields less than soft red winter wheat. However, the price premium durum producers receive for high quality durum wheat can compensate for the difference in yield and make durum a more profitable alternative. Since this price premium depends on the durum quality, a complete feasibility study of durum production must incorporate a detailed analysis of durum quality. Over the five years of Virginia field trials, the number of durum lines was gradually narrowed down based on yield and quality data. By 1998, only 19 of 63 lines remained that were included in field trials from 1996-1998. The objectives of the quality analyses of these 19 lines were:

1. To determine the marketable quality of the Virginia grown winter durum wheat based on physical quality characteristics,
2. To assess the suitability of the Virginia grown durum for pasta production based on protein quality, and
3. To estimate color, cooking loss, and firmness of the end product produced from Virginia grown durum.

Materials and Methods

The top 19 performing durum lines, based on yield and quality data, were selected for further quality analysis in this study (Table 1). Grain produced in field trials at the Montgomery County (southern ridge and valley), Orange County (northern piedmont plateau) and Clarke County (northern ridge and valley) locations were included in the 1996 quality analyses. An additional location, in Richmond County (northern coastal plain), was included in 1997 and 1998. In 1998, the Clarke County location was replaced by another northern ridge and valley location in Shenandoah County, while the other locations were the same. The grain produced in the field trials each year was composited by line over replications within locations. However, in 1998, grain samples were separated by disease control practices in Richmond and Shenandoah Counties. At these locations, two different disease control practices were employed. Half of the plots were managed as in previous years (fungicide was applied every 14 days or as needed), while the other plots were grown under a restricted fungicide regime (limited to two fungicide applications). Grain from each location was harvested in late June to early July, depending upon location. A Hege 3SA Seed Cleaner (Colwich, KS) with a 0.5 cm screen opening was used to clean the grain before quality analyses. Unless otherwise noted, from each composite sample within each location, a single subsample was taken for the quality analyses. Therefore, the number of replications for each test equaled the number of locations included in the field trials each year.

Physical Quality Characteristics and Protein Content

Winter durum wheat grown in Virginia was graded by either Miller Milling Company (Minneapolis, MN) (1996 and 1997) or the Federal Grain Inspection Service (FGIS) (1998), according to the USDA grain grading standards (USDA, 1985). Additional quality characteristics were determined at the same time, including test weight, kernel vitreousness, falling number, and protein content. Miller Milling Company also performed some preliminary quality analysis of durum produced in 1994, but this data is incomplete (Appendix D). The 1000 kernel weight of all lines from each region was determined at Virginia Tech (Blacksburg, VA).

Table 1. Virginia grown durum lines selected for quality analyses, 1996-1998.

Virginia Line Designation	Origin	Actual Line Designation
BASA	Hungary	BASA
BZ8W90-27	Arizona	Experimental line
BZ8W91-8	Arizona	Experimental line
BZ8W92-10	Arizona	Experimental line
BZ8W92-2	Arizona	Experimental line
BZ8W92-8	Arizona	Experimental line
KORALL	Colorado	KORALL
MINARET	Hungary	MINARET
ODESSA #63	Ukraine	N1291/86
ODESSA #65	Ukraine	N1013/84
ODESSA #66	Ukraine	N1439/83
ODESSA #69	Ukraine	N736/89
OR3880152	CIMMYT	UVY162/61.130//73.44//OVI65/3/BERK/OVI65/4/C.BUG1018//BR180
OR3880158	CIMMYT	UVY162/61.130//73.44//OVI65/3/BERK/OVI65/4/C.BUG1018//BR180
OR3880181	Ukraine	PARUS
OR3910084	Romania	DF 38-86
OR3910085	France	AMBRAL
OR3910214	Romania	DF 222-95
PANNONDUR	Hungary	PANNONDUR

Aluminum Lactate – Polyacrylamide Gel Electrophoresis (A-PAGE)

To obtain a preliminary indication of the quality of the winter durum wheat germplasm grown in this test, as well as to aid in the selection of lines for breeding purposes, the gliadin fraction of each line was screened for markers that indicate excellent viscoelastic strength, and thus imply superior cooking quality. The gliadin fraction of the wheat proteins was separated by a modified procedure for 6% 3mm aluminum lactate – polyacrylamide gel electrophoresis (A-PAGE) described by Bushuk and Zillman (1978) (Appendix E).

Whole grain samples of each line were ground in a Cyclotec® Mill with a 1 mm sieve opening. Samples were obtained from 1996 composite samples. Markers for the A-PAGE were selected based upon previous knowledge of the banding patterns. Marquis, a hard red spring wheat grown in Canada, is the primary gliadin PAGE reference, with its γ-gliadin band 50 chosen as an arbitrary reference for comparison of band mobility (Bushuk and Zillman, 1978). In order to have a durum line as a reference, Quilafen, a spring durum wheat line, was obtained from Agriculture and Agri-Food Canada. In addition, Basa, a Hungarian winter durum wheat in this study, proved to be suitable as a mobility reference because of its characteristic banding pattern, which contained all of the protein bands to be identified in this analysis. Since the availability of Marquis was limited and Quilafen was not obtained until mid way through the research, Basa was run on all the gels to serve as a consistent comparison. For each line tested, banding patterns were run on two separate gels to confirm protein band identification. To demonstrate the suitability of Basa as a mobility reference, this line was run on a gel alongside lines with known banding patterns. Both Marquis and Quilafen were ground with a mortar and pestel since there were not enough kernels to use the Cyclotec® Mill.

A 6% gel solution was prepared to pH 3.1 and filtered before adding the catalyst, hydrogen peroxide. Upon addition of the catalyst, the solution was stirred for 30 s and promptly poured into glass plates, which were separated by 3 mm spacers. A 10 well comb was carefully placed on top of the gel solution. Polymerization occurred in approximately 30 minutes. The comb was carefully removed and the wells were rinsed several times with running buffer. The gel was then properly placed in the electrophoresis unit. The Hoefer electrophoresis unit (Hoefer, Vertical Slab Gel SE 60.00, Hoefer Scientific Instruments, San Francisco, CA) was connected to a Brinkman RM6 Refrigerating Circulator (Sybron Corp, Westbury, NY) maintained at 5°C.

Gliadin proteins were extracted with 70% ethanol. Samples were sonicated for 30 minutes in a Bransonic-52 (SmithKline Company, Philadelphia, PA), and then micro-centrifuged at 4500xg (Fisher Micro-Centrifuge Model 235, Bohemia, NY) for five minutes. Four drops of glycerol and 30 μl of methyl dye were added to 250 μl of the supernatant, and the samples were vortexed. Since there was some difficulty in dispersing the glycerol, the microcentrifuge tubes were inverted, tapped, and vortexed again until all of the glycerol was well dispersed. Running buffer was added in both the top and the bottom of the unit, with care being taken to remove any bubbles at the bottom of the gel. Wells were loaded using a Gilson 100 μl pipette set at 15 μl for each Virginia grown sample and 30 μl for Quilafen and Marquis. The higher amount of Quilafen and Marquis loaded on the gel was to help ensure band visibility of the hand ground samples. The gels were run with reverse polarity for fifteen minutes at 150 V, and for four hours at 375 V, or until the dye front had completely run off plus 30 minutes. Gels were stained with Coomassie R-250 Blue, 50% trichloroacetic acid (TCA) and distilled water overnight. Excess stain was removed with the same solution minus the Coomassie R-250 Blue. Gels were refrigerated overnight in a clean destaining solution to sharpen bands before being photographed. Relative mobility bands 42 and 45 were identified as the γ-gliadin protein bands as described in Bushuk and Zillman (1978). The distance each protein band traveled, or band mobility, was compared to the reference sample on each gel for identification.

Sodium Dodecyl Sulfate - Polyacrylamide Gel Electrophoresis (SDS-PAGE)

In 1993, Hussain and Lukow suggested that the presence of ω-gliadin d_4 was a better indicator of poor cooking quality attributes than γ-gliadin band 42. Furthermore, the suggested detection method, sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE), was reported to be easier and to have better resolution than that of the A-PAGE (Hussain and Lukow, 1993). Thus, in an attempt to find a less expensive, simpler method for screening lines, as well as garnering more information about the winter durum lines in this study, SDS-PAGE was performed using a modified version of the method suggested by Hussain and Lukow (1993).

The Hoefer electrophoresis unit was connected to a Brinkman RM6 Refrigerating Circulator maintained at 10°C. The gel was prepared with 1.5 mm spacers and 15 well combs. Due to the difficulty in achieving a 7.5-9.0% gradient polyacrylamide gel, an 8% polyacrylamide separating gel was utilized. The stacking gel (3.5%) was poured on top of the polymerized gradient after degassing and addition of ammonium persulfate (polymerization initiator) and TEMED (polymerization catalyst).

Whole grain samples were ground in a Cyclotec® Mill with a 1 mm sieve opening. As in the A-PAGE runs, Marquis and Quilafen were ground using a mortar and pestel since there were not enough kernels to use the Cyclotec® Mill. Quilafen served as a reference since the presence of ω-gliadin d_5 and the absence of ω-gliadin d_4 was detected in this durum line by Hussain and Lukow (1993). Basa was also run on each gel, since work performed in previous tests suggested that it would serve as a good marker due to its characteristic band pattern. Dalton Mark VII-L SDS-7 Molecular Weight Marker, which contained markers from 66 000 to 14 200 MW, was also run in one lane. This was to ensure proper identification of the ω-gliadin region, which is around 65 000 MW (Hussain and Lukow, 1993). Gliadins were extracted from the wheat samples overnight with 70% ethanol. The wheat samples were centrifuged and the supernatant was mixed 1:1 with a Modified Solution C (Solution C + dithiothreitol (DTT) and vinyl pyridine) (Appendix F). Solution C (sodium dodecyl sulfate, glycerol and bromophenol blue in Tris buffer) was filtered before making Modified Solution C to eliminate large dye particles that cause streaking in gels (Appendix F). Samples (supernatant and Modified Solution C) were incubated in a 65°C water bath for 30 minutes. Two drops of glycerol were added to the samples to improve the band clarity. Twenty microliters of each sample and 15 μl of the marker were loaded in the wells after centrifuging.

Gels were run at 40 mA until the dye front ran off, approximately four hours and fifteen minutes, longer than first anticipated. The gel was shaken gently in a fixing solution of 100% TCA, methanol, and distilled water for one hour and fifteen minutes, before staining the gel overnight with Sigma Dye Solution (B-4523). The staining solution did not stain the gels sufficiently for good visibility, so 5 ml of Coomassie R-250 Brilliant Blue was added to the staining solution. Once the gel was stained to an extent that the bands were clearly visible, the gel was destained in the same destaining solution as described for the A-PAGE (Appendix E). After destaining, the gel was transferred to a clean destaining solution and refrigerated to sharpen the bands. An attempt at identifying the omega gliadins was made based upon knowledge of the absence of d_4 and presence of d_5 in Quilafen and the molecular weight markers, as described in Hussain and Lukow (1993).

Sodium Dodecyl Sulfate Sedimentation Test

The SDS-sedimentation test disperses the semolina flour in lactic acid and sodium dodecyl sulfate. The amount of flocculation and sediment that occur over a fixed period of time is then recorded. The sediment is composed mainly of occluded starch and swollen gluten. The higher the amount of sedimentation, the stronger the gluten. The SDS-sedimentation test was performed according to the procedure developed by Dick (1981) (Appendix G).

Since only a small amount of sample was necessary for this test, replicate samples from each region were available. In 1996, 13 durum lines from Clarke County (northern ridge and valley), and 19 lines from Montgomery County (southern ridge and valley) and Orange County (northern piedmont plateau) were tested. In 1997 and 1998, 19 lines from the southern ridge and valley (Montgomery County), northern ridge and valley (Clarke County in 1997, Shenandoah County in 1998), northern piedmont plateau (Orange County) and northern coastal plain (Richmond County) locations were obtained for this test. Ten different samples were run simultaneously. Samples were run in triplicate at room temperature (24°C).

Semolina Yield and Milling

Composite seed samples of each line from the 1996-1997 growing season were sent to C. W. Brabender Instruments (South Hackensack, NJ) to be milled, with a Quadrumat Jr., at 14% moisture content into semolina. Semolina yield for each line was determined by weighing the total sample, the individual bran and the individual semolina. The percent semolina yield was then calculated as the ratio of semolina to total sample, by weight. This semolina was used for all subsequent quality tests.

Farinograph

While tests such as those using the mixograph or alveograph are more common when analyzing durum wheat, the farinograph was selected for this study due to its availability. Several research articles suggest the use of 31.5% absorption and a different lever setting for the small (50 g) farinograph bowl when studying durum wheat, however; this method has yet to become approved by the AACC (Irvine et al., 1961; Dexter and Matsuo, 1977). Therefore, the rheology (dough strength) of the winter durum wheat samples was determined with a farinograph by the constant flour weight method (AACC Method 54-21; AACC, 1984).

The farinograph test for each of the 19 semolina samples was run in triplicate. A store purchased semolina, La Rinascente brand, was selected for comparison to the Virginia grown durums because of its availability and similarity to the semolina being tested. An important note is that the commercial semolina seemed to be slightly finer in texture than the Virginia semolina, probably due to differences in the milling process, the consequences of which will be discussed later. A Brabender Farinograph® Resistograph® (C. W. Brabender Instruments, South Hackensack, NJ), with a small 50 g bowl, connected to a Julabo F10 water circulator set at 30.0°C was employed for the constant flour weight procedure. Dough strength was determined by measuring, on the farinogram, the arrival time, peak time, departure time, mixing time stability, mixing time index, tolerance index and the twenty minute drop. These parameters are defined below, as well as shown in Fig. 1.

1. Arrival Time (AT) is the amount of time in minutes it takes the curve to first intersect the 500 B.U. line.

2. Peak Time (PT), Dough Development Time (DDT), or Mixing Time (MT) are all terms used to describe the time it takes the dough to reach the point of maximum consistency. The point of maximum consistency is the highest point, or the peak, of the curve.

3. Departure Time (DT) is the time it takes for the curve to completely drop below the 500 B.U. line.

4. Mixing Time Stability (MTS) is the length of the section between AT and DT. Curve stability gives an indication of the flour's tolerance to mixing.

5. The Twenty Minute Drop (TMD) is the drop of the curve in B.U. from the 500 B.U. line to the middle of the curve after the farinograph has run for 20 minutes.

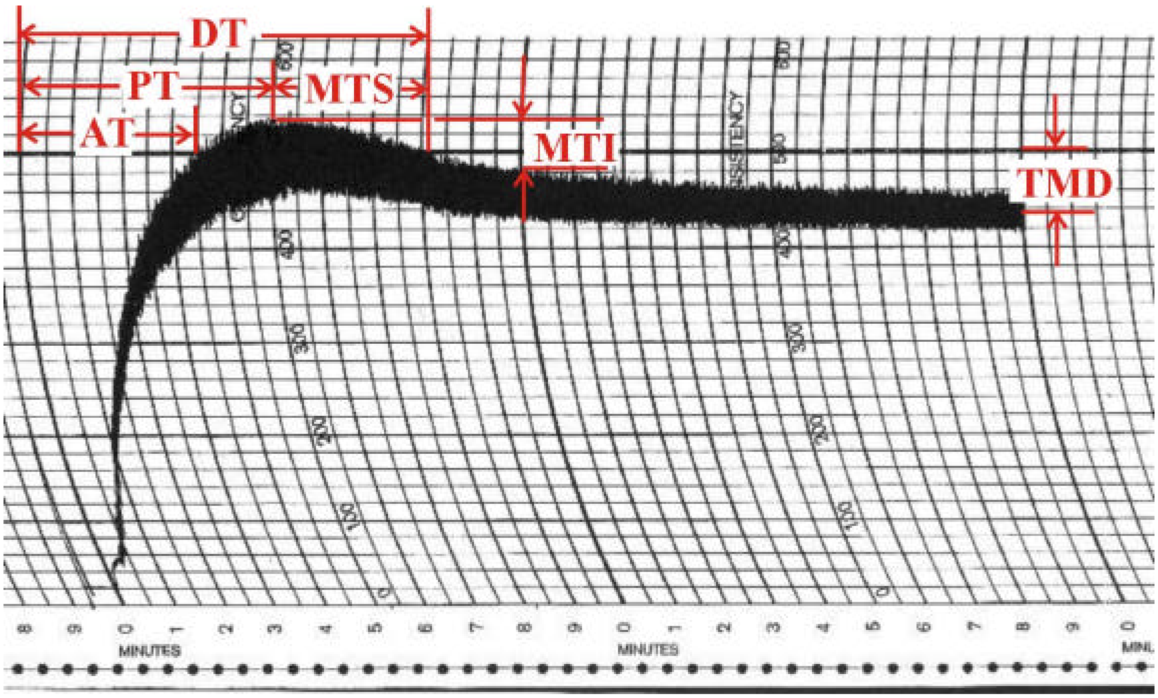


Fig. 1. Farinogram of control (store bought) semolina showing AT, PT, DT, MTS, MTI, and TMD.

6. The Mixing Time Index (MTI) is the difference in B.U. from the peak of the curve to the point five minutes later.

7. The Tolerance Index (TI) is the difference in B.U. from the peak of the curve to the point four minutes later. This is essentially the same as MTI, but suggested by Irvine et al., 1961.

Spaghetti Noodle Production

Spaghetti noodles were made from the Virginia grown durum semolina to test the end product cooking quality and firmness. Since commercial dies and pasta machinery for micromacaroni processing methods were not available, the semolina produced from each line was compared to a commercially sold semolina for home pasta making. The same semolina chosen for the farinograph tests, La Rinascente brand semolina, was used as the control due to its availability. The pasta dough was made according to the recipe on the back of the La Rinascente brand semolina box to mimic typical consumer use (Appendix H). First, two cups of semolina were measured and poured into a mixing bowl. Canola oil was then added to the semolina to help tenderize the dough. Tap water was added to the mixture and stirred in with a fork. The amount of water varied slightly by sample, according to the semolina absorption characteristics, farinogram water absorption results were a helpful guideline, and handling properties. The dough was kneaded for five minutes to develop the gluten, then covered with plastic film for 15 minutes to allow the dough to rest. The dough was rolled into strips using a commercially available Atlas pasta maker, with roll setting number four. The roll setting was determined by comparing the diameter of commercially available Creamette™ spaghetti with that produced by the pasta maker. Dried spaghetti noodles are approximately 1.9 mm in diameter. Trial runs with the pasta maker determined that roll setting 4 came closest to this noodle diameter, producing noodles of approximately 1.4 mm. After rolling each dough strip, the strip was air-dried on a kitchen towel, sprinkled with semolina and permitted to sit for five minutes. The strip was then run through the spaghetti cutter of the pasta maker. Noodles were individually separated, and placed on a kitchen towel to dry for one and a half-hours. The noodles were then arranged in a single layer on wax paper, and stored in dark drawers overnight at room temperature (24°C).

Spaghetti Color Determination

Spaghetti color may be determined by testing the color of dry semolina. The color of semolina may be quantified by visual comparison with standards, reflectance spectrophotometry, and chemical extraction of pigments and subsequent spectrophotometry. The chemical extraction of carotenoid pigments is accomplished with water soluble n-butanol (Irvine et al., 1953), but the process is tedious and the n-butanol is a noxious, flammable solvent. Tristimulus colorimeters offer a simpler and more rapid alternative to pigment extraction methods for spaghetti color measurements. Using a colorimeter, the yellowness and browness of semolina samples are reported using the Judd-Hunter tristimulus coordinates of L* (brightness) and b* (yellow-blue chromaticity) (Francis, 1983). A third coordinate, a*, is determined at the same time as the L* and b* values. The a* value offers an indication of the redness or greenness of a sample. This value is not as important in pasta production in the United States as it is in parts of Europe. The color of spaghetti noodles may be identified with only the L* and b* values (AACC Method 14-22; AACC, 1984). The yellowness of the semolina is the most important of the readings due to consumer association of noodle yellowness with quality.

For this study, the Hunter Lab D25 L Optical Sensor (Reston, VA), a colorimeter, was used to determine the lightness and yellowness of dry semolina, dried spaghetti noodles and cooked spaghetti noodles (Appendix I). By assessing the color of all three stages of pasta making, interesting comparisons can be drawn pertaining to consumer acceptance. For each of the 19 samples, color determination was performed in triplicate. The Hunter Colorimeter was calibrated with a white standard ceramic tile with L*= 93.8, a*= -0.9 and b*= -0.3. The instrument was also zeroed with a black standard ceramic tile. Semolina samples were each placed in an open disposable plastic 50 x 11 mm petri dish. Each dish was completely filled with semolina and leveled off, making the surface as smooth as possible. For both the dried and cooked spaghetti noodles, each sample was mounted in a single, nonoverlapping layer on a black piece of construction paper. Each sample was placed directly underneath the viewing area in such a way that the entire viewing area was covered. La Rinascente semolina and noodles made from La Rinascente semolina, were used as the control where appropriate. The lightness (L*) and yellowness (b*) of the samples were recorded. According to Miller Milling Company (Minneapolis, MN), it is desirable to obtain L* values greater than 81 and b* values greater than 30, with the yellowness (b*) value holding greater importance.

Spaghetti Cooking Loss and Firmness

Cooking quality and firmness were tested according to AACC Method 16-50 (AACC, 1984). Rather than utilize distilled water, tap water was used to best mimic a home situation. The tap water was analyzed by the Virginia Cooperative Extension Department of Biological Systems Engineering, to ensure the absence of any contaminants that would adversely affect the spaghetti cooking quality. The excessively negative saturation index, an estimate of the potential corrosion of metal pipes, etc., is not of concern since the pH of the water is greater than 7.0 (Table 2).

Four 25.0 g portions of dry noodles broken into pieces about 5 cm in length, were prepared for each durum line to be tested. Three hundred milliliters of tap water in a 1-quart pot were brought to a rolling boil on an electric burner. An extra pot of boiling water was kept in reserve to maintain the volume of water in the primary pot. To determine the optimum cooking time, as soon as the first sample was placed in the boiling water, the timer was started. Every thirty seconds, a strand of spaghetti was removed from the pot and pressed between the top and bottom of a clear plastic 50 x 11 mm petri dish (Fig. 2). If the center core of the spaghetti strand was still white, then the noodles were allowed to continue boiling. More boiling water, from the reserve pot, was added as necessary. When the white center core just disappeared, the timer was stopped. Optimum cooking time is the time from when the noodles were first placed in the boiling water to the time the white center core disappears. Once cooking time for a given sample had been determined, fresh water was added to both pots and brought to a boil. The timer was set to the optimum cooking time. One of the three replicates of the line being tested was added to the water, and the timer was started. Noodles were occasionally stirred to encourage free movement, and more boiling water was added as needed. When the optimum cooking time had been reached, the noodles and cooking water were immediately poured into a Buchner funnel, separating the noodles and cooking water. The cooking water, and later, the rinse water, were drained into a preweighed 500 ml glass beaker. The noodles were rinsed in the funnel with 50 ml of tap water and immediately transferred to a glass bowl of room temperature tap water.

Five strands of noodles were promptly selected and placed in the sample holder on the Instron's bottom plate. The sample was then compressed with a 1kg load at 10.0 mm/min until the tooth was within 0.5 mm from the bottom of the plate (Fig. 3). Construction of the plexiglass

Table 2. Household water quality analysis of tap water used for cooking loss analysis of durum grown in Virginia, 1996-1997 [1].

Test	**Household Water Sample**	**Maximum Recommended Level or Range**
Iron (mg/l)	0.0086	0.3
Manganese (mg/l)	<0.001	0.05
Hardness (mg/l)	53	180
Sulfate (mg/l)	6.5	250
Chloride (mg/l)	<40	250
Fluoride (mg/l)	<0.1	2
Total Dissolved Solids (mg/l)	104.0	500
pH	7.4	6.5 to 8.5
Saturation Index	-1.80	-1 to 1
Copper (mg/l)	0.014	1.0
Sodium (mg/l)	8.37	20
Nitrate-N (mg/l)	2.045	10

[1]Report by the Water Quality Laboratory, Department of Biological Systems Engineering, Virginia Tech, Montgomery County, VA 24061-0303

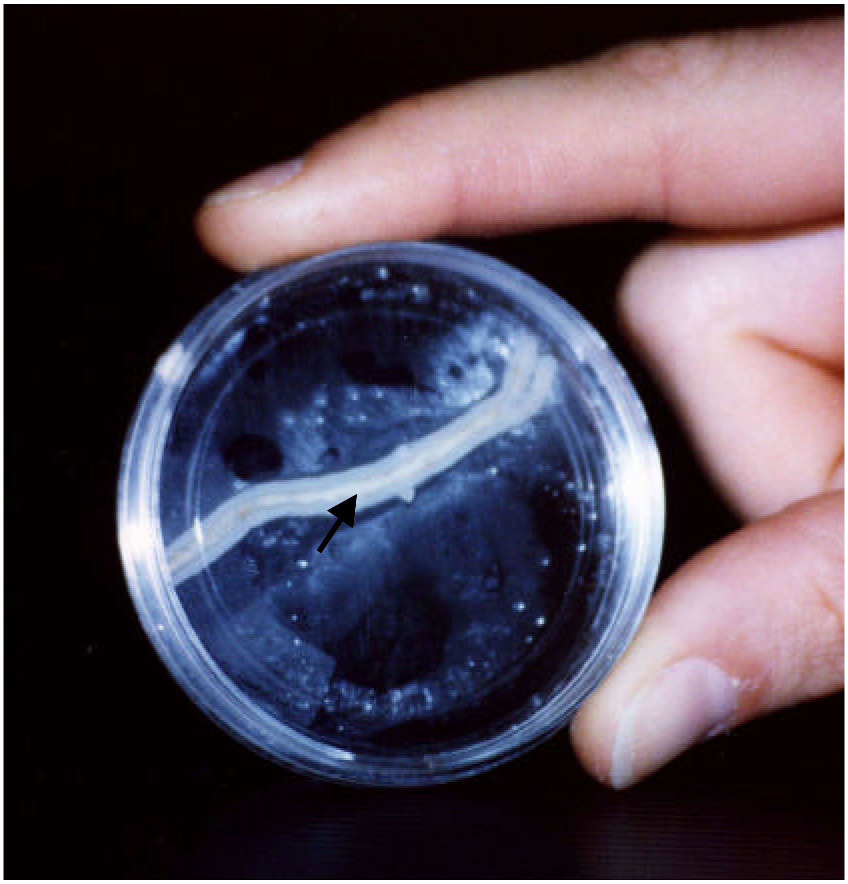


Fig. 2. The white core of the pasta noodle indicates that it optimum cooking time has not yet been reached.

Fig. 3. Instron with plexiglass tooth attachment used for testing noodle firmness.

tooth was modeled after designs suggested in Walsh and Gilles (1971) and Oh et al. (1983) (Fig. 4). The sample holder was 8 cm x 7 cm and 0.8 cm thick. Five 0.4 cm deep slots were cut horizontally across the plexiglass. Perpendicular to the five spaghetti noodle slots, a slot was cut 0.8 cm wide, just wide enough for the tooth to fit without creating any friction. The tooth was beveled down to a 1 mm flat edge that came in contact with the noodles. Cooked noodles were then lined up on a black piece of construction paper. The noodles were placed adjacent to one another without overlapping. The noodles were then tested for lightness and brightness of appearance after cooking using the Hunter Lab D25 L Optical Sensor according to the same method as for the semolina and dry pasta. The process was repeated for each replicate.

The cooking water and rinse water, which had been collected in a preweighed 500 ml beaker, was placed in a Fisher Scientific Iso Temp® Oven at 100 $\pm$ 1°C. Samples were left overnight to dry. Beakers were cooled in a desiccator and weighed. The increase in the beaker weight multiplied by four equaled the percent cooking loss.

The area under the curve generated by the Instron corresponds to the noodle firmness. In each case, the area was estimated by constructing the triangle that best fit the curve. The firmness of the noodles was compared to the control score, with high firmness values being more desirable.

Data Analysis

Analysis of variance was calculated using the SAS software package (SAS Inst., 1991). A randomized complete block design was employed for all tests, except for data from the 1998 Richmond and Shenandoah County locations, where the experimental design was a split block design. Effect of differences in disease control (for data only from Richmond County and Shenandoah County, 1998), replication, line and all interactions were tested. In cases where the data was unbalanced due to limited availability of grain, the general linear model (GLM) procedure was employed (SAS Inst., 1991). Mean separations were performed by location and line for the SDS-sedimentation tests, and by line for all other tests, if the ANOVA F-statistic indicated significant effect at the 0.05 probability level (SAS Inst., 1991).

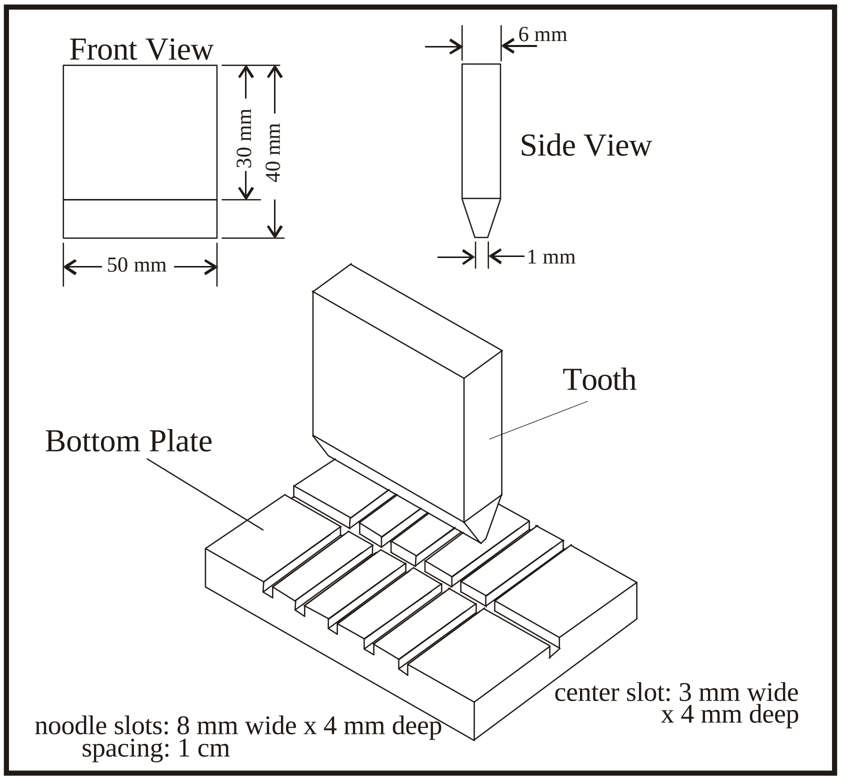


Fig. 4. Plexiglass tooth and holder used in Instron bite test for pasta firmness.

Results and Discussion

Durum genotype affected ($P<0.0001$) all of the quality tests. Statistical analysis of grade, test weight, kernel weight, kernel vitreousness, falling number and protein content was only performed on data over locations, since only one sample of each line was taken from each location. Therefore, each location represented a replication. In these cases, statistical analysis indicated that replication, and therefore location, had an effect ($P<0.0001$). This suggests the need to analyze physical quality characteristics within location, as well as across locations in Virginia.

Grade

In 1996, two winter durum lines grown in Virginia, Pannondur and Korall, received grade No.1 (Table 3). Only one line, Odessa #69, was graded No.1 in 1997, and none of the durums received the grade U.S. No.1 in 1998 (Tables 8 and 9). Out of the nineteen lines tested, eleven in 1997, six in 1996, and none in 1998 were assigned grade No.2 (Tables 3, 8 and 9). According to the 1998 Regional Crop Quality Report, the 5 year average grade for North Dakota durum is U.S. No. 2 Hard Amber Durum (NDWC, 1998). In comparison, the average grade assigned to Virginia grown durum in 1997 was U.S. No. 2, however; the average grades assigned in 1996 and 1998 were lower. However, as shown in Appendix J, the average grade across Virginia tends to hide both the best and the worst results. Several lines performed well within a single location. In 1995-1996, grade U.S. No. 1 was assigned to one line in Montgomery County and seven lines in Orange County. Furthermore, six lines in Orange County, five in Clarke County, and all 19 in Richmond County, received grade U.S. No. 1.

Overall, the weather conditions greatly influenced the grade of each line grown in Virginia. Wet weather in 1997-1998, and cold, wet weather in 1995-1996, resulted in a significant amount of weathered and disease-damaged grain. Consequently, some of the grade factors were adversely affected. For example, test weights in both years were low, and the percent of damaged kernels total was high in 1998. In contrast, the generally higher grade assigned to the durum lines in 1997 may be attributed in part to the more favorable growing conditions, which resulted in higher test weights and a lower number of damaged kernels.

Table 3. Physical quality characteristics of durum wheat grown in Virginia, averaged over locations, 1995-1996.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**1000 Kernel Weight (g)**	**Falling Number (s)**
BASA	3	13.0	74.4	62.5	11.2	40.3	450
PANNONDUR	1	12.2	79.3	45.7	12.0	43.7	390
MINARET	4	13.1	72.6	54.5	16.0	38.9	425
KORALL	1	13.1	76.8	57.0	11.8	41.9	431
BZ8W90-27	2	13.7	75.7	69.5	11.7	41.9	450
BZ8W91-8	4	11.8	71.5	30.5	11.8	38.2	430
BZ8W92-2	4	13.4	69.8	60.0	11.3	38.9	372
BZ8W92-8	3	11.9	75.5	58.3	11.7	39.7	398
BZ8W92-10	2	12.2	77.3	61.5	11.7	39.1	418
OR3880152	2	12.5	76.7	55.3	11.6	39.9	441
OR3880158	2	12.3	76.4	51.3	11.7	38.2	399
OR3910084	4	13.6	70.2	58.3	11.3	40.3	447
OR3910085	3	13.2	73.2	59.5	10.3	40.5	487
OR3880181	4	12.9	69.5	49.5	11.3	39.3	408
OR3910214	3	12.5	74.5	58.0	11.4	43.0	450
ODESSA #63	3	12.8	73.8	61.3	11.7	40.4	415
ODESSA #65	2	12.7	75.0	63.0	11.7	42.0	409
ODESSA #66	3	13.8	73.7	69.8	11.3	44.2	443
ODESSA #69	2	12.5	76.1	64.3	11.8	42.5	381
LSD (0.05)		*	*	*		4.7	*
C.V.		5.4	1.8	22.9		6.9	9.0
VA Average	3	13	74.6	60	12	41	420
Standard Deviation		1.0	0.6	2.7	9	1.1	1.8
Minimum[1]	2	12.0	74.6	75.0	<13	25.0	250

[1]Minimum specifications for pasta production

*See Tables 4-7 for significant comparisons.

Table 4. Comparisons of significant difference between falling numbers of durum grown in Virginia, 1995-1996.

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BASA	1					*							*							*
BZ8W90-27	2																			
BZ8W91-8	3																	*		
BZ8W92-10	4																	*		
BZ8W92-2	5	*																*	*	
BZ8W92-8	6																	*		
KORALL	7																	*		
MINARET	8																	*		
ODESSA #63	9																	*		
ODESSA #65	10																	*		
ODESSA #66	11												*							*
ODESSA #69	12	*										*					*	*	*	
OR3880152	13																			
OR3880158	14																	*		
OR3880181	15																	*		
OR3910084	16												*							*
OR3910085	17			*	*	*	*	*	*	*	*		*		*	*				*
OR3910214	18					*							*							*
PANNONDUR	19	*										*					*	*	*	

*Significant at P≤0.05

Table 5. Comparisons of significant difference between test weights of durum grown in Virginia, 1995-1996.

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BASA	1			*		*										*	*			*
BZ8W90-27	2							*			*			*		*				*
BZ8W91-8	3	*			*		*	*		*	*	*	*	*	*	*			*	*
BZ8W92-10	4			*		*		*								*	*			*
BZ8W92-2	5	*			*		*			*	*	*	*	*	*			*	*	*
BZ8W92-8	6			*		*										*	*			*
KORALL	7		*	*		*			*							*	*			*
MINARET	8							*			*			*	*	*	*			*
ODESSA #63	9			*		*										*	*			*
ODESSA #65	10		*	*		*			*							*	*			*
ODESSA #66	11			*		*										*	*			*
ODESSA #69	12			*		*										*	*			*
OR3880152	13		*	*		*			*							*	*			*
OR3880158	14			*		*			*							*	*			*
OR3880181	15	*	*	*	*		*	*	*	*	*	*	*	*	*			*	*	*
OR3910084	16	*			*		*	*	*	*	*	*	*	*	*			*	*	*
OR3910085	17					*										*	*			*
OR3910214	18			*		*										*	*			*
PANNONDUR	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

*Significant at P≤0.05.

Table 6. Comparisons of significant difference between kernel vitreousness of durum grown in Virginia, 1995-1996.

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BASA	1			*																
BZ8W90-27	2			*																
BZ8W91-8	3	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
BZ8W92-10	4			*																
BZ8W92-2	5			*																
BZ8W92-8	6			*																
KORALL	7			*																
MINARET	8			*																
ODESSA #63	9			*																
ODESSA #65	10			*																
ODESSA #66	11			*												*				*
ODESSA #69	12			*																
OR3880152	13			*																
OR3880158	14			*																
OR3880181	15			*								*								
OR3910084	16			*																
OR3910085	17			*																
OR3910214	18			*																
PANNONDUR	19											*								

*Significant at P≤0.05

Table 7. Comparisons of significant difference between protein content of durum grown in Virginia, 1995-1996.

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BASA	1		*	*																
BZ8W90-27	2	*		*	*	*	*			*	*		*		*	*			*	*
BZ8W91-8	3	*	*			*		*	*	*		*	*	*		*	*	*	*	
BZ8W92-10	4		*																	
BZ8W92-2	5		*	*																
BZ8W92-8	6		*					*				*					*			
KORALL	7			*			*													
MINARET	8			*																
ODESSA #63	9		*	*																
ODESSA #65	10		*									*								
ODESSA #66	11			*			*				*									
ODESSA #69	12		*	*																
OR3880152	13			*																
OR3880158	14		*																	
OR3880181	15		*	*																
OR3910084	16			*			*													
OR3910085	17			*																
OR3910214	18		*	*																
PANNONDUR	19		*																	

*Significant at P≤0.05

Table 8. Physical quality characteristics of durum wheat grown in Virginia, averaged over locations, 1996-1997.

Line	Grade	Protein (%)	Test Weight (kg/hl)	Vitreousness (%)	Moisture (%)	1000 Kernel Weight (g)	Falling Number (s)
BASA	2	14.4	78.5	73.0	12.7	43.5	525
PANNONDUR	2	13.3	81.5	71.8	13.0	42.2	407
MINARET	3	13.6	77.8	63.0	12.6	39.3	446
KORALL	2	14.4	79.3	81.3	13.2	40.0	407
BZ8W90-27	2	14.0	76.9	82.5	13.2	42.6	440
BZ8W91-8	3	13.1	76.1	66.0	12.6	37.4	346
BZ8W92-2	3	13.2	77.3	59.8	13.4	40.8	323
BZ8W92-8	2	14.3	69.5	74.3	13.1	44.1	322
BZ8W92-10	2	13.4	78.0	68.5	12.7	42.0	334
OR3880152	2	14.1	78.9	77.3	13.4	46.0	455
OR3880158	2	13.5	79.2	71.3	14.0	44.1	404
OR3910084	3	14.4	75.8	59.8	12.6	46.6	383
OR3910085	3	14.3	78.1	72.5	12.6	43.8	441
OR3880181	3	13.8	77.7	74.0	12.5	43.9	378
OR3910214	3	14.3	77.7	66.8	13.0	46.2	421
ODESSA #63	2	13.4	79.4	74.8	12.6	42.9	390
ODESSA #65	2	13.4	79.1	61.3	12.4	42.8	356
ODESSA #66	2	14.4	79.4	85.8	12.3	46.8	384
ODESSA #69	1	13.2	79.2	64.3	12.5	44.6	387
LSD (0.05)		0.6	1.5	16.9		3.8	76
C.V.		36.0	1.8	19.1		6.3	13.6
VA Average	2	14	78	70	12.9	43	400
Standard Deviation		0.5	2.6	8	0.4	2.5	50
Minimum[1]	2	12.0	74.6	75.0	<13	25.0	250

[1]Minimum specifications for pasta production

Table 9. Physical quality characteristics of durum wheat grown in Virginia, averaged over locations, 1997-1998.

Line	**Grade**	**Protein (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	5	13.9	11.5	359
BZ8W90-27	5	15.4	11.8	369
BZ8W91-8	SG[1]	12.8	11.7	368
BZ8W92-10	SG	14.1	11.5	365
BZ8W92-2	SG	14.1	11.8	341
BZ8W92-8	SG	14.3	11.9	346
KORALL	4	13.5	12.2	345
MINARET	SG	14.2	11.3	351
ODESSA #63	5	13.8	11.3	326
ODESSA #65	5	13.6	11.2	371
ODESSA #66	5	14.2	11.8	342
ODESSA #69	5	13.7	11.4	332
OR3880152	5	14.0	11.8	374
OR3880158	5	14.1	11.6	439
OR3880181	SG	13.9	11.9	342
OR3910084	SG	14.5	11.4	360
OR3910085	SG	14.7	11.7	362
OR3910214	SG	14.1	11.6	324
PANNONDUR	4	13.7	11.9	373
LSD (0.05)		0.4		76
C.V.		3.4		17.04
VA Average	5	14	11.6	360
Standard Deviation		0.6	0.32	47
Minimum[2]	2	12.0	<13	250

[1]SG = Sample Grade

[2]Minimum specifications for pasta production

Two other grading factors, contrasting classes of wheat and wheat of other classes, warrant special consideration in durum due to their potential detrimental effect on end product quality. Other wheats are usually too soft, and produce more flour and finer semolina than is desirable for high quality pasta (Feillet and Dexter, 1996). Additionally, soft wheat with low protein content reduces the nutritional value. Although the durum field trials were near soft red winter wheat plots, neither of these grading factors presented a problem. Disease management and interaction between disease management and line did not affect the grade assigned at the 0.05 level in 1998. Since the difference in disease control practices did not affect grade, it appears that there was no benefit to grade with additional fungicide treatments.

Test Weight

The first step in grading a wheat sample, even before test weight determination, is to remove the dockage, or foreign material such as chaff. Samples were cleaned before the preliminary test weight of each sample was measured at Virginia Tech (Montgomery County, VA). Samples were cleaned a second time by the milling company and the FGIS before grading. As a result, the test weights measured by the milling company and the FGIS were higher than those reported from Montgomery County, VA. To be assigned grade No.1, the test weight of a durum sample needs to be at least 77.2 kg/hl (60.0 lb/bu). This requirement was met on average only in 1996-1997 (Table 8). That year, fifteen of the 19 lines analyzed produced test weights of 77.2 kg/hl (60.0 lb/bu) or greater. In fact, in 1997, Virginia grown durum had a slightly higher average test weight, 77.9 kg/hl (60.5 lb/bu), than durum grown in North Dakota the same year, 76.2 kg/hl (59.2 lb/bu). However, the three year average of the Virginia grown durum, 72.3 kg/hl (56.2 lb/bu), was less than the North Dakota five year average of 76.7 kg/hl (59.6 lb/bu) (NDWC, 1998). The high test weights in 1997 can be partly attributed to the more timely nitrogen fertilization program than in the previous year, but are primarily due to the more favorable growing conditions. Dry conditions during grain filling allowed the seeds to become plump, reduced the incidence of disease and reduced the amount of weathered kernels. As previously mentioned, the effects of wet weather and high disease pressure lowered test weights in 1996 and 1998 (Tables 3 and 10). In 1998, limiting the fungicide treatments in Richmond and Shenandoah Counties affected ($P<0.05$) test weight. However, whether or not the reduction in fungicide applications was detrimental is difficult to determine after only one year of testing. No

Table 10. Physical quality characteristics of durum wheat grown in Virginia, averaged over locations separated by fungicide treatment, 1997-1998.

Line	**Test Weight (kg/hl)**		**1000 Kernel Weight (g)**		**Vitreousness (%)**	
	As Needed Fungicide	**Restricted Fungicide**	**As Needed Fungicide**	**Restricted Fungicide**	**As Needed Fungicide**	**Restricted Fungicide**
BASA	68.8	67.6	35.3	35.3	39	49
BZ8W90-27	66.4	64.9	33.5	33.3	54	54
BZ8W91-8	66.5	65.3	29.9	28.8	21	29
BZ8W92-10	64.1	65.3	30.9	31.0	28	41
BZ8W92-2	65.8	64.3	32.1	30.8	33	40
BZ8W92-8	66.7	64.8	33.2	32.5	46	48
KORALL	72.5	71.8	33.6	34.0	39	40
MINARET	66.4	65.2	33.0	32.8	26	27
ODESSA #63	67.6	65.5	32.6	33.0	56	49
ODESSA #65	67.2	66.2	34.3	35.0	46	49
ODESSA #66	70.2	68.4	37.9	37.8	56	57
ODESSA #69	67.3	66.8	33.8	33.3	38	52
OR3880152	68.4	66.8	33.6	33.8	41	45
OR3880158	68.9	68.4	32.8	32.5	47	57
OR3880181	63.1	62.9	33.4	34.3	41	43
OR3910084	64.9	65.1	37.5	38.5	36	52
OR3910085	65.0	64.6	31.4	30.8	44	41
OR3910214	66.5	65.2	34.5	34.5	29	35
PANNONDUR	70.4	70.2	34.9	34.0	48	51
LSD (0.05)	1.0	1.0	2.0	2.0	12	12
C.V.	1.9	1.9	5.0	5.0	27.5	27.5
VA Average	67	66	34	33	40	50
Standard Deviation	2.3	2.2	2.0	2.3	15.0	9
Minimum[1]	74.6	74.6	25	25	75	75

[1]Minimum specifications for pasta production

interaction between the different disease control practices and line was found. Over all years, a few durum lines were consistently high producers in terms of test weight. For instance, from 1996-1998, the Hungarian line Pannondur tended to produce the highest test weight among the durums tested, while OR3880181 often had the lowest test weight (Tables 3, 8, and 10).

1000 Kernel Weight

The 1000 kernel weight of all the Virginia grown durums was acceptable (>25 g), over all years (Tables 3, 8, and 10). In terms of individual durum lines, the highest kernel weights were usually observed Odessa #66 and OR3910084, suggesting that these lines will produce the best semolina yields. The average durum kernel weight was around 40 g in both 1996 and 1997 (Tables 3 and 8), however; the average 1000 kernel weight was slightly lower in 1998, for both treatments (Table 10). The wet weather and high disease pressure in 1998 could explain the drop in quality. Therefore, it is not surprising that limiting the number of fungicide applications affected ($P<0.05$) the 1000 kernel weight. However, the overall detriment (or benefit) of restricting fungicide applications is difficult to assess after a single year of testing. No interaction between disease control practices and line was found.

Kernel Vitreousness

Four durum lines grown in Virginia met or surpassed the minimum requirement for Hard Amber Durum (>75% vitreous kernels) in 1997 (Table 8). The highest percent vitreousness was produced by Odessa #66, with 86% vitreous kernels. The requirement for Amber Durum, which is 60-75% vitreous kernels, was met by 8 lines in 1996 and 13 lines in 1997 (Tables 3 and 8). Of those lines with >60% kernel vitreousness, 4 in 1996, and 12 in 1997, were assigned grade U.S. No. 2 (Tables 3 and 8). Each growing season, Odessa #66 and BZ8W90-27 consistently produced grain with more vitreous kernels than the other durum lines tested. Although individual lines performed well, as a whole, Virginia grown durum did not meet kernel vitreousness requirements for Hard Amber Durum on average in 1996, 1997 or 1998 (Tables 3, 8, and 10). As with grade and test weight, it is important to consider the performance of durum lines within location, as well as across Virginia (Appendix J). In 1995-1996, 15 of the 19 durum lines grown in Orange County had a vitreous kernel content greater than 75%. Six lines in

Montgomery County, all 19 lines in Clarke County, and 18 lines in Richmond County were classed as Hard Amber Durum in 1996-1997.

The lowest amount of vitreous kernels was produced in 1998, under complete treatment. As with other quality attributes, the wet winter during the 1997-1998 growing season was partly responsible for the poor vitreousness of the durum kernels. Durum prefers a drier environment than other classes of wheat, and it is more susceptible to weathering. The amount of yellow berries naturally increases under low protein (wet) conditions (Gooding and Davies, 1997). Disease, insect infestation or other factors affecting the kernel coloration also may have a negative effect on the kernel vitreousness. Several of the durum lines had diseased and/or weathered grain, which contributed to the reduction in kernel vitreousness. Limiting the number of fungicide applications in 1998 affected ($P<0.05$) kernel vitreousness, but the interaction between disease control practices and line was not significant at the 0.05 level.

Falling Number

The falling number test detects the amount of preharvest sprouting that has occurred. When cereal grains pregerminate, alpha-amylase and lipase are synthesized. The falling number test detects changes in viscosity of a gelatinized starch solution due to alpha-amylase activity. Therefore, high falling numbers are desirable, as they indicate a low amount of preharvest sprouting. Falling numbers were within the acceptable range of 250-500 s from 1996-1998 (Tables 3, 8, and 9). Falling numbers were not tested for the durum grown under limited fungicide applications. Since preharvest sprouting is a reflection of the weather conditions around harvest time, the acceptable falling numbers of the complete treatment suggest that the standard treatment grain would also have little, if any, sprouting. Based on this limited data, from 1996-1998, it can be concluded that preharvest sprouting is not a problem for Virginia grown durum.

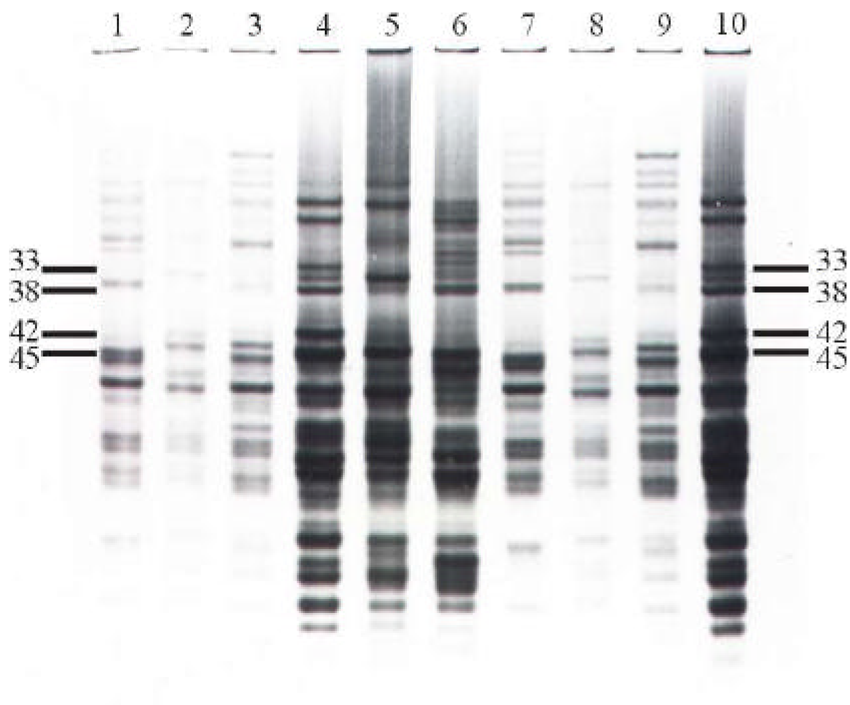
Protein Content

The protein content of most winter durum wheat lines grown in Virginia was within the acceptable range (12-16%) for all years (Tables 3, 8, and 9). In fact, the acceptable minimum of 12% protein content was not met only by two lines, BZ8W91-8 (11.8%) and BZ8W92-8 (11.9%), and only in 1996. Furthermore, eight lines in 1996 and all of the lines in 1997 had protein levels ≥ 13%, which is the desired level for high quality pasta. In 1998, BZ8W91-8 was the only line that did not have a protein level ≥ 13%. The average protein content of the durum lines increased each year from 1996-1998, mainly due to more precise timing of spring nitrogen applications during durum production. During the 1995-1996 growing season, two nitrogen applications were applied, one at Zadoks growth stage 25 and one at Zadoks growth 30. In the 1996-1997 and 1997-1998 growing seasons, a later spring application as urea was applied at flag leaf emergence (Zadoks growth stage 37). Protein content was not affected ($P>0.05$) by limiting the fungicide treatments or the interaction between fungicide treatment and durum line, in 1998. Although overall quality of the 1998 Virginia grown durum was low, the highest protein levels were observed in the 1997-1998 growing season. Some of the durum lines appeared to produce inherently high levels of protein. Lines BZ8W90-27 and OR3910084 consistently contained the highest percent protein, while BZ8W91-8 was consistently low in protein. Although percent protein and kernel vitreousness are usually correlated, this is not always the case. For example, OR3910084 had one of the highest protein contents in 1997, while the same year it had one of the lowest levels of kernel vitreousness. Overall, the acceptable levels of protein in the durum lines suggests that there is potential to produce durum with good cooking quality in Virginia.

Aluminum Lactate – Polyacrylamide Gel Electrophoresis (A-PAGE)

To determine the suitability of durum line Basa in providing a reference marker for the A-PAGE, this line was run alongside wheat lines Quilafen and Marquis, which have known banding patterns. The presence of γ-gliadin bands 42 and 45 in Quilafen and γ-gliadin band 42 in Marquis were identified in the gel shown in Fig. 5. These findings are in agreement with the findings of Kosmolak, et al.(1980) and Bushuk and Zillman (1978). As is shown on this gel, the presence of both bands 42 and 45, combined with its distinct banding pattern, make Basa a suitable reference marker for the A-PAGE .

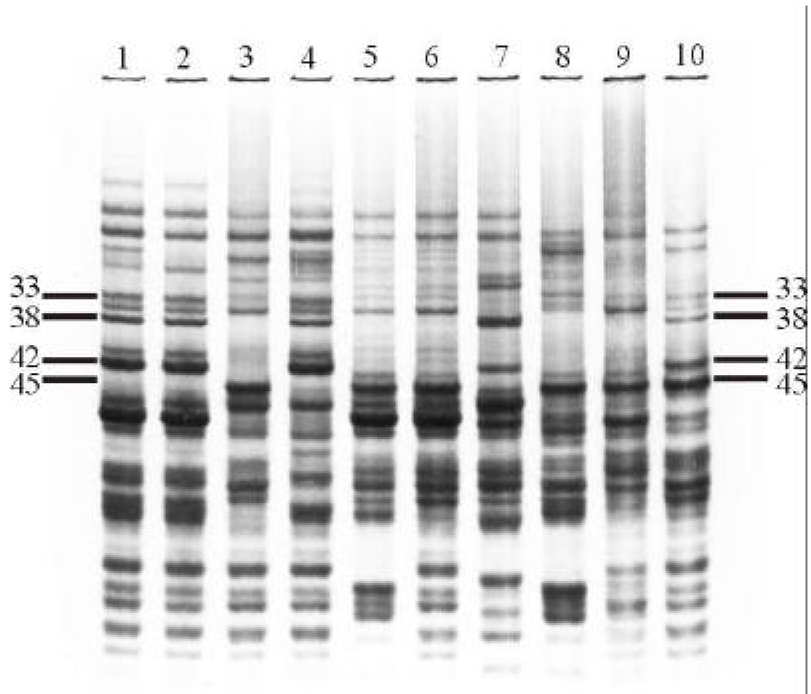
The presence of γ-gliadin band 45 was detected in 12 of the 19 lines tested (Figs. 6a and 6b). Eight of the 19 lines contained γ-gliadin band 42, suggesting inferior cooking quality. Basa was the only line found to have both bands 42 and 45. While the presence of γ-gliadin band 45 suggests strong viscoelastic properties, and thus potentially good cooking quality, the relationship of the presence of both 42 and 45 to gluten quality has not yet been definitively



Slot Number	Sample	γ-gliadin bands		ω-gliadin band d_4	
		42	**45**	**33**	**38**
1	Neepawa	-	+	-	+
2	Quilafen	+	+	-	-
3	Marquis	+	-	-	+
4	Basa	+	+	+	+
5	Minaret	-	+	-	-
6	Pannondur	-	+	-	+
7	Neepawa	-	+	-	+
8	Quilafen	+	+	-	-
9	Marquis	+	-	-	+
10	Basa	+	+	+	+

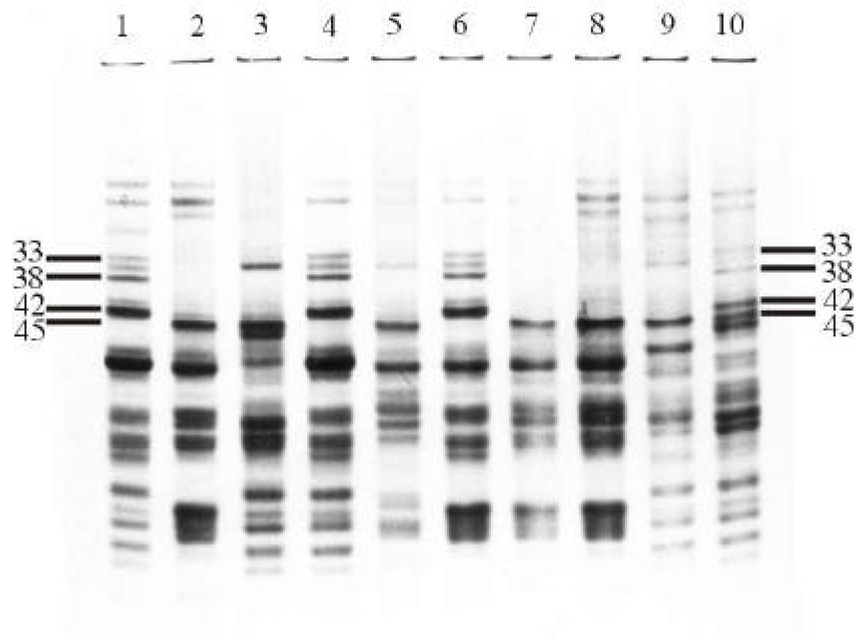
Fig. 5. A-PAGE depicting the suitability of Basa as a reference for detection of γ-gliadin bands 42 and 45.

a:



Slot Number	Sample	γ-gliadin bands		ω-gliadin band d_4	
		42	**45**	**33**	**38**
1	Odessa #63	+	-	+	+
2	Odessa #65	+	-	+	+
3	BZ8W92-8	-	+	-	-
4	BZ8W92-2	+	-	+	+
5	BZ8W91-8	-	+	-	-
6	BZ8W90-27	-	+	-	-
7	Korall	+	-	-	+
8	Pannondur	-	+	-	-
9	Minaret	-	+	-	-
10	Basa	+	+	+	+

Fig. 6. A-PAGE depicting the presence or absence of γ-gliadin bands 42 and 45, as well as ω-gliadin band d_4 in winter durum wheat grown in Virginia.



Slot Number	Sample	γ-gliadin bands		ω-gliadin band d_4	
		42	45	33	38
1	Odessa #69	+	-	+	+
2	Odessa #66	-	+	-	-
3	OR3910214	-	+	-	-
4	OR3880181	+	-	+	+
5	OR3910085	-	+	-	-
6	OR3910084	+	-	+	+
7	OR3880158	-	+	-	-
8	OR3880152	-	+	-	-
9	BZ8W92-10	-	+	-	-
10	Basa	+	+	+	+

Fig. 6. A-PAGE depicting the presence or absence of γ-gliadin bands 42 and 45, as well as ω-gliadin band d_4 in winter durum wheat grown in Virginia.

determined. However, in a study by Kosmolak, et al. (1980), one line that contained both bands possessed superior viscoelastic properties.

Sodium Dodecyl Sulfate - Polyacrylamide Gel Electrophoresis (SDS-PAGE)

Compared to the A-PAGE previously discussed, the resolution of the SDS-PAGE gels was low. Separation of the ω-gliadins was poor, making identification of ω-gliadin d_4 difficult. Chemical purity is one possible cause of error, but it is more probable that the lack of a gradient in the gel reduced the separation of the gliadins within the gel. Since the results were not decisive in this experiment, results of the A-PAGE experiment were utilized to identify the presence or absence of the ω-gliadin d_4. Omega gliadin d_4 is reported to have a relative mobility 33 and 38 in A-PAGE (Hussain and Lukow, 1993). The presence of both subunits was detected in 7 of the 8 Virginia grown durum lines possessing γ-gliadin band 42 (Figs. 6a and 6b). One of the 8 lines possessing γ-gliadin band 42 and another line possessing γ-gliadin band 45 possessed only the subunit with a relative mobility of 38 (Fig. 6a). The presence of both subunits indicates ω-gliadin d_4, and therefore suggests inferior quality, but the absence of one of the subunits has not yet been investigated in relation to durum quality attributes.

Sodium Dodecyl Sulfate Sedimentation Test

The sodium dodecyl sulfate (SDS) sedimentation test results were affected ($P<0.0001$) by location, as well as line, for all years. As previously stated, half of the plots in Shenandoah County and Richmond County were limited to no more than two fungicide applications disease control. In 1998, limiting the fungicide applications affected ($P<0.05$) sedimentation volumes in both of these regions. Additionally, sedimentation volumes were also affected by the interaction between limited fungicide applications and region ($P<0.05$). These results suggest that the effect of limiting fungicide treatments on sedimentation volumes can only be determined by considering both the individual durum line and the region where it is grown.

Sedimentation volumes were greater than the acceptable minimum of 20 mm for all lines, in all regions, from 1996-1998 (Tables 11-14). However, durum lines with sedimentation values between 50-60 mm are considered to have strong gluten characteristics (Pitz, 1992). In 1996, durum with strong gluten was only produced at Clarke County (Table 11). In 1997, three lines at Montgomery County, and four lines at Clarke County, fell into the strong gluten category

(Tables 11 and 12). Both the Orange County and Montgomery County locations had four strong gluten lines in 1998 (Tables 12 and 13). The same year, five lines in Richmond County and two lines in Shenandoah County fit into the strong gluten category (Table 11). However, with restricted fungicide applications, only the Richmond County location produced durum with strong gluten (six lines). These results emphasize that the affect of limited fungicide applications can only be interpreted on an individual line basis, within a single region. Three lines, BZ8W92-10, BZ8W92-8 and OR3910214, consistently produced some of the highest sedimentation volumes at all of the locations, over all of the years, suggesting inherent gluten strength as well as some adaptation to the Virginia environment. No single region consistently produced the highest sedimentation values over all years of this study.

Farinograph

Results of this test, shown in Table 15, are best understood by relative comparison to the control, store bought semolina (Fig. 1). The rate water is taken up by the semolina is measured by the arrival time (AT). The AT of the store bought semolina was higher ($P<0.05$) than all of the Virginia grown durums. A higher AT is more desirable since the AT increases as protein content increases (Shuey, 1984b). After the initial hydration, the dough begins to develop. At this point, the gluten protein fibrils begin to spread out over the starch to form a continuous matrix with a homogeneous appearance (Preston and Kilborn, 1984). The dough continues to develop until it reaches a point of maximum consistency. The peak time (PT) of 8 of the 19 tested lines was not different ($P>0.05$) from the control. A higher concentration of glutenins increases the PT, while a higher concentration of gliadins shortens the PT (Lorenz, 1984). Therefore, one might expect that those lines with higher peak times would have a high concentration of glutenins.

As the dough begins to breakdown, the curve begins to drop. The time it takes the curve to completely drop below the 500 Brabender Units (B.U.) line is the departure time (DT). A stronger flour is indicated by a longer departure time (DT). The longest departure time was

Table 11. SDS-sedimentation test results for durum grown in Clarke County (1995-1997) and Shenandoah County (1997-1998) in the northern ridge and valley of Virginia.

	Sedimentation Volume (mm)			
Line	**1995-1996**	**1996-1997**	**1997-1998**	
			As Needed Fungicide	**Restricted Fungicide**
BASA	29.8	46.3	31.7	31.0
PANNONDUR	33.0	50.3	37.8	34.3
MINARET	40.0	38.0	41.0	42.5
KORALL	32.8	30.0	28.3	26.3
BZ8W90-27	Not available	36.2	41.7	40.0
BZ8W91-8	Not available	33.5	33.7	33.5
BZ8W92-2	39.0	38.8	35.5	34.7
BZ8W92-8	51.5	55.3	48.5	38.8
BZ8W92-10	50.5	65.0	52.3	47.0
OR3880152	36.0	40.7	36.2	34.0
OR3880158	32.7	30.0	36.7	33.5
OR3910084	23.3	23.2	25.7	34.7
OR3910085	50.7	37.0	44.2	44.0
OR3880181	27.8	24.2	33.3	30.0
OR3910214	46.8	58.0	51.2	46.5
ODESSA #63	Not available	20.7	25.7	23.0
ODESSA #65	Not available	20.7	26.3	26.5
ODESSA #66	Not available	29.0	35.0	31.7
ODESSA #69	Not available	20.8	27.8	26.7
LSD (0.05)	4.0	3.5	2.2	2.2
C.V.	6.3	5.8	5.3	5.3
Average	40	40	40	30
Standard deviation	9	13	8	7

Table 12. SDS-sedimentation test results for durum grown in Montgomery County, in the southern ridge and valley of Virginia.

	Sedimentation Volume (mm)		
Line	**1995-1996**	**1996-1997**	**1997-1998**
BASA	28.2	31.7	38.8
PANNONDUR	32.2	37.3	44.6
MINARET	37.7	44.8	55.4
KORALL	33.5	30.8	35.2
BZ8W90-27	33.3	43.8	43.8
BZ8W91-8	27.5	32.0	37.8
BZ8W92-2	33.7	38.0	43.8
BZ8W92-8	44.8	52.3	61.2
BZ8W92-10	46.8	50.3	65.4
OR3880152	32.8	32.8	38.9
OR3880158	32.3	33.2	41.3
OR3910084	22.7	22.7	24.3
OR3910085	43.0	45.5	45.2
OR3880181	25.8	26.3	29.8
OR3910214	42.7	54.2	64.9
ODESSA #63	22.7	20.2	26.4
ODESSA #65	25.7	23.5	27.9
ODESSA #66	45.0	36.3	44.0
ODESSA #69	26.5	23.5	27.5
LSD(0.05)	2.3	2.7	3.6
C.V.	4.2	4.5	7.6
Average	30	40	40
Standard deviation	8	10	12

Table 13. SDS-sedimentation test results for durum grown in Orange County, in the northern piedmont plateau of Virginia.

	Sedimentation Volume (mm)		
Line	**1995-1996**	**1996-1997**	**1997-1998**
BASA	30.5	26.2	35.1
PANNONDUR	32.2	31.3	38.4
MINARET	45.3	32.7	51.4
KORALL	35.7	26.0	28.1
BZ8W90-27	35.7	36.8	43.3
BZ8W91-8	23.2	25.3	32.3
BZ8W92-2	34.8	27.2	39.6
BZ8W92-8	33.5	37.3	57.6
BZ8W92-10	47.7	42.0	59.9
OR3880152	29.5	22.2	33.3
OR3880158	32.5	29.5	34.8
OR3910084	21.3	19.7	23.3
OR3910085	36.7	26.5	46.3
OR3880181	24.5	21.5	27.6
OR3910214	45.3	35.3	50.7
ODESSA #63	22.5	19.7	21.8
ODESSA #65	20.8	20.3	25.9
ODESSA #66	29.8	26.2	36.9
ODESSA #69	24.3	20.7	23.9
LSD(0.05)	3.4	3.1	2.6
C.V.	6.5	6.7	5.9
Average	30	30	40
Standard deviation	8	7	12

Table 14. SDS-sedimentation test results for durum grown in Richmond County, in the northern coastal plain of Virginia.

Line	Sedimentation Volume (mm) 1996-1997	1997-1998 As Needed Fungicide	1997-1998 Restricted Fungicide
BASA	27.8	38.5	39.7
PANNONDUR	33.3	39.5	38.8
MINARET	37.0	59.8	59.7
KORALL	29.5	31.7	34.3
BZ8W90-27	36.7	43.3	47.8
BZ8W91-8	30.0	35.8	47.3
BZ8W92-2	30.7	47.2	51.5
BZ8W92-8	42.0	59.8	65.3
BZ8W92-10	45.7	64.7	66.8
OR3880152	30.3	38.2	43.7
OR3880158	36.7	43.2	43.3
OR3910084	20.6	24.7	26.8
OR3910085	28.4	50.7	57.8
OR3880181	22.5	29.7	28.7
OR3910214	42.0	64.5	65.7
ODESSA #63	19.8	25.7	24.0
ODESSA #65	22.4	29.3	26.8
ODESSA #66	32.1	44.3	40.7
ODESSA #69	23.0	29.0	28.0
LSD(0.05)	1.9	2.8	2.8
C.V.	3.7	5.7	5.7
Average	30	40	40
Standard deviation	8	13	14

Table 15. Semolina yield and farinogram data for durum grown in Virginia, 1996-1997.

Line	Semolina Yield (%)	Absorption (%)	Peak Time (min)	Arrival Time (min)	Departure Time (min)	Mixing Time Stability (min)	Mixing Tolerance Index (BU)	Tolerance Index (BU)	Twenty Minute Drop (BU)
		Farinograph Results							
CONTROL[1]	.	57.2	5.00	3.40	8.27	4.87	55	52	53
BASA	68.12	52.1	4.75	2.17	10.70	8.53	33	32	50
PANNONDUR	68.08	53.1	2.53	1.95	3.32	1.37	138	133	158
MINARET	64.44	54.6	5.00	2.90	7.47	4.57	47	40	67
KORALL	62.21	52.3	3.42	2.45	5.00	2.55	95	87	143
BZ8W90-27	61.41	55.3	3.25	2.33	5.02	2.68	105	87	157
BZ8W91-8	64.24	55.2	2.67	1.97	3.92	1.95	107	97	140
BZ8W92-2	64.36	56.6	3.73	2.57	7.53	4.97	50	50	33
BZ8W92-8	64.25	53.8	4.90	2.53	12.25	9.72	35	27	53
BZ8W92-10	65.38	56.3	5.10	3.12	10.18	7.07	40	38	43
OR3880152	64.06	53.6	3.37	2.47	5.00	2.53	67	57	107
OR3880158	64.37	54.7	4.67	2.88	8.12	5.23	52	45	70
OR3910084	64.99	54.1	4.00	2.50	6.58	4.08	80	70	77
OR3910085	66.16	55.5	4.08	2.93	6.00	3.07	80	70	103
OR3880181	60.67	56.7	4.50	3.08	7.83	4.75	50	47	53
OR3910214	62.45	59.4	3.58	2.75	6.33	3.58	58	53	97
ODESSA #63	56.66	55.1	4.58	3.00	7.42	4.42	67	57	67
ODESSA #65	55.78	58.9	5.00	3.00	9.75	6.75	48	38	70
ODESSA #66	59.15	54.7	3.83	2.58	6.00	3.42	72	63	97
ODESSA #69	62.92	53.9	3.17	2.42	5.25	2.83	73	70	103
LSD (0.05)		0.6	0.75	0.22	0.79	0.84	10	14	11
C.V.		.65	11.2	5.1	6.7	17.3	9.0	13.6	7.9
VA Average	63	55	4	2.6	7	4	70	60	90
Standard Deviation	3.3	2	0.8	0.36	2.4	2.2	28	26	39

[1]La Rinascente semolina

observed for BZ8W92-8. Furthermore, four durum lines (Basa, BZ8W92-8, BZ8W92-10, and Odessa #65) had a longer DT ($P<0.05$) than the store bought semolina, which suggests a higher glutenin content than the control. Three lines (BZ8W92-2, OR3880158, and OR3880181) had a DT that was not different ($P>0.05$) from the control. Durum line BZ8W92-8 also held the highest value for mixing time stability (MTS), which provides an indication of the durum's tolerance to mixing. The durum lines BZ8W92-8, Basa, BZ8W92-10, and Odessa #65 had MTS values higher ($P<0.05$) than all other lines, including the control. Six other lines grown in Virginia were not different ($P>0.05$) from the store bought semolina for MTS.

Good mixing tolerance is also shown by a low mixing tolerance index (MTI) and a low tolerance index (TI). As previously noted, the granulation of the store bought semolina appeared to be a little finer than that of the Virginia grown durum. This is important to keep in mind when comparing the scores of the control with Virginia grown durum, as smaller particle sizes can result in increased TI values (Irvine et al., 1961). Spaghetti production is usually at lower absorption levels (26.5-36.0%) than those employed in this farinograph method (Irvine et al., 1961). The TI is therefore very useful in assessing the durum gluten strength in this test, since it is not affected by absorption (Irvine et al., 1961). Three lines, BZ8W92-8, Basa and BZ8W92-10, had better ($P<0.05$) MTI and TI scores than the store bought semolina. A long PT with a low TI indicates excellent gluten quality (Irvine et al., 1961; Matsuo et al., 1972). A tolerance index of 75 Brabender Units (B.U.) or less indicates a very elastic, extensible dough that forms a strong, thin membrane upon sheeting, which is common for bread wheats (Irvine et al., 1961). Fifteen of the durum lines grown in Virginia had a TI less than 75 B.U. Interestingly, the control semolina also had a TI less than 75 B.U. Irvine et al. (1961) suggest that a low TI may be the result of heterogeneous semolina samples, low protein samples, or just a characteristic of certain durum lines. This places an ambiguous light on the interpretation of these results, as a high TI is generally associated with high quality durum.

The last parameter measured, the twenty minute drop (TMD), provides a good indication of the breakdown rate of the flour, with a higher TMD indicating a weaker flour (Shuey, 1984a). The five lowest TMD scores were not different ($P>0.05$) from the store bought semolina, suggesting that these lines have acceptable viscoelastic strength.

Overall, BZ8W92-8, Basa, and BZ8W92-10 appeared to have the strongest viscoelastic characteristics in comparison to the other durum lines. In many cases, the farinogram attributes of these three lines surpassed those of the store bought semolina. These positive farinograph results support the A-PAGE results for these three lines, as they contain γ-gliadin band 45, a genetic marker for the low molecular weight sub unit glutenins responsible for good viscoelastic properties. In addition, both BZ8W92-8 and BZ8W92-10 consistently produced high SDS-sedimentation volumes, another important test for gluten strength. The importance of the farinograph test is that is provides very specific knowledge of the dough properties which are not always clear from the SDS-sedimentation tests or gel electrophoresis. For example, the farinograph clearly indicates that Pannondur and BZ8W91-8 produced weak dough, even though both lines contained γ-gliadin band 45 (Fig. 7). Another example is Basa, whose gluten strength is difficult to determine based on gel electrophoresis or SDS-sedimentation tests, since it contains both γ-gliadin band 45 and γ-gliadin band 42, and generated only moderate SDS-sedimentation volumes. However, the farinograph clearly indicates that Basa produces a strong dough (Fig. 8). This is in agreement with findings of Kosmolak et al. (1980) who found one line containing both γ-gliadin band 45 and 42 to have superior viscoelastic strength. It is important to keep in mind that the results of this test are only as good as the control semolina used as a comparison. Good durum lines usually have less elastic and more extensible gluten than that utilized for bread doughs. Therefore, lines such as Pannondur, which have relatively poor viscoelastic properties may still be suitable for pasta production.

As observed in this study, often a single test for gluten strength does not give the complete story. If possible, it is helpful to consider the results of more than one test for gluten strength. It is clear from the protein markers, the SDS-sedimentation volumes and the farinograms of Virginia grown durum that it is possible to produce durum with good gluten strength in Virginia.

Semolina Yield and Milling

The highest semolina yields were obtained from Basa and Pannondur, both yielding around 68% semolina (Table 15). As previously reported, Pannondur consistently produced grain with a high test weight and kernel weight. This suggested that Pannondur would also have a higher semolina yield relative to the other durum lines, as this measurement demonstrated. High semolina yields are more desirable. The five year average semolina yield for durum in

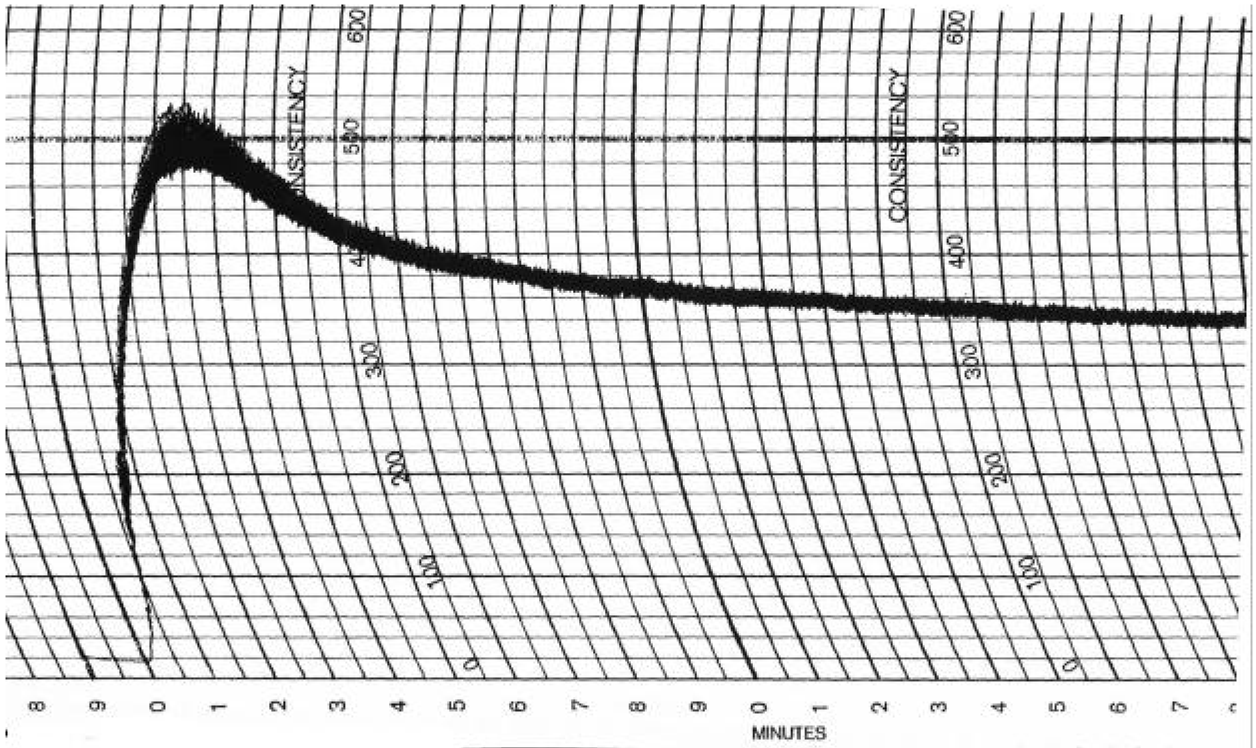


Fig. 7. Farinogram of the winter durum wheat line Pannondur.

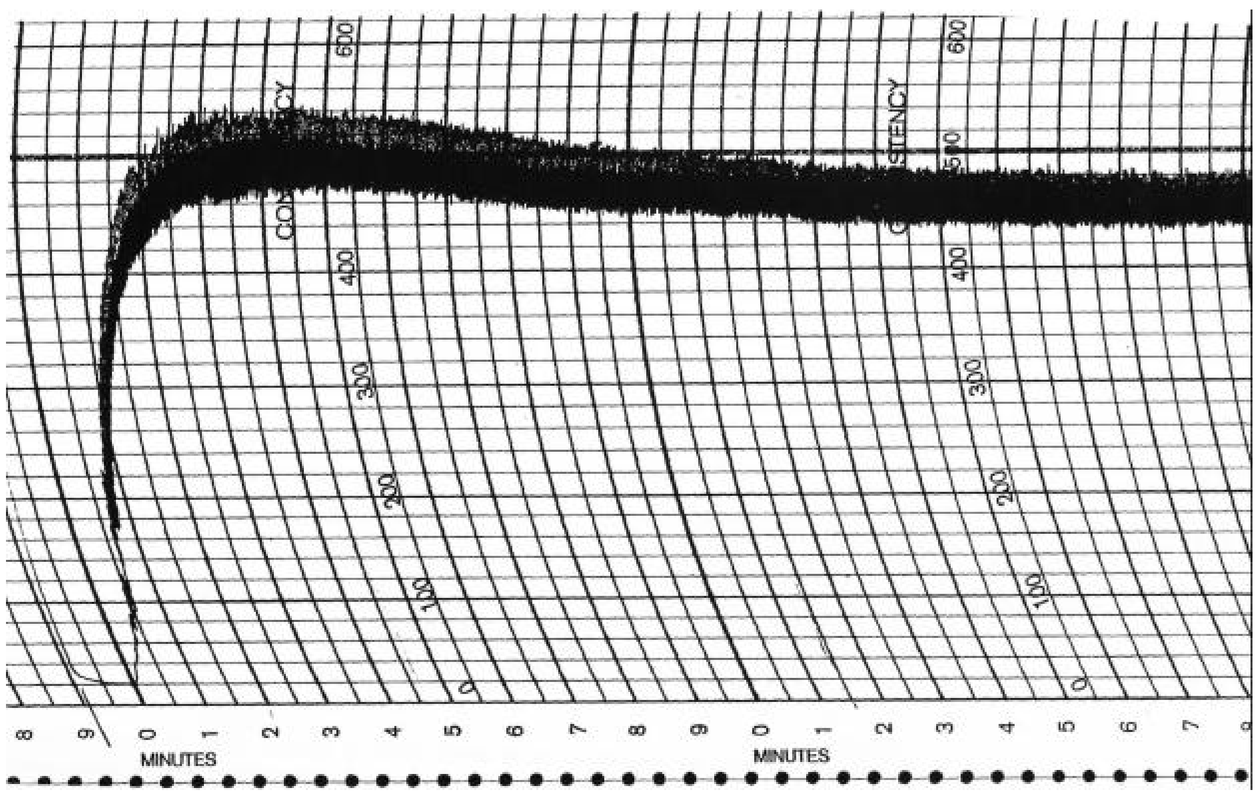


Fig. 8. Farinogram of the winter durum wheat line Basa.

North Dakota and Montana is 61% (NDWC, 1998). Overall, the semolina yield average (63%) was slightly higher than that of North Dakota durum in 1997 (60%) (NDWC,1998).

Spaghetti Color Determination

All of the durum lines grown in Virginia had acceptable semolina lightness scores, ranging from 85.3-88.2 (Table 16). The store bought semolina had the most desirable lightness score L*= 91.5, while the highest lightness score from a Virginia grown durum was L*= 88.2 for Odessa #69 (Table 16). As mentioned previously, the store bought semolina appeared to be of finer granulation than the Virginia grown durum semolina. While the store semolina had the highest lightness scores, it is important to keep in mind that the finer the semolina granulation, the paler it appears. The pale color of the semolina was observed not only visually, but with colorimeters as well (Irvine, 1971; Symons and Dexter, 1991). The store bought semolina also had the highest yellowness score, b*= 27.0, but this was not different (P>0.05) from that of the best Virginia grown durum with a score of b* = 26.5 for Odessa #65 (Table 16). None of the lines, including the store bought semolina, met the minimum score b*>30 for semolina yellowness (Table 16).

Dried noodles, as well as cooked noodles, were also tested using the colorimeter. Testing of the dried and cooked noodles gives a good assessment of the end product quality, relative to the control. Most of the overnight dried strands of noodles had high lightness scores compared to the noodles made from store bought semolina, with BZ8W91-8 having the highest score of L*= 66.4 (Table 16). Four of the lines had lightness scores not different (P>0.05) from the store bought semolina, and ten lines had higher scores (P<0.05, Table 16). As with the semolina, the highest yellowness score for dried pasta was produced by Odessa #65 (Table 16). The noodles made from the store bought semolina had the second highest score, and three noodle samples from Virginia grown durum lines had yellowness scores that were not different (P>0.05) from the store bought control (Table 16).

Odessa #65 consistently proved to have the highest yellowness score, in semolina, dried noodles and cooked noodles (Table 16). In the cooked noodle test, the next highest b* scores were for the noodles made from store semolina and those from Odessa #63. Three Virginia grown durum lines produced cooked noodles with lightness color scores that were not different (P>0.05) from the control. The durum line OR3880152 had the highest L* score, and

Table 16. Semolina, dried pasta and cooked pasta color scores for durum grown in Virginia, 1996-1997.

	Semolina Color Scores		Dried Overnight Spaghetti Strands Color Scores		Cooked Pasta Color Scores	
Line	**L[2]**	**b[3]**	**L**	**b**	**L**	**b**
CONTROL[1]	91.5	27.0	59.0	29.4	66.1	12.8
BASA	85.4	20.1	58.8	22.5	66.6	7.7
PANNONDUR	85.3	23.4	65.1	23.1	70.2	10.6
MINARET	85.6	20.7	60.2	21.1	65.2	7.9
KORALL	87.4	23.8	52.2	23.9	65.2	10.5
BZ8W90-27	86.3	22.4	59.0	23.0	67.9	10.2
BZ8W91-8	86.9	24.7	66.4	26.7	70.8	10.5
BZ8W92-2	86.5	25.3	57.9	27.2	70.6	10.3
BZ8W92-8	86.5	24.2	61.1	28.2	68.5	9.0
BZ8W92-10	87.2	21.5	56.9	24.5	67.3	8.5
OR3880152	88.0	22.4	62.4	26.6	71.8	10.3
OR3880158	87.9	20.1	51.3	22.8	65.7	8.0
OR3910084	87.1	25.2	64.6	28.7	68.9	10.2
OR3910085	87.2	21.7	54.9	24.2	65.9	8.6
OR3880181	86.8	25.3	63.8	26.9	70.8	11.2
OR3910214	86.9	25.3	62.0	26.2	68.8	10.6
ODESSA #63	86.5	24.9	62.1	28.7	69.9	12.7
ODESSA #65	85.3	26.5	62.5	31.7	70.2	14.0
ODESSA #66	87.2	20.9	48.6	19.8	62.0	9.3
ODESSA #69	88.2	24.0	61.8	0.0	67.2	11.1
LSD (0.05)	0.8	0.6	1.5	1.7	0.8	0.6
C.V.	0.6	1.6	1.5	4.1	0.7	3.7
VA Average	87	23	60	20	68	10
Standard Deviation	0.9	2.0	4.9	7	2.5	1.6

[1]La Rinascente Semolina

[2] L = 0 = Black; 100 = White

[3] b = +30 = Yellow; -30 = Blue

BZ8W91-8, which had the highest dried overnight noodle L* score, produced the second highest cooked noodle L* score.

In terms of lightness, the results of the colorimetry test indicated that the spaghetti noodles produced from the Virginia grown durum be comparable to those made from commercially available semolina. All of the winter durums had higher semolina lightness scores than the minimum acceptable score (L*= 81). Furthermore, several lines had dried pasta and cooked noodle lightness scores that were higher or not different (P>0.05) from the control. The guidelines provided by Miller Milling Company (Minneapolis, MN) for semolina yellowness, b*>30, were not even met by the store bought semolina. Therefore, potential acceptance of the durum yellowness may be judged relative to the control. While the semolina yellowness scores of the winter durum were all less (P<0.05) than that of the control, several lines had dried and cooked noodles of comparable quality. These results suggest that spaghetti noodles produced from the Virginia grown durum will be of acceptable lightness and yellowness in comparison to noodles produced from commercial semolina.

Spaghetti Cooking Loss and Firmness

Cooking loss provides an overall measure of how much the spaghetti breaks down during cooking. Cooking loss is very sensitive to water hardness. As previously noted, the water analysis results did not suggest any extraordinary chemicals present that would adversely affect the results obtained (Table 2). The optimum cooking time for most durum lines was longer than that for the control (Table 17). The amount of cooking loss has been correlated to sensory evaluation for stickiness (D'Egidio et al., 1982). Only four Virginia grown lines, Odessa #65, Basa, BZ8W92-8 and BZ8W91-8, had a higher (P<0.05) cooking loss than noodles produced from the store bought semolina, suggesting excessive noodle stickiness (Table 17). Odessa #66, in contrast, had less (P<0.05) cooking loss than the control. The cooking loss from the other 15 Virginia grown lines was not different (P>0.05) from noodles made with store bought semolina. These results indicated that noodles made from Virginia grown durum will generally be acceptable, in terms of stickiness, in comparison to noodles made from commercial semolina. Additionally, a high glutenin content is correlated to low amounts of cooking loss, thus it is probable that Virginia grown durum has an acceptable glutenin content necessary for good cooking quality (Walsh and Gilles, 1971).

Table 17. Cooking quality characteristics of durum grown in Virginia, 1996-1997.

Line	Cooking Time (min)	Cooking Loss (%)	Spaghetti Firmness g-cm
CONTROL[1]	5.5	5.0	0.71
BASA	8.5	6.5	0.89
PANNONDUR	7.5	5.2	0.95
MINARET	8.0	4.8	0.82
KORALL	9.0	5.2	0.61
BZ8W90-27	6.5	4.8	0.59
BZ8W91-8	8.0	5.9	0.78
BZ8W92-2	8.5	5.0	0.70
BZ8W92-8	10.0	6.0	0.71
BZ8W92-10	7.0	5.3	0.82
OR3880152	5.0	4.3	0.66
OR3880158	7.0	4.7	0.94
OR3910084	7.0	4.7	0.76
OR3910085	6.5	4.5	0.76
OR3880181	8.5	4.9	0.75
OR3910214	8.0	4.9	0.83
ODESSA #63	8.0	4.7	0.61
ODESSA #65	10.0	7.1	0.85
ODESSA #66	5.5	4.2	0.74
ODESSA #69	5.5	4.4	0.79
LSD (0.05)		0.7	0.19
C.V.		8.3	15.3
VA Average	8	5	0.8
Standard Deviation	1.4	0.8	0.10

[1]La Rinascente semolina

A high glutenin content is also correlated to high noodle firmness scores, which provide an indication of consumer acceptance of the end product (Walsh and Gilles, 1971; Oh et al., 1983). Two Virginia grown durum lines, Pannondur and OR3880158, produced noodles with greater ($P<0.05$) firmness than the control (Table 17). All other firmness scores did not differ ($P<0.05$) from those of noodles made from store bought semolina. The lack of difference ($P>0.05$) in firmness between the noodles made from lines grown in Virginia and those made from store bought semolina is an excellent indication that Virginia durum can produce good quality semolina for homemade noodles.

Conclusions

Production of high quality pasta products, such as spaghetti and linguini, requires high quality durum wheat. The tests performed in this study provide an estimate of the quality, and therefore an indication of the suitability for pasta, of winter durum grown in Virginia. These tests covered physical quality characteristics, protein quantity and quality, and end product quality. Tests that measured physical quality characteristics included: grade, test weight, 1000 kernel weight, kernel vitreousness, and falling number. These tests are of great interest to durum millers, since they are used to predict milling or semolina quality. When used together, both the test weight and 1000 kernel weight test results are useful in predicting semolina yield. However, the extra confidence gained by performing both tests is not always necessary. Since 1000 kernel weight does not depend on kernel shape, and therefore the packing of the kernels, it is a suitable screen for preliminary analyses of new durum lines.

Potential production and cooking quality characteristics of durum are predicted by tests for protein content and protein quality (gluten strength). Protein content is also an important factor in grain marketability, as premiums are paid for high protein wheat. Three different ways to estimate gluten strength were employed in this study: gel electrophoresis, SDS-sedimentation tests, and farinograph. Use of gel electrophoresis to screen for γ-gliadin 45, an indicator of strong gluten, and γ-gliadin 42, an indicator of weak gluten, proved to be especially helpful when screening lines for breeding purposes, since the presence of these proteins bands are not affected by growing conditions. However, the procedure is expensive and time consuming. Since reagents and apparati for SDS-PAGE have become increasingly commonplace in laboratories, this technique was used to screen lines for ω-gliadin d_4. Unfortunately, the resolution of these gels was too poor to be useful. Careful analysis of the gels used to detect γ-gliadins 42 and 45 showed that it is possible to detect the presence of ω-gliadin d_4 on these gels. The ω-gliadin d_4, or at least one of its subunits, was detected in all lines containing γ-gliadin 42. From this analysis, it is difficult to determine whether the presence of ω-gliadin d_4 was equivalent to or better than γ-gliadins 42 as an indicator of weak gluten. In contrast to gel electrophoresis, the SDS-sedimentation test for gluten strength does not require sophisticated equipment and is much more rapid. However, since this test is affected by wheat protein content, results for the same line may vary from location to location. Furthermore, a standardized process for small samples has not yet been widely accepted, so results often differ between laboratories. The third technique used to test gluten strength employed the farinograph. Compared to data from the other tests, data from the durum farinograms are most closely related the end product performance. This more specific information proved to be especially helpful in clarifying ambiguous data gathered in other gluten tests. Unfortunately, unlike the other gluten strength tests, the farinograph requires large amounts of milled samples. Furthermore, like the SDS-sedimentation test, this test may be affected by additional factors, such as protein. Although these three tests contain some overlap, they offer enough important differences to make each worthwhile for a detailed quality study. If only one or two gluten strength tests are to be used, the appropriate test may be selected based on expense and sample availability.

Appeal of the final product from Virginia grown winter durum wheat was assessed by tests for color, cooking loss and noodle strength. Color analysis for lightness and brightness of the semolina, dried noodles and cooked noodles provides useful insight into appearance of the finished product. Cooking loss and noodle strength test results correlate to the stickiness and firmness, respectively, of the end product (D'Egidio et al., 1982; Oh et al., 1983).

While no single line met all of the minimum acceptable quality standards from 1996-1998, there were several lines that excelled in particular quality tests. Detailed information of the quality test results for these lines will be important in future development of durum lines suitable for Virginia. A summary of the quality test results for the lines having notable performance in specific quality areas follows.

<u>Odessa #66</u> – Odessa #66 is of particular interest since this line excelled in the highest number of physical quality attributes, an area where the Virginia grown durum tends to be weak. The test weight, kernel weight, protein content and kernel vitreousness were usually among the highest of those tested. Furthermore, this line possesses γ-gliadin band 45, an indicator of good gluten strength. However, sedimentation volumes and the farinogram for this line suggest that its gluten strength is average in comparison to the other 18 lines. Semolina yield was less than the Virginia average. Although the lightness and brightness scores of the semolina were about average, both scores were below average for the dried and cooked noodles. Furthermore, visual observations of Odessa #66 dough and noodles suggest that, without modification, the dough may be too dull and gray for acceptable noodle production. Interestingly, Walsh and Gilles

(1971) found that a high glutenin content and a low gliadin content are correlated to poor color durum lines. Perhaps due in part to the good protein content and gluten strength, noodles made from this line had below average cooking loss and high firmness scores, indicating low noodle stickiness and acceptable noodle firmness.

Basa - Interestingly, Basa possesses both γ-gliadin bands 42 and 45. Based on SDS-sedimentation test results, this line produces an acceptable level of gluten strength across all regions. Further testing for gluten strength with the farinogram indicates that this line has superior viscoelastic properties to other lines tested. Even though Basa's test weight met the minimum weight of 77.2 kg/hl for grade No. 1 in 1997, it produces only an average test weight relative to the other winter durums. The 1000 kernel weight met the minimum requirements each year. Furthermore, Basa yielded the most semolina of the milled durums. Basa has a good protein level, in fact, in 1997, this line contained the highest percent protein of those tested. Relative to the other durum lines, Basa kernels are of average vitreousness, however; from 1996-1998 grain from this line never met the 75% vitreous kernels minimum requirement for grade No.1. Basa semolina, as with all of the Virginia semolina, is light in color. However, the lightness and yellowness of this line's semolina, dried noodles, and cooked noodles tended to be low relative to the other durums, as well as to the control. Although the cooked noodles had good firmness, they were also very sticky, as indicated by the high amount of cooking loss.

Pannondur – This Hungarian line consistently produced grain of a good test weight and an acceptable kernel weight. In both 1996 and 1997, Pannondur met the minimum test weight necessary for grade No.1. Like Basa, Pannondur produced a high semolina yield. Kernel vitreousness of this line is generally poor compared to the other durum lines tested, and it never met the requirements for the class Hard Amber Durum. While produced at an acceptable level each year, the protein content of this line was low in comparison to the other durums. A weak farinogram indicates that in comparison to the other lines, this dough has weak viscoelastic properties. Sedimentation volumes were average each year, at each location, with the exception of the 1996-1997 growing season. That season, the sedimentation volumes of Pannondur grown in the northern ridge and valley suggested strong gluten characteristics. This indication was further supported by the presence of γ-gliadin band 45, an indicator of strong viscoelastic properties. Furthermore, Pannondur noodles were firmer (P>0.05) than the control and were not excessively sticky (as shown by the cooking loss test). While the lightness of Pannondur's semolina was less than the Virginia average, the semolina yellowness was slightly higher than average. Furthermore, the lightness and yellowness of both the dried and cooked noodles surpassed the Virginia average.

BZ8W92-10 - BZ8W92-10 consistently produced top sedimentation volumes, indicating good gluten strength. This is further supported by the presence of γ-gliadin band 45 and a good farinogram. In addition to good gluten quality, the physical quality characteristics of this line are comparable to, or better than, the other lines tested. This line met the minimum test weight requirement for grade No.1 in both 1996 and 1997. Additionally, the kernel weight and protein content were acceptable all years. Kernel vitreousness was average in comparison to the other lines grown. Semolina yield for this line was greater than the Virginia average. While semolina color scores were average, lightness and yellowness scores for both dried and cooked noodles were just below average. Noodle firmness and stickiness were not different (P>0.05) from the control, which suggests good textural characteristics.

Odessa #65 – Odessa #65 stands out from the other durum lines because of its good color. While the semolina lightness scores for this line were less than average, the yellowness scores were not different (P>0.05) from the control. Furthermore, both the lightness and the yellowness scores surpassed the average for cooked and dried noodles. In comparison to the other lines tested, Odessa #65 has an average test weight (>77.2 kg/hl in 1997), average kernel weight, low protein content, and average percent kernel vitreousness. The semolina yield was below average. Although γ-gliadin band 42 suggests poor viscoelastic properties and this line has only low to moderate sedimentation volumes, the farinogram produced from Odessa #65 indicates moderate viscoelastic properties. Additionally, Odessa #65 noodles possess good firmness. However, the noodles were sticky, as shown by its significantly high cooking loss.

Meeting physical quality standards such as test weight and kernel vitreousness, which are greatly affected by environmental conditions, appears to be the most problematic area for Virginia grown durum. A closer look at specific locations where durum was grown would be useful in determining whether or not these standards might only be met in specific regions within Virginia. Currently, across Virginia, many of the durum lines show potential to meet standards for U.S. No. 2 Amber Durum, which may be blended with higher quality durum to produce pasta. Protein content and quality of these lines was shown to be equal to or above the minimum acceptable requirements. Pasta quality tests suggest that the finished product from these lines will appeal to the consumer. To be a competitive alternative crop to soft red winter wheat, durum lines with better adaptation to the wet Virginia climate and greater disease resistance must be found before the durum will consistently meet the standards necessary to be marketable for use in premium pasta products.

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Chapter V
Conclusions

Since durum wheat is not currently produced at a commercial level in Virginia, milling companies in this state must import durum wheat, or miss out on the durum market. Although Virginia is typically a soft red winter wheat region, successful durum production could translate into a profit for durum producers since transportation costs would be significantly reduced. In 1993, an investigation into the feasibility of producing durum wheat in Virginia began at the request of extension agents in Shenandoah, Frederick, Clarke, and Page Counties. The primary objectives of this study were to determine the adaptation and yield potential of available durum lines to a region, Virginia, south and east of its traditional U.S. areas of production, to assess the quality of Virginia grown durum, and to estimate consumer acceptance of the end product produced from this durum.

Over the period from 1993 to 1998, 63 durum lines were tested in Virginia. These lines originated from many different areas of the world so, not surprisingly, their adaptation to Virginia varied. Furthermore, this study shows that the agronomic production characteristics of each line varies between different regions in Virginia. Field trials in the 1993-1994 growing season demonstrated that only true winter type durum could survive the cold Virginia winters. The humid, often wet weather of Virginia is much different from areas where durum wheat is typically grown. While soft red winter wheat is well adapted to Virginia, durum is better suited to regions, such as North Dakota, with rainfall during vegetative growth and dry periods during grain maturation (Berzonsky and Lafever, 1993).

Durum thrived in the relatively dry 1996-1997 growing season, however; these growing conditions were the exception for Virginia, rather than the rule. The wet, humid weather that is typical for Virginia, encourages the spread of disease. This was especially problematic for durum, which is more susceptible than soft red winter wheat to many diseases. *Fusarium* head blight was particularly devastating to many of the durum lines. Currently there are no known resistant durum lines, and seed treatment fungicides offer limited protection in wet environments. In the 1994-1995 growing season, the entire crop was lost due to poor growing conditions (excessive moisture and high disease pressure). The wet weather in 1997-1998 encouraged the spread of disease and increased the number of weathered kernels. Results from these growing seasons clearly demonstrate the need for durum lines with high levels of disease resistance (especially to *Fusarium* head blight) and better tolerance to wet growing conditions.

In terms of cultural practices, winter durum wheat fits into the soft red winter wheat region well. Winter durum is planted in mid-October and harvested in late June, around the same time as soft red winter wheat. Lodging is not a problem in durum, and the height of most durum lines is acceptable (<101.6 cm). Heading date for most lines, however, was later than the later heading soft red winter wheat cultivar FFR 555W. As mentioned previously, durum yields differed significantly from region to region. Durum wheat consistently performed well in the northern piedmont plateau, in comparison to other regions. This region is characterized by clay to clay loam soils. Durum had relatively average yields on fine loamy soils, but fared poorly in sandy or coarse loamy soil. While durum is more susceptible to disease than soft red winter wheat, preliminary data in 1998 indicates that fungicide applications may not always be necessary or useful.

Finally, a few of the lines from the Ukraine, Odessa #63, Odessa #65, Odessa #66 and Odessa #69, were consistently among the highest yielding durum lines. However, no single line was the highest producer at any location for more than two years. This indicates that while these lines are perhaps better adapted to Virginia, further improvements must be made before durum is truly adapted to any region in Virginia.

The yield of available winter durum lines, as with all other classes of wheat, is inherently lower than that of soft red winter wheat in Virginia. However, the price premium associated with high quality durum can compensate for the lower yield, making durum production economically advantageous. In Virginia, durum production would have been more profitable on average than soft red winter wheat production in 1994 and 1997. However, the opposite is true for years 1995, 1996 and 1998. Since a price premium is only received for high quality durum, the economic advantage referred to here relies on the assumption that Virginia durum meets U.S. No. 2 Hard Amber Durum standards.

It is important to consider the extent of the potential economic advantage. For example, based on results from the northern piedmont plateau, durum production would have been 13% more profitable in 1994 and 34% more profitable in 1997. In contrast, soft red winter wheat production would have been more profitable in 1996 and 1998 by 29% and 24%, respectively, in the same region. Furthermore, the unfavorable growing conditions in the 1994-1995 growing season were disastrous to the durum crop, while soft red winter wheat still managed to produce moderate yields. Although not always the economically advantageous choice over soft red winter wheat, this study shows that durum wheat production at an economically competitive level with soft red winter wheat is possible in Virginia.

As the economic analysis indicates, both yield and quality are critical to the success of durum production in Virginia. The price received for durum grain depends on its quality, as millers pay a premium price for high quality durum wheat. The grade and subclass designations are important because these characteristics provide millers with much needed insight into the potential milling and semolina quality of the wheat. Tests such as falling number and 1000 kernel weight can supplement those used for grading purposes, and offer additional information concerning the durum's potential quality. A high protein content is important due to its tremendous influence on pasta cooking quality. By assessing the quality of this protein, further insight into the pasta making potential of Virginia grown winter durum wheat is gained. Cooking loss, color and firmness tests can further support selection of lines with good quality by offering a different perspective on the quality of Virginia grown durum, that of end product acceptance by the consumer.

Over 1996-1998, durum wheat produced in Virginia consistently met the quality requirements for 1000 kernel weight, percent protein, falling number, and sedimentation volumes. Furthermore, twelve of the 19 lines tested possess γ-gliadin band 45, an indicator of good viscoelastic strength, thus implying good cooking quality. Farinograph test results further suggest that at least three of the durum lines possess rheological properties and cooking properties equal to or better than commercially available semolina. Additionally, results of the color, cooking loss, and noodle firmness tests indicate that, overall, Virginia grown durum can produce an end product comparable to that produced from commercially available semolina. Although protein quantity, protein quality, and end product quality were acceptable for most Virginia grown durum, the physical quality characteristics were weak overall. The minimum requirements for physical quality characteristics such as test weight, kernel vitreousness and semolina yellowness were not met by most of the durum lines over all years. Also, due primarily to low test weights and low percent kernel vitreousness, in most cases Virginia grown durum did not meet the requirements for a grade designation of U.S. No.1. Hard Amber Durum. Many of the lines, however, met the standards for U.S. No. 2 Amber Durum. Although this designation results in a lower market value, U.S. No. 2 Amber Durum may be used in blends with higher quality durum for pasta production. Results of the quality analysis did not reveal one durum line of superior quality, rather several lines with good quality in specific areas. These results will be useful in future selection for good quality traits in the development of durum lines suitable to Virginia.

Clearly, there will be a significant economic advantage to Virginia growers if high yielding, quality durum can be produced in Virginia. The wet, humid Virginia climate is the primary limiting factor in durum production, since durum inherently performs better in dry environments. Virginia’s climate often encourages high disease pressure or extensive kernel weathering, which not only reduces durum yields, but durum quality as well. These factors greatly increase the risk of growing durum wheat as an alternative to soft red winter wheat. Due to the lower yields of durum wheat relative to those of soft red winter wheat, it is especially important that the physical quality characteristics of durum at least meet U.S. No. 2 Hard Amber Durum standards. Only then can the shortcoming in yield be compensated for by the difference in price for durum wheat. When averaged over all of Virginia, the grade designation of U.S. No. 2 Hard Amber Durum was only achieved in a few cases, in 1996-1997. For the above reasons, winter durum wheat cannot currently be considered an economically feasible alternative to soft red winter wheat over all of Virginia.

It is important to note that the physical quality results represent the average of each line over all of Virginia. Careful consideration of the test results reveals that location always made a significant difference in the physical quality characteristics of durum wheat. This study shows that several lines have promise to meet the minimum requirements for U.S. No. 2 Hard Amber Durum in some years, although the Virginia average is of a lower market quality. Perhaps Virginia is simply too diverse for a single line to be successful over the entire state. Therefore, it is recommended that physical quality characteristics of each line be addressed within location. In other words, the low average Virginia grade designation may be due to poor quality results from a few specific regions that are less suitable for durum production.

Overall, no single durum line grown in Virginia stood out as both the highest yielding and best quality durum line. In fact, as a general rule, lines with relatively high yields often had poor quality characteristics. The good news, however, is that lines do exist that exhibit either excellent quality characteristics or relatively high yields. Therefore, the existing lines demonstrate promise for future success through breeding for the appropriate traits. The information gathered in field trials and quality analyses will be useful towards improvement of the durum lines. However, durum lines with higher adaptation to the wet Virginia climate and greater disease resistance must be found before durum will consistently be a competitive alternative to soft red winter wheat in Virginia.

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Apendices
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Appendix A
Durum Plot Management Practices, 1993-1998

Table 1. Durum wheat production management practices during the 1993-1994 growing season.

County	Date	Management	Description
Montgomery			
	10/1/93	Fertilization	20-60-100 (N-P-K)/2.47ha (20-60-100/acre)
	10/5/93	Planting	
	3/15/94	Fertilization	N 67.2 kg/ha (60 lb/acre)
	7/5/94	Harvest	
Shenandoah			
	Oct-93	Fertilization	according to soil test recommendations
	Oct-93	Planting	
	3/7/94	Fertilization	70-0-0-10 (N-P-K-S)/2.47 ha (70-0-0-10/acre)
	Jul-94	Harvest	
Orange			
	9/30/93	Fertilization	10-10-10 (N-P-K) 627 kg/ha (600 lb/acre)
	10/14/93	Planting	
	4/8/94	Fertilization	N 67.2 kg/ha (60 lbs/acre)
	5/5/94	Fungicide	Bayleton 18.3 ml/ha (0.25 oz/acre)
	5/25/94	Fungicide	Bayleton 18.3 ml/ha (0.25 oz/acre)
	6/23/94	Harvest	

Table 2. Durum wheat management practices during the 1994-1995 growing season.

County	Date	Management	Description
Orange			
	10/3/94	Fertilization	5-10-10 (N-P-K) 672 kg/ha (600 lb/acre)
	10/12/94	Planting	
	3/13/95	Fertilization	N 44.8 kg/ha (40 lb/acre)
	4/7/95	Fertilization	N 50.4 kg/ha (45 lb/acre)
	4/14/95	Fungicide	Bayleton 292 ml/ha (4 oz/acre)
	7/12/95	harvest	
Richmond			
	10/1/94	Fertilization	30-60-80-15 (N-P-K-S)/2.47ha (30-60-80-15/acre)
	10/11/94	Planting	
	2/7/95	Fertilization	N 44.8 kg/ha (40 lb/acre)
	2/7/95	Herbicide	Harmony Extra 36.6 ml/ha (0.5 oz/acre)
	6/19/95	harvest	
Montgomery			
	9/20/94	Fertilization	25-60-60 (N-P-K)/2.47 ha (25-60-60/acre)
	9/27/94	Planting	
	11/1/94	Herbicide	Glean 18.3 ml/ha (0.25 oz/acre)
	7/10/95	harvest	

Table 3. Durum wheat management practices during the 1995-1996 growing season.

County	Date	Management	Description
Orange			
	9/22/95	fertilization	30-60-150 (N-K-P)/2.47 ha (30-60-150/acre) On 39A (Rep 3 and 4)
	9/22/95	fertilization	30-60-0 (N-K-P)/2.47 ha (30-60-0/acre) On 38B (Rep 1 and 2)
	10/13/95	planting	
	2/26/96	fertilization	N 22.4 kg/ha (20 lb/acre)
	3/13/96	herbicide	Alleys sprayed with Roundup and Paraquat
	4/15/96	fertilization	N 22.4 kg/ha (20 lb/acre)
	4/23/96	fungicide	Tilt 292 ml/ha (4 oz/acre)
	5/15/96	herbicide	2,4 D amine 3/4 pint/acre
		herbicide	Banvel 1/4 pint/acre
		herbicide	Harmony 36.5 ml/ha (0.5 oz/acre)
	5/23/96	fungicide	Bayleton 584 ml/ha (8 oz/acre)
	6/27/96	harvest	
Richmond			
	10/11/95	fertilization	30-60-80 (N-P-K)/2.47 ha (30-60-90/acre)
	10/19/95	planting	
	12/5/95	herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
	2/1/96	fertilization	N 75 kg/ha (67 lb/acre)
	3/1/96	herbicide	Butricil 36.5 ml/ha (0.5 oz/acre)
	3/30/96	fertilization	N 44.8 kg/ha (40 lb/acre)
	5/4/96	fungicide	Karate 183 ml/ha (2.5 oz/acre)
	6/26/96	harvest	
Montgomery			
	9/21/95	fertilization	25-60-60 (N-P-K)/2.47 ha (25-60-60/acre)
	10/2/95	planting	
	11/27/95	herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
	3/12/96	fertilization	30-0-0 (N-P-K)/2.47 ha (30-0-0)/acre
	3/12/96	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	4/12/96	fertilization	60-0-0 (N-P-K)/2.47 ha (60-0-0/acre)
	Jul-96	harvest	
Clarke			
	9/1/95	fertilization	According to soil test recommendations
	10/1/95	planting	
	3/12/96	fungicide	Tilt 292 ml/ha (4 oz/acre)
	4/4/96	fertilization	60-0-0 (N-P-K)/2.47 ha (60-0-0/acre)
	Jul-96	harvest	

Table 4. Durum wheat management practices during the 1996-1997 growing season.

County	Date	Management	Description
Orange	10/14/96	fertilization	35-70-70 (N-K-P)/2.47 ha (35-70-70/acre)
	10/14/96	planting	
	3/17/96	fertilization	N 67.2 kg/ha (60 lb/acre)
	4/2/97	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	4/3/97	fertilization	N 44.8 kg/ha (40 lb/acre)
	4/24/97	fungicide	Cerone 0.5 pint/acre
	4/24/97	fungicide	Tilt 292 ml/ha (4 oz/acre)
	4/24/97	fertilization	Urea 33.6 kg/ha (30 lb/acre)
	7/1/97	harvest	Plots 101,102,119,120,121
	7/7/97	harvest	Remaining plots
Richmond			
	10/7/96	fertilization	30-60-60 (N-P-K)/2.47 ha (30-60-60/acre)
	10/17/96	planting	
	2/19/97	fertilization	25-0-0-3 (N-P-K-S) 67.2 kg/ha (60 lb/acre)
		herbicide	Harmony Extra 44 ml/ha (0.6 oz/acre)
	3/25/97	fertilization	25-0-0-3 (N-P-K-S) 50.4 kg/ha (45 lb/acre)
	4/11/97	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	4/17/97	fertilization	Urea 33.6 kg/ha (30 lb/acre)
	4/21/97	fungicide	Tilt 292 ml/ha (4 oz/acre)
	4/30/97	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	5/18/97	fungicide	Karate 146 ml/ha (2 oz/acre)
	5/20/97	fungicide	Bayleton 438.5 ml/ha (6 oz/acre)
	6/25/97	harvest	
Montgomery			
	9/25/96	fertilization	25-60-80 (N-P-K)/2.47ha (25-60-80/acre)
	10/13/96	planting	
	2/19/97	fertilization	60-0-0 (N-P-K)/2.47 ha (60-0-0/acre)
	3/25/97	fertilization	12-0-0-13 (N-K-P-S)/2.47 ha (12-0-0-
		fertilization	Urea 53.8 kg/ha (48 lb/acre)
		herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
	5/1/97	fertilization	30-0-0 as urea in 57 gallons water/acre
	5/2/97	fungicide	Tilt 292 ml/ha (4 oz/acre)
	7/9/97	harvest	
Clarke			
	Sep-96	fertilization	According to soil test recommendations
	Oct-96	planting	
	3/7/97	fertilization	60-0-0 (N-P-K)/2.47 ha (60-0-0/acre)
		herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
		fungicide	Bayleton 219.3 ml/ha (3 oz/acre)
	May-97	fertilization	30-0-0 as urea in 57 gallons water/acre
		fungicide	Tilt 292 ml/ha (4 oz/acre)
	Jul-97	harvest	

Table 5. Durum wheat management practices during the 1997-1998 growing season.

County	Date	Management	Description
Montgomery			
	10/3/97	fertilization	25-60-90 (N-P-K)/2.47ha (25-60-90/acre)
	10/7/97	planting	
	2/25/98	fertilization	40-0-0-5 (N-P-K-S)/2.47ha (40-0-0-5/acre)
	3/23/98	herbicide	Gramaxone 1.5 pts/a
	3/27/98	fertilization	60-0-0-7 (N-P-K-S)/2.47ha (60-0-0-7/acre)
		herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
	4/7/98	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	4/21/98	fertilization	granular urea 15-0-0/2.47 ha (15-0-0/acre)
	4/28/98	fungicide	Tilt 292 ml/ha (4 oz/acre)
	Jul-98	harvest	
Richmond			
	10/8/97	fertilization	30-80-120 (N-P-K)/2.47ha (30-80-120/acre)
	10/23/97	planting	
	2/10/98	fertilization	N 67.2 kg/ha (60 lb/acre)
		herbicide	Harmony Extra 44 ml/ha (0.6 oz/acre)
	3/25/98	fertilization	N 67.2 kg/ha (60 lb/acre)
	8-Apr	fungicide	Tilt 292 ml/ha (4 oz/acre)
	4/27/98	fungicide	Bayleton 44 ml/ha (0.6 oz/acre)
			(As needed fungicide treatment only)
	5/15/98	fungicide	Bayleton 44 ml/ha (0.6 oz/acre)
	6/21/98	harvest	
Orange			
	9/8/97	fertilization	25-50-60 over 1 acre
		fertilization	25-25-25 over the other acre
	10/9/97	planting	
	12/3/97	herbicide	Harmony Extra 36.5 ml/ha (0.5 oz/acre)
	2/25/98	fertilization	N 33.6 kg/ha (30 lb/acre)
	3/27/98	fertilization	N 67.2 kg/ha (60 lb/acre)
	6/24/98	harvest	
Suffolk, Shenandoah and Nottoway			
	Sep-97	fertilization	According to soil test recommendations
	Oct-97	planting	
	Zadoks GS 25	fertilization	25-0-0-3 (N-P-K-S) 44.8 kg/ha (40 lb/acre)
		herbicide	Harmony Extra 44 ml/ha (0.6 oz/acre)
	Zadoks GS 30	fertilization	25-0-0-3 (N-P-K-S) 56 kg/ha (50 lb/acre)
	Zadoks GS 37	fertilization	granular urea (N) 16.8 kg/ha (15 lb/acre)
	4/11/98	fungicide	Bayleton 292 ml/ha (4 oz/acre) (As needed treatment only)
	4/21/98	fungicide	Tilt 292 ml/ha (4 oz/acre)
	4/30/98	fungicide	Bayleton 292 ml/ha (4 oz/acre) (As needed treatment only)
	5/18/98	pesticide	Karate 146 ml/ha (2 oz/acre)
	5/20/98	fungicide	Bayleton 292 ml/ha (4 oz/acre)
	Jul-98	harvest	

Appendix B
Average yield and test weight of durum grown in Nottoway County, VA (southern piedmont plateau): 1997-1998

Table 1. Average yield and test weight of durum grown in Nottoway County, VA (southern piedmont plateau): 1997-1998.[3]

Rank[1]	**Line**	**Yield (kg/ha)**	**Test Weight (kg/hl)**
1	FFR 555W[2]	7595	69.3
2	OR3910084	4432	69.0
3	ODESSA #66	4327	72.2
4	ODESSA #65	4279	72.0
5	ODESSA #63	4257	70.8
6	ODESSA #69	3897	71.8
7	MINARET	3809	70.3
8	OR3910214	3794	68.9
9	KORALL	3743	75.1
10	OR3880152	3635	70.6
11	OR3880158	3563	71.1
12	OR3910085	3434	66.4
13	BZ8W91-8	3332	71.2
14	OR3880181	3294	67.7
15	BZ8W90-27	3235	64.3
16	BZ8W92-8	3194	69.9
17	BASA	3042	69.8
18	PANNONDUR	2955	73.2
19	BZ8W92-10	2787	66.5
20	BZ8W92-2	2408	66.9
Durum Test Average		3548	69.8
SRWW Yield Advantage		4047	

[1]Rank according to yield.
[2]Soft red winter wheat
[3]See Tables 2 and 3 for comparisons of significant difference.

Table 2. 1997-1998 Comparisons of significant difference between yields of durum grown in Nottoway County, VA (southern piedmont plateau).

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BASA	1					*		*	*	*	*	*	*	*	*			*		*	
BZ8W90-27	2					*		*			*	*	*	*				*			
BZ8W91-8	3					*		*			*	*	*					*			
BZ8W92-10	4							*	*	*	*	*	*	*	*	*		*	*	*	
BZ8W92-2	5	*	*	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	
BZ8W92-8	6					*		*		*	*	*	*	*				*			
FFR 555W[1]	7	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*
KORALL	8	*			*	*		*					*					*			*
MINARET	9	*			*	*	*	*										*			*
ODESSA #63	10	*	*	*	*	*	*	*								*	*		*		*
ODESSA #65	11	*	*	*	*	*	*	*								*	*		*		*
ODESSA #66	12	*	*	*	*	*	*	*	*							*	*		*		*
ODESSA #69	13	*	*		*	*	*	*									*				*
OR3880152	14	*			*	*		*										*			*
OR3880158	15				*	*		*			*	*	*					*			*
OR3880181	16					*		*			*	*	*	*				*			
OR3910084	17	*	*	*	*	*	*	*	*	*					*	*	*		*	*	*
OR3910085	18				*	*		*			*	*	*					*			
OR3910214	19	*			*	*		*										*			*
PANNONDUR	20							*	*	*	*	*	*	*	*	*		*		*	

[1] soft red winter wheat

*Significant at P≤0.05

Table 3. 1997-1998 Comparisons of significant difference between test weights of durum grown in Nottoway County, VA (southern piedmont plateau).

Entry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BASA	1		*		*	*			*										*		*
BZ8W90-27	2	*		*			*	*	*	*	*	*	*	*	*	*	*	*		*	*
BZ8W91-8	3		*		*	*			*										*		
BZ8W92-10	4	*		*			*		*	*	*	*	*	*	*	*					*
BZ8W92-2	5	*		*			*		*	*	*	*	*	*	*	*					*
BZ8W92-8	6		*		*	*			*										*		*
FFR 555W[1]	7		*						*										*		*
KORALL	8	*	*	*	*	*	*	*		*	*	*		*	*	*	*	*	*	*	
MINARET	9		*		*	*			*										*		
ODESSA #63	10		*		*	*			*								*		*		
ODESSA #65	11		*		*	*			*								*	*	*	*	
ODESSA #66	12		*		*	*											*	*	*	*	
ODESSA #69	13		*		*	*			*								*		*	*	
OR3880152	14		*		*	*			*										*		
OR3880158	15		*		*	*			*								*		*		
OR3880181	16		*						*		*	*	*	*		*					*
OR3910084	17		*						*			*	*								*
OR3910085	18	*		*			*	*	*	*	*	*	*	*	*	*					*
OR3910214	19		*						*			*	*	*							*
PANNONDUR	20	*	*		*	*	*	*									*	*	*	*	

[1] soft red winter wheat

*Significant at P≤0.05

Appendix C
General Agronomic Characteristics of Durum Wheat Grown in Virginia, 1993-1998

Table 1. Average heading date, height, and winter kill of durum grown in Montgomery County, VA (southern ridge and valley): 1993-1994.

Line	Heading Date (Mar 31 +)	Height (cm)	Winter Kill (%)	Line	Heading Date (Mar 31 +)	Height (cm)	Winter Kill (%)
COKER 9803[1]	40	84	0	BZ8W92-20	46	78	0
FFR 555W[1]	44	86	0	BZ8W92-21	46	81	0
MASSEY[1]	43	106	0	BZ8W92-22	48	77	0
PIONEER 2548[1]	41	90	0	BZ8W92-3	48	79	0
WAKEFIELD[1]	43	105	0	BZ8W92-4	46	80	13
BASA	45	83	6	BZ8W92-5	47	75	87
BZ8289-6	46	80	1	BZ8W92-6	47	79	0
BZ8W90-2	44	73	15	BZ8W92-7	46	75	3
BZ8W90-27	48	73	2	BZ8W92-8	45	80	0
BZ8W90-29	45	76	0	BZ8W92-9	46	81	0
BZ8W90-33	46	78	2	ELBURZ	46	75	65
BZ8W90-7	39	77	25	ELBURZ-1	48	69	91
BZ8W90-8	39	79	25	HAD-6	55	79	37
BZ8W91-1	45	74	1	KORALL	46	108	0
BZ8W91-2	47	70	0	MINARET	45	83	4
BZ8W91-4	42	70	2	OR3880015	44	80	20
BZ8W91-7	46	77	0	OR3880152	47	79	1
BZ8W91-8	44	73	0	OR3880158	46	81	0
BZ8W92-1	51	77	0	OR3880181	46	79	1
BZ8W92-10	46	82	0	OR3910084	41	80	1
BZ8W92-11	48	74	0	OR3910085	45	73	50
BZ8W92-12	47	75	0	OR3910106	46	74	3
BZ8W92-13	46	76	0	OR3910214	41	82	2
BZ8W92-14	47	84	0	OR3910246	48	70	93
BZ8W92-15	46	80	1	OR3910258	43	77	90
BZ8W92-16	46	79	0	OR916121	40	80	6
BZ8W92-17	46	82	0	PANNONDUR	44	77	1
BZ8W92-18	51	68	0	THHA	46	90	14
BZ8W92-19	45	81	0	TOMA	45	78	80
BZ8W92-2	48	85	1	TOURUS-1	46	79	5
LSD (0.05)	2.0	4.0	14.0				
C.V.	2.6	3.4	69.2				
Durum Average	46	77	3				

[1] soft red winter wheat

Table 2. Average heading date, height, winter kill, and powdery mildew count of durum grown in Orange County, VA (northern piedmont plateau): 1993-1994.

Line	Heading Date (Mar 31 +)	Height (cm)	Winter Kill (%)	Powdery Mildew (0-9)
COKER 9803[1]	29	79	5	0
FFR 555W[1]	30	86	1	0
MASSEY[1]	30	91	2	1
PIONEER 2548[1]	29	77	1	1
WAKEFIELD[1]	31	88	2	2
BASA	33	82	1	2
BZ8289-6	30	80	2	1
BZ8W90-2	31	72	1	0
BZ8W90-27	35	74	1	1
BZ8W90-29	30	68	2	3
BZ8W90-33	34	75	2	2
BZ8W90-7	28	80	9	6
BZ8W90-8	28	80	4	6
BZ8W91-1	31	75	1	4
BZ8W91-2	36	67	3	1
BZ8W91-4	30	69	1	2
BZ8W91-7	34	81	3	3
BZ8W91-8	31	64	2	3
BZ8W92-1	41	73	9	6
BZ8W92-10	32	80	1	1
BZ8W92-11	34	72	2	7
BZ8W92-12	34	68	1	4
BZ8W92-13	34	71	1	3
BZ8W92-14	35	80	1	5
BZ8W92-15	29	89	2	0
BZ8W92-16	32	75	1	8
BZ8W92-17	34	80	2	2
BZ8W92-18	37	62	3	1
BZ8W92-19	33	77	1	6
BZ8W92-20	34	75	1	4
BZ8W92-21	34	76	1	7
BZ8W92-22	23	79	3	2
BZ8W92-3	35	82	1	1
BZ8W92-4	33	81	9	1
BZ8W92-5	33	79	32	2
BZ8W92-6	35	76	1	2
BZ8W92-7	34	75	2	1
BZ8W92-8	31	80	5	0

Table 2 (continued). Average heading date, height, winter kill, and powdery mildew count of durum grown in Orange County, VA (northern piedmont plateau): 1993-1994.

Line	Heading Date (Mar 31 +)	Height (cm)	Winter Kill (%)	Powdery Mildew (0-9)
ELBURZ	32	72	9	2
ELBURZ-1	32	67	9	1
HAD-6	39	82	5	2
KORALL	35	94	4	1
MINARET	31	81	1	0
OR3880015	32	80	16	0
OR3880152	35	75	2	1
OR3880158	35	77	1	1
OR3880181	32	78	1	0
OR3910084	30	84	2	0
OR3910085	30	75	2	0
OR3910106	31	75	2	1
OR3910214	30	83	1	1
OR3910246	30	69	12	0
OR3910258	29	80	4	0
OR916121	29	82	2	0
PANNONDUR	31	75	2	0
THHA	32	83	4	1
TOMA	29	83	7	0
TOURUS-1	31	73	2	0
LSD (0.05)	5	8	10	2
C.V.	8.6	6.1	162.6	71.4
Durum Average	32	77	4	2

[1] soft red winter wheat

Table 3. Average heading date, height, and barley yellow dwarf count of winter durum grown in Montgomery County, VA (southern ridge and valley): 1996-1997.

Line	Heading Date (Mar 31 +)	Height (cm)	Barley Yellow Dwarf (0-9)
COKER 9803[1]	44	85	1
COKER 9835[1]	49	81	2
FFR 555W[1]	50	90	1
MASSEY[1]	49	99	1
PIONEER 2548[1]	50	92	2
WAKEFIELD[1]	50	98	2
BASA	54	91	1
BZ8W90-27	58	86	3
BZ8W91-1	54	83	3
BZ8W91-2	60	78	2
BZ8W91-4	56	77	3
BZ8W91-7	57	91	2
BZ8W91-8	56	75	2
BZ8W92-10	55	93	1
BZ8W92-2	59	93	2
BZ8W92-3	58	86	3
BZ8W92-6	57	89	1
BZ8W92-8	54	91	3
BZ8W92-9	56	94	2
BZ90-7	47	83	3
BZ92-13	59	82	2
KORALL	57	116	1
MINARET	52	91	2
ODESSA #63	53	89	1
ODESSA #64	56	89	1
ODESSA #65	54	90	2
ODESSA #66	52	88	1
ODESSA #67	55	93	2
ODESSA #69	54	91	1
OR3880152	56	91	1
OR3880158	57	91	1
OR3880181	54	86	2
OR3910084	51	88	2
OR3910085	51	81	2
OR3910106	54	81	2
OR3910214	48	85	2
OR916121	48	89	2
PANNONDUR	52	82	1
LSD (0.05)	2	4	1.0
C.V.	3.1	3.3	40.9
Durum Average	54	88	2

[1] soft red winter wheat

Table 4. Average heading date, height, lodging, winter kill, powdery mildew, and barley yellow dwarf count of durum grown in Orange County, VA (northern piedmont plateau): 1996-1997.[2]

Line	Heading Date (Mar 31 +)	Height (cm)	Lodging (%)	Winter Kill (0-5)	Powdery Mildew (0-9)	Barley Yellow Dwarf (0-9)
COKER 9803[1]	30	91	0	0	0	0
COKER 9835[1]	34	84	5	0	0	0
FFR 555W[1]	33	94	0	0	0	0
MASSEY[1]	34	107	33	0	0	0
PIONEER 2548[1]	33	94	0	0	0	0
WAKEFIELD[1]	36	104	0	0	0	0
BASA	40	89	0	0	0	0
BZ8W90-27	43	86	0	0	0	0
BZ8W91-1	40	84	0	0	0	0
BZ8W91-2	44	86	0	0	0	0
BZ8W91-4	41	86	0	0	0	0
BZ8W91-7	41	94	0	0	0	0
BZ8W91-8	42	81	0	0	0	0
BZ8W92-10	42	94	0	0	0	0
BZ8W92-2	43	107	0	0	0	0
BZ8W92-3	43	97	0	0	0	0
BZ8W92-6	43	89	0	0	0	0
BZ8W92-8	41	94	0	0	0	0
BZ8W92-9	41	97	0	0	0	0
BZ90-7	34	94	0	0	0	0
BZ92-13	43	81	0	0	0	0
KORALL	39	124	0	0	0	0
MINARET	38	94	0	0	0	0
ODESSA #63	39	91	0	0	0	0
ODESSA #64	41	89	0	0	0	0
ODESSA #65	39	94	0	0	0	0
ODESSA #66	37	94	0	0	0	0
ODESSA #67	41	97	0	0	0	0
ODESSA #69	38	94	0	0	0	0
OR3880152	42	91	0	0	0	0
OR3880158	44	91	0	0	0	0
OR3880181	41	84	0	0	0	0
OR3910084	36	89	0	0	0	0
OR3910085	38	86	0	0	0	0
OR3910106	41	86	0	0	0	0
OR3910214	37	97	0	0	0	0
OR916121	36	86	0	0	0	0
PANNONDUR	37	86	0	0	0	0
Durum Average	40	92	0	0	0	0

[1] soft red winter wheat
[2] no replicate data available

Table 5. Average heading date, height, lodging and winter kill of winter durum grown in Montgomery County, VA (southern ridge and valley): 1997-1998.

Line	Heading Date (Mar 31 +)	Height (cm)	Lodging (%)	Winter Kill (0-5)
FFR 555W[1]	39	104	33	0
BASA	43	90	3	1
BZ8W90-27	47	85	0	1
BZ8W91-8	44	84	0	1
BZ8W92-10	44	89	46	0
BZ8W92-2	48	97	2	1
BZ8W92-8	44	91	4	0
KORALL	45	119	13	0
MINARET	43	89	20	0
ODESSA #63	42	85	1	2
ODESSA #65	42	93	0	1
ODESSA #66	40	93	11	1
ODESSA #69	42	88	1	1
OR3880152	45	88	1	0
OR3880158	46	87	0	1
OR3880181	43	87	0	0
OR3910084	40	90	7	1
OR3910085	42	82	11	0
OR3910214	40	87	67	0
PANNONDUR	41	83	0	0
LSD (0.05)	0.7	7.6	18.0	0.7
C.V.	1.4	7.4	147.0	116
Durum Average	43	90	10	1

[1] soft red winter wheat

Table 6. Average heading date, height, and lodging of winter durum grown in Orange County, VA (northern piedmont plateau): 1997-1998.

Line	Heading Date (Mar 31 +)	Height (cm)	Lodging (%)
FFR 555W[1]	29	108	0
BASA	39	101	0
BZ8W90-27	45	83	0
BZ8W91-8	39	79	0
BZ8W92-10	39	96	0
BZ8W92-2	44	94	0
BZ8W92-8	38	97	0
KORALL	38	144	0
MINARET	39	94	0
ODESSA #63	36	93	0
ODESSA #65	37	96	0
ODESSA #66	33	99	0
ODESSA #69	35	95	0
OR3880152	43	89	0
OR3880158	42	90	0
OR3880181	36	89	0
OR3910084	35	97	0
OR3910085	37	88	0
OR3910214	32	96	13
PANNONDUR	33	88	0
LSD (0.05)	1.5	3.8	4.2
C.V.	3.4	3.4	547.7
Durum Average	38	95	1

[1] soft red winter wheat

Table 7. Average heading date, height, lodging and powdery mildew count of winter durum grown in Richmond County, VA (northern coastal plain): 1997-1998.

Line	Heading Date (Mar 31 +)	Height (cm)	Lodging (%)	Powdery Mildew (0-9)
FFR 555W[1]	23	90	0	6
BASA	33	87	0	1
BZ8W90-27	39	72	1	0
BZ8W91-8	35	69	0	2
BZ8W92-10	34	86	13	0
BZ8W92-2	37	90	23	0
BZ8W92-8	34	86	3	0
KORALL	38	119	29	3
MINARET	33	82	4	1
ODESSA #63	31	86	8	1
ODESSA #65	30	86	8	1
ODESSA #66	28	89	4	2
ODESSA #69	31	86	6	1
OR3880152	37	79	4	0
OR3880158	37	81	2	1
OR3880181	31	82	0	1
OR3910084	27	83	8	2
OR3910085	29	78	3	1
OR3910214	25	86	28	1
PANNONDUR	29	80	0	3
LSD (0.05)	2.3	4.1	13.4	0.7
C.V.	4.7	3.1	126.2	37.5
Durum Average	32	85	8	1

[1] soft red winter wheat

Table 8. Average heading date, height, lodging and powdery mildew count of new winter durum lines grown in Richmond County, VA (northern coastal plain): 1997-1998.[2]

Line	Heading Date (Mar 31 +)	Height (cm)	Lodging (%)	Powdery Mildew (0-9)
FFR 555W[1]	23	90	0	6
ACADUR	28	87	7	2
AGEDUR	31	86	67	1
ALIDUR	28	86	0	3
AMADUR	23	86	5	0
OR3920036	36	73	0	0
OR3950055	38	79	0	0
OR936773	29	77	7	0
OR948578	34	78	0	1
OR948612	33	85	3	0
OR948763	21	84	22	1
OR948927	40	75	0	0
OR948948	35	75	18	0
OR949024	35	80	0	0
OREXP#10	26	87	12	0
OREXP#11	25	89	10	1
OREXP#12	23	80	2	1
OREXP#13	20	81	2	2
OREXP#14	25	78	0	0
PANDUR	22	86	28	6
RODUR	27	80	0	1
Durum Average	29	82	9	1

[1] soft red winter wheat
[2] based upon 1 replication

Table 9. Average heading date of winter durum grown in Nottoway County, VA (southern piedmont plateau): 1997-1998.

Line	Heading Date (Mar 31 +)
FFR 555W[1]	25
BASA	34
BZ8W90-27	40
BZ8W91-8	34
BZ8W92-10	37
BZ8W92-2	39
BZ8W92-8	34
KORALL	36
MINARET	35
ODESSA #63	34
ODESSA #65	35
ODESSA #66	31
ODESSA #69	34
OR3880152	39
OR3880158	39
OR3880181	33
OR3910084	32
OR3910085	32
OR3910214	27
PANNONDUR	31
LSD (0.05)	2
C.V.	3
Durum Average	35

[1] soft red winter wheat
[2] based upon 1 replication

Appendix D
Quality Data for Select Durum Lines Grown in the 1993-1994 Growing Season

Table 1. Quality data for select durum lines grown in the 1993-1994 growing season.

Line	Protein (%)	Test Weight (lb/bu)	Vitreousness (%)	Falling Number (s)	1000 Kernel Weight (g)	Sedimentation Volume (mm)
BASA	11.7	59.3	.	400	.	29
PANNONDUR	11.5	61.2	58	400	42.5	30
MINARET	.	.	.	.	.	40
KORALL	.	.	.	.	.	.
BZ8W90-27	12.4	.	69	400	.	.
BZ8W91-8	.	.	.	.	.	.
BZ8W92-2	.	.	.	.	41.3	.
BZ8W92-8	.	59.7	59	.	42.1	36
BZ8W92-10	.	59.7	62	.	.	44
OR3880152	11.3	60.4	.	400	44.2	.
OR3880158	.	60.8	.	.	43.0	.
OR3910084	11.7	.	62	377	42.0	.
OR3910085	12.0	.	62	400	.	45
OR3880181	11.3	58.9	.	.	42.4	.
OR3910214	12.4	58.9	63	398	.	40
Minimum[1]	12	74.6	75	250	25.0	20

[1] Minimum for pasta production

Appendix E
Aluminum Lactate-Polyacrylamide Gel Electrophoresis
(A-PAGE)

Tank Buffer Preparation

aluminum lactate	5.0 g
deionized water	3500 ml

pH to 3.1 with d-lactic acid (Sigma L1250)
total volume to 4000 ml

Stir well, recheck pH, and refrigerate overnight in plastic bottles in to chill.

Gel apparatus

Set up according to Hoefer instructions.
Set up casting stand and level.
Use 3 mm spacers and combs; 10 well comb is preferred.

Start cooling device, set at 5°C.

6% Gel for wheat or flour samples

aluminum lactate	250 mg
ascorbic acid	24 mg
bis-acrylamide	250 mg
acrylamide	6 g
ferrous sulfate	200 µl

(10 mg $FeSO_4$/10 ml $7H_20$)

Weigh out reagents and dissolve in beaker for 20 minutes.
pH to 3.1 with d-lactic acid before bringing to volume.
Total volume: 100 ml

Filter. Filter used (25991 at 0.45 microns).

Catalyst

Add 100µl hydrogen peroxide for one gel while stirring. Pour gel quickly.

Pour Gel

Pour gel into plates clamped together on casting stand without bubbles.
Pour within a few mm of the top.
Insert teflon combs, being sure no bubbles appear in the slots under the combs.
Polymerize for 30 minutes.

Sample Preparation

wheat or flour 250 g in 500 µl microtube
70% ethanol 750 µl

Vortex samples. Sonicate for 30 minutes.

Centrifuge in micro-centrifuge for 5 minutes, full speed.
Remove 250 µl of supernatant to clean microtube.
Add 4 drops glycerol
Add 30 µl methyl green dye
Vortex until glycerol is dispersed. Inverting the tubes and tapping sometimes helps.

Place running buffer on top of gel with pasteur pipette and remove combs gently, adding buffer as needed so the wells do not collapse.

Pour out excess buffer. Rinse wells with running buffer.

Fill outer tank with running buffer to marked line.
Remove casting stand and attach to the running tank.
Fill upper tank with running buffer, just below the top.

Load 15µl/slot through the buffer using Gilson 100µl pipettor set at 15 µl.
Use special electrophoresis pipettes.

Remove any air bubbles at bottom of the running gel.

Reverse polarity.
Run at 375 volts per gel.
Program voltage step-up:
S1 Volts 150. 15 minutes
S2 Volts 375 4 hours
Set using instructions for power supply.

Run for 2 times the time for the markers to run off plus an additional 30 minutes.

Stain Solution

50% trichloric acetic acid	80 ml
2% Coomassie R-250 in methanol	9 ml
Distilled water	216 ml

After gel is finished running, turn off power supply. Using spacer and squirting water underneath gel, take the two plates apart. Mark gel by placing a small cut at the top to identify which side is slot number one. Do not touch the gel. Use enough water so the gel floats on the glass plate into a 2.8 quart container with staining solution.

Allow gel to stain overnight by rocking on the shaker on low speed.
Destain with the Stain Solution minus the Coomassie R-250.
Destain with gentle rocking on the shaker on low speed.
Refridgerate to sharpen bands.

Acrylamide is a neurotoxin. Always use gloves and a mask when weighing it.
Always use gloves when pouring gels and removing them from the plates.
TCA will cause severe burns. Always wear goggles or safety glasses when handling it.

Appendix F
Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS-PAGE) for D-Zone Omega Gliadins in Durum Wheat

Sample Preparation

1. Weigh out 100 mg of ground wheat into a microcentrifuge tube.

2. Add 500 µl of 70% ethanol.

3. Vortex. Hold overnight at room temperature. Vortex again.

4. Centrifuge at full speed for 5 minutes.

5. Mix supernatant 1:1 with "Modified Solution C". (100 µl supernatant + 100 µl "Modified Solution C".

6. Incubate at 65°C for 30 minutes. Centrifuge. Load 15 µl/slot.

Reagents

Solution C

200 mg of sodium dodecyl sulfate
4 ml of glycerol
2 mg of bromophenol blue

Bring to 10 ml total volume with 0.08M Tris/HCl pH 8.0
(2.442 g Tris/ 250 ml H_2O pH to 8.0 with HCl)

Filter Solution C before making Modified Solution C to remove excess dye.

Modified Solution C

Add 50 mg of DTT (dithiothreitol) and 70 µl of vinyl pyridine to 5 ml of Solution C. Make fresh just before use.

MW Marker – Dalton Mark VII-L SDS-7

66 000
45 000
35 000
29 000
24 000
20 000
14 200
Load 22 µl/slot for marker solution.

Prepare with the following buffer solution before loading:

1 mg/ml of:	3.0 ml water
	1.0 ml stacking buffer
	1.6 ml glycerol
	1.6 ml 10% sodium dodecyl sulfate
	0.4 ml mercaptoethanol
	0.4 ml 0.5% bromophenol blue

Incubate in a boiling water bath for 60 seconds before applying to gel.

Separating Gel 8%

glycerol	13.50 ml
30% abis stock	12.00 ml
1.5M Tris HCl buffer	11.26 ml
deionized water	7.62 ml
10% SDS	450 µl
Polymerization :	
10% APS	136 µl
TEMED	46 µl

Stacking Gel 3.5%

30% abis stock	2.334 ml
1.0M Tris pH 6.8	2.500 ml
deionized water	14.846 ml
10% SDS	200 µl
Polymerization :	
10% APS	90 µl
TEMED	30 µl

Use 1.5 mm spacers, 11.5 cm length
Pour 3.5 cm from the top.
Overlay with water.

Abis Stock

Acrylamide	29.2 g
Bis-acrylamide	0.8 g

Total volume: 100 ml
Store in dark brown bottle at 4°C.

Ammonium Persulfate

ammonium persulfate	200 mg
deionized water	2 ml

Make fresh daily.

Tank Buffer

Tris pH 8.3	12 g
glycine	57.6 g
10% SDS	40 ml
Water to 4 L	

10% SDS

SDS	10 g
deionized water	100 ml

1.5M Tris

Tris	18.17 g
deionized water	100 ml
pH to 8.8 with HCl	

1.0M Tris

Tris	12.12 g
deionized water	100 ml
pH to 6.8 with HCl	

TEMED

(N, N, N^1, N^1 tetramethylethylene diamine)

Running Conditons

40 mA per gel for 3-3.5 hours (until marker runs off gel).
Cooling at 10°C

Fixing Solution/Staining

100% TCA	25 ml
methanol	83 ml
distilled water	143 ml

On shaker:

Fix 1-2 hours prior to staining with Sigma Dye Solution (B-4523) plus 5 ml Coomassie R-250 Brilliant Blue.
Stain until protein bands are as dark blue as desired for photo.
Destain and store with: 50% trichloric acetic acid 80 ml
Distilled water 216 ml

Appendix G

Micro Sedimentation Test

Sample Preparation

Grind wheat in a Udy Grinder (or Cyclotec® Mill) with a 1 mm sieve opening.

Procedure

1. Weigh out 1 g of ground wheat or reground semolina in a test tube (150 mm x 14 mm internal diameter) with a screw cap lid.

2. Add 4 ml of distilled water and mix content at high speed on a vortex mixer until thoroughly mixed.

3. After 5 minutes again mix for 2 seconds on a vortex mixer.

4. After 5 minutes, add 12 ml of stock solution (SDS-Lactic Acid stock) replace lid and invert the test tube 10 times.

5. Allow to settle for 15 minutes in a vertical position and measure the interface line in millimeters (height from bottom of the tube to the top of the sediment). Record height for each tube.

Stock Solution

500 ml of Distilled Water
10 g of Sodium Dodecyl Sulfate
10.4 g of Lactic Acid

Mix solution well. Make fresh weekly.

Procedure developed by Joel W. Dick in February, 1981, for use in the wheat quality testing program for durum of the Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND 58105.

Appendix H
Pasta Making

(Adapted from La Rinascente Macaroni Co., South Hackensack, N.J. 07606)

Ingredients

2 cups semolina
2 tbsp canola oil
½ cup warm water

Procedure

1. Add oil to semolina and mix.
2. Add water and mix. More or less water may be necessary depending on the semolina absorption properties.
3. Knead dough for 5 minutes until smooth.
4. Cover with plastic film and allow gluten to develop for 15 minutes.
5. Cut dough into strips and roll out. Use roll setting 4 on the Atlas pasta maker. Roll dough through the first setting 6 times before moving in one step increments up to roll setting 4.
6. Allow strips to air dry while rolling the rest of the dough strips.
7. Cut the strips into spaghetti noodles.
8. Separate the noodles and allow to air dry for 90 minutes.
9. Place noodles in a single layer on wax paper and store overnight in a dark, cool place.

Appendix I
Determination of Color using a Reflectance Colorimeter
Hunter Color Difference Meter, Hunter Lab D25 L Optical Sensor

(Reston, VA)

Adapted from AACC Method 14-22 (AACC, 1984)

Procedure

1. Turn on machine 30 minutes before reading samples.
2. Place black ceramic tile on the sample stand and press read to zero the colorimeter.
3. Place white ceramic tile on the sample stand and press read.
4. Once the colorimeter has been calibrated, samples may be placed on the sample stand, covering the entire viewing area. It is important that the samples are mounted on a black background.
5. Spaghetti color scores may be reported directly as brightness, L% (L*) and yellowness, b% (b*).

Appendix J
Physical Quality Characteristics by Location

Table 1. Physical quality characteristics of durum wheat grown in Montgomery County, VA: 1995-1996.

Line	Grade	Protein (%)	Test Weight (kg/hl)	Vitreousness (%)	Moisture (%)	Falling Number (s)
BASA	3	11.8	74.4	12	11.6	400
BZ8W90-27	.	.	.	.	.	.
BZ8W91-8	6	10.4	67.7	14	11.7	388
BZ8W92-10	.	.	.	.	.	.
BZ8W92-2	4	12.2	70.8	42	11.6	355
BZ8W92-8	6	12.7	72.5	37	11.6	362
KORALL	2	13.1	74.6	36	12.2	400
MINARET	4	12.8	71.4	47	11.2	400
ODESSA #63	3	12.3	72.1	37	12	388
ODESSA #65	3	12	74.4	53	11.5	391
ODESSA #66	3	13.6	73.5	62	11.5	400
ODESSA #69	3	12.8	72.1	50	11.6	347
OR3880152	3	12.5	73.6	40	11.4	400
OR3880158	3	11.6	72.3	51	11.6	400
OR3880181	5	13.1	67.8	29	11.4	388
OR3910084	5	14.2	66.7	61	11.3	400
OR3910085	4	13.4	69.8	48	7.2	547
OR3910214	3	12.3	72.7	27	11.4	400
PANNONDUR	1	12.3	77.6	35	12.6	400
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 2. Physical quality characteristics of durum wheat grown in Orange County, VA: 1995-1996.

Line	Grade	Protein (%)	Test Weight (kg/hl)	Vitreousness (%)	Moisture (%)	Falling Number (s)
BASA	2	13.5	76.4	89	10.8	500
BZ8W90-27	3	15.3	74.0	72	11.4	400
BZ8W91-8	2	12.3	74.6	44	11.5	400
BZ8W92-10	2	13	76.3	73	11	390
BZ8W92-2	3	13.3	74.0	70	11.1	345
BZ8W92-8	2	11.1	76.6	83	11.1	398
KORALL	1	14.8	77.2	97	11	432
MINARET	3	14.1	74.3	78	10.9	400
ODESSA #63	1	13.3	77.7	91	11.5	400
ODESSA #65	1	13.3	77.6	92	11.3	374
ODESSA #66	2	14.8	77.0	93	10.8	499
ODESSA #69	1	13.4	77.2	92	11.4	323
OR3880152	2	13.9	76.3	84	11.1	422
OR3880158	2	14	76.8	78	11.2	338
OR3880181	3	13	72.5	82	11	367
OR3910084	3	13.8	73.2	84	10.8	425
OR3910085	1	14.1	78.5	92	11	500
OR3910214	1	13.6	77.2	93	11.1	500
PANNONDUR	1	13.4	79.7	84	11.2	300
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 3. Physical quality characteristics of durum wheat grown in Clarke County, VA: 1995-1996.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	5	14.7	69.9	73	10.6	400
BZ8W90-27	.	.	.	.	.	.
BZ8W91-8	5	13.6	67.1	39	11.6	487
BZ8W92-10	.	.	.	.	.	.
BZ8W92-2	6	14.8	64.7	68	11.2	417
BZ8W92-8	.	.	.	.	.	.
KORALL	.	.	.	.	.	.
MINARET	6	14.1	68.9	55	29.4	400
ODESSA #63	6	14.7	67.7	67	11.3	400
ODESSA #65	4	14.4	70.4	69	11.6	416
ODESSA #66	5	13.8	67.2	49	10.8	400
ODESSA #69	.	.	.	.	.	.
OR3880152	.	.	.	.	.	.
OR3880158	.	.	.	.	.	.
OR3880181	6	14.9	62.4	43	10.7	400
OR3910084	6	15	65.6	49	11	433
OR3910085	5	15.2	68.3	72	10.8	400
OR3910214	6	.	71.6	65	11.2	400
PANNONDUR	.	.	.	.	.	.
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 4. Physical quality characteristics of durum wheat grown in Montgomery County, VA: 1996-1997.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	2	14.6	75.5	75	14.9	505
BZ8W90-27	4	14.3	69.5	87	15.4	408
BZ8W91-8	4	13.8	69.8	65	14.2	363
BZ8W92-10	3	14.6	72.3	72	14.2	280
BZ8W92-2	4	13.9	70.9	52	15.4	290
BZ8W92-8	4	15.7	69.8	42	14.1	215
KORALL	2	15.2	75.7	77	14.9	352
MINARET	3	14.5	73.6	77	14	405
ODESSA #63	2	14	75.2	68	14.1	366
ODESSA #65	3	14.4	74.5	56	13.8	281
ODESSA #66	2	15.2	75.3	81	13.5	378
ODESSA #69	2	13.8	74.8	53	14.1	357
OR3880152	3	14.7	73.4	76	15.5	460
OR3880158	2	13.5	74.6	60	16.4	397
OR3880181	3	14.5	72.6	65	14	343
OR3910084	4	15.6	71.0	54	14.1	307
OR3910085	4	15.2	70.1	73	13.8	447
OR3910214	3	14.4	73.9	52	13.8	379
PANNONDUR	2	13.5	77.5	52	15.5	411
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 5. Physical quality characteristics of durum wheat grown in Orange County, VA: 1996-1997.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	1	13.8	77.7	32	11.6	534
BZ8W90-27	2	13.1	78.6	57	11.8	353
BZ8W91-8	2	11.3	76.3	25	11.8	279
BZ8W92-10	3	12.3	77.3	25	11.8	314
BZ8W92-2	3	12	76.7	22	12	246
BZ8W92-8	.	.	.	.	.	.
KORALL	2	13.4	78.6	66	11.7	426
MINARET	2	12.5	77.2	13	11.7	473
ODESSA #63	1	12.8	78.2	49	11.8	353
ODESSA #65	1	12.6	78.1	10	11.6	257
ODESSA #66	1	13.7	79.0	74	11.6	238
ODESSA #69	1	12.5	78.6	28	11.9	324
OR3880152	3	13.5	80.3	70	11.7	482
OR3880158	2	13	80.3	58	11.7	393
OR3880181	2	13.1	77.0	55	11.7	426
OR3910084	2	12.8	75.9	0	11.9	433
OR3910085	1	13.1	79.0	38	11.7	430
OR3910214	3	14	76.4	37	14	422
PANNONDUR	2	12.8	81.7	57	11.7	442
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 6. Physical quality characteristics of durum wheat grown in Clarke County, VA: 1996-1997.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	4	16.3	79.5	91	12.3	569
BZ8W90-27	2	15.5	79.0	92	12.8	499
BZ8W91-8	4	15.5	78.8	89	12.4	351
BZ8W92-10	1	14.7	80.4	89	12.4	296
BZ8W92-2	4	15	79.9	88	13.1	253
BZ8W92-8	1	14.6	68.7	89	12.4	323
KORALL	3	15.6	80.8	91	12.7	402
MINARET	4	15.5	80.3	86	12.5	408
ODESSA #63	4	14.7	81.1	90	12.3	422
ODESSA #65	1	14.6	81.0	85	12.2	441
ODESSA #66	4	15.6	80.8	93	12.2	425
ODESSA #69	1	14.8	80.8	86	12.2	447
OR3880152	2	16	80.6	92	12.1	419
OR3880158	1	15	80.8	87	12.8	420
OR3880181	4	15.3	79.3	85	12.4	306
OR3910084	4	16.7	76.3	90	12.5	385
OR3910085	4	15.9	79.8	88	13.1	451
OR3910214	4	15.2	79.4	91	12.1	433
PANNONDUR	3	14.6	81.6	89	12.5	399
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 7. Physical quality characteristics of durum wheat grown in Richmond County, VA: 1996-1997.

Line	**Grade**	**Protein (%)**	**Test Weight (kg/hl)**	**Vitreousness (%)**	**Moisture (%)**	**Falling Number (s)**
BASA	1	13	81.2	94	12	492
BZ8W90-27	1	12.9	80.3	94	12.8	498
BZ8W91-8	1	11.7	79.7	85	12.1	389
BZ8W92-10	1	12	82.0	88	12.2	444
BZ8W92-2	1	11.8	81.6	77	13.2	501
BZ8W92-8	1	12.5	69.9	92	12.7	428
KORALL	1	13.3	82.0	91	13.3	448
MINARET	1	12	80.2	76	12.1	497
ODESSA #63	1	11.9	83.1	92	12	419
ODESSA #65	1	11.9	82.8	94	12	443
ODESSA #66	1	12.9	82.5	95	11.9	493
ODESSA #69	1	11.7	82.5	90	11.9	419
OR3880152	1	12.2	81.3	71	14.3	458
OR3880158	1	12.4	81.1	80	14.9	407
OR3880181	1	12.1	82.0	91	12	435
OR3910084	1	12.6	79.8	95	11.9	408
OR3910085	1	12.9	83.3	91	11.9	437
OR3910214	1	13.6	81.1	87	12	451
PANNONDUR	1	12.3	85.3	89	12.1	374
Minimum[1]	2	12	74.6	75	<13	250

[1]Minimum specifications for pasta production

Table 8. Physical quality characteristics of durum wheat grown in Montgomery County, VA: 1997-1998.

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	408	5	61	69.0	13.8
BZ8W90-27	377	SG[1]	36	62.0	17.7
BZ8W91-8	366	SG	16	65.4	12.1
BZ8W92-10	378	SG	38	61.3	15.2
BZ8W92-2	321	SG	31	62.2	14.8
BZ8W92-8	337	SG	39	64.7	15.6
KORALL	477	3	31	72.3	12.9
MINARET	348	5	43	66.9	14.6
ODESSA #63	402	SG	76	65.0	14.2
ODESSA #65	329	5	50	68.9	12.8
ODESSA #66	278	4	88	70.8	14.7
ODESSA #69	242	5	41	66.8	14.1
OR3880152	437	5	50	67.4	13.7
OR3880158	.	5	71	68.9	14.8
OR3880181	386	SG	69	64.5	14.3
OR3910084	369	SG	51	64.4	14.7
OR3910085	468	SG	29	62.0	15.2
OR3910214	286	SG	34	65.5	15
PANNONDUR	382	3	69	72.1	14
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

Table 9. Physical quality characteristics of durum wheat grown in Montgomery County, VA under restricted fungicide treatment: 1997-1998

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	.	5	49	68.2	13.8
BZ8W90-27	.	SG[1]	44	63.1	17.1
BZ8W91-8	.	SG	38	63.7	12
BZ8W92-10	.	SG	48	63.7	14.5
BZ8W92-2	.	SG	46	63.7	14.4
BZ8W92-8	.	5	69	65.9	15
KORALL	.	3	64	72.7	13.6
MINARET	.	5	26	65.6	14.6
ODESSA #63	.	SG	52	64.7	13.8
ODESSA #65	.	5	73	67.2	13.2
ODESSA #66	.	5	80	69.5	14.3
ODESSA #69	.	5	52	65.8	13.7
OR3880152	.	4	69	68.3	14.3
OR3880158	.	5	68	69.4	13.9
OR3880181	.	SG	55	64.4	13.6
OR3910084	.	5	47	65.6	13.3
OR3910085	.	SG	47	62.2	15.6
OR3910214	.	SG	57	64.9	15.3
PANNONDUR	.	3	86	72.1	14.4
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

Table 10. Physical quality characteristics of durum wheat grown in Orange County, VA: 1997-1998.

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	315	4	35	69.9	13.8
BZ8W90-27	372	3	81	72.3	13.9
BZ8W91-8	358	4	22	69.5	12.6
BZ8W92-10	310	5	24	67.7	13.9
BZ8W92-2	205	5	19	68.9	13.6
BZ8W92-8	355	5	60	69.5	14
KORALL	257	4	47	75.3	13.3
MINARET	332	5	16	68.7	14.2
ODESSA #63	350	3	63	73.5	13.1
ODESSA #65	386	4	50	69.8	13.5
ODESSA #66	309	4	53	73.5	13.7
ODESSA #69	311	4	37	71.6	13.3
OR3880152	386	3	48	72.3	13.3
OR3880158	487	4	35	71.7	13.3
OR3880181	309	5	16	66.3	13.8
OR3910084	301	5	38	69.2	13.6
OR3910085	276	5	65	67.6	13.9
OR3910214	333	5	28	69.4	13.8
PANNONDUR	370	4	48	75.3	13.6
Minimum[1]	250	2	75	74.6	12

[1]Minimum specifications for pasta production

Table 11. Physical quality characteristics of durum wheat grown in Orange County, VA under restricted fungicide treatment: 1997-1998

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	.	3	61	72.8	13.1
BZ8W90-27	.	4	67	71.0	14.4
BZ8W91-8	.	4	19	69.9	12.1
BZ8W92-10	.	3	35	70.1	13.5
BZ8W92-2	.	5	26	67.4	13.2
BZ8W92-8	.	4	43	70.8	13.5
KORALL	.	3	26	75.0	12.8
MINARET	.	5	33	68.2	14
ODESSA #63	.	4	71	72.8	13
ODESSA #65	.	4	62	72.2	13
ODESSA #66	.	3	66	73.6	13.8
ODESSA #69	.	4	59	73.6	12.6
OR3880152	.	3	40	74.3	12.6
OR3880158	.	3	60	73.6	13.2
OR3880181	.	5	52	65.1	13.5
OR3910084	.	4	62	69.6	12.8
OR3910085	.	4	44	70.9	13.2
OR3910214	.	5	51	70.1	13.6
PANNONDUR	.	3	37	74.9	12.9
Minimum[1]	250	2	75	74.6	12

[1]Minimum specifications for pasta production

Table 12. Physical quality characteristics of durum wheat grown in Shenandoah County, VA: 1997-1998.

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	369	SG[1]	29	69.6	13.9
BZ8W90-27	357	SG	56	68.3	15.4
BZ8W91-8	380	SG	22	65.5	13.6
BZ8W92-10	400	SG	21	62.9	13.5
BZ8W92-2	388	SG	30	67.6	13.2
BZ8W92-8	305	SG	31	65.9	13.4
KORALL	303	SG	38	73.4	14.6
MINARET	417	SG	25	67.7	13.4
ODESSA #63	385	SG	31	65.5	14.1
ODESSA #65	394	SG	25	64.1	14
ODESSA #66	298	SG	23	65.3	14.3
ODESSA #69	385	SG	24	64.9	13.8
OR3880152	324	SG	38	67.8	14
OR3880158	388	SG	40	68.5	14.3
OR3880181	355	SG	28	57.3	13.2
OR3910084	332	SG	22	63.2	17.1
OR3910085	329	SG	36	65.6	15
OR3910214	331	SG	20	64.7	14.3
PANNONDUR	410	SG	28	63.1	13.8
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

Table 13. Physical quality characteristics of durum wheat grown in Shenandoah County, VA under restricted fungicide treatment: 1997-1998.

Line	**Falling Number (s)**	**Grade**	**Vitreousness (%)**	**Test Weight (kg/hl)**	**Protein (%)**
BASA	.	SG	18	64.1	13.2
BZ8W90-27	.	SG	40	64.7	14.4
BZ8W91-8	.	SG	12	64.4	13.4
BZ8W92-10	.	SG	24	63.3	13.5
BZ8W92-2	.	SG	29	64.4	13.1
BZ8W92-8	.	SG	13	57.1	13.3
KORALL	.	5	17	71.2	13.6
MINARET	.	SG	17	66.3	13.1
ODESSA #63	.	SG	16	62.5	13.2
ODESSA #65	.	SG	18	62.4	13.7
ODESSA #66	.	SG	26	61.5	14.1
ODESSA #69	.	SG	31	63.8	13.4
OR3880152	.	SG	27	60.0	14.9
OR3880158	.	SG	35	64.2	14
OR3880181	.	SG	20	56.2	15.1
OR3910084	.	SG	25	64.7	14.1
OR3910085	.	SG	15	64.0	14.9
OR3910214	.	SG	23	61.8	13.6
PANNONDUR	.	SG	14	61.8	13
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

Table 14. Physical quality characteristics of durum wheat grown in Richmond County, VA: 1997-1998.

Line	Falling Number (s)	Grade	Vitreousness (%)	Test Weight (kg/hl)	Protein (%)
BASA	342	SG[1]	32	66.5	14.4
BZ8W90-27	369	SG	41	63.1	14.8
BZ8W91-8	366	SG	24	65.6	13
BZ8W92-10	371	SG	30	64.4	13.9
BZ8W92-2	448	SG	50	64.7	14.4
BZ8W92-8	388	SG	55	66.5	14.4
KORALL	343	5	41	69.0	13.6
MINARET	305	SG	21	62.4	14.2
ODESSA #63	165	5	52	66.4	13.4
ODESSA #65	376	SG	60	66.3	13.6
ODESSA #66	483	4	60	71.4	14.4
ODESSA #69	388	5	48	66.0	13.5
OR3880152	349	5	27	66.0	14
OR3880158	443	SG	40	66.7	14
OR3880181	316	SG	52	64.4	13.4
OR3910084	439	SG	31	62.9	14.2
OR3910085	376	SG	45	64.6	13.8
OR3910214	345	5	33	66.4	13.1
PANNONDUR	328	5	47	71.0	13.5
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

Table 15. Physical quality characteristics of durum wheat grown in Richmond County, VA under restricted fungicide treatment: 1997-1998.

Line	**Falling Number (s)**	**Grade**	**Vitreousness (%)**	**Test Weight (kg/hl)**	**Protein (%)**
BASA	.	5	69	65.3	15.1
BZ8W90-27	.	SG[1]	63	60.9	15.8
BZ8W91-8	.	SG	45	63.2	13.7
BZ8W92-10	.	SG	55	64.0	15
BZ8W92-2	.	SG	58	61.8	16.2
BZ8W92-8	.	SG	66	65.4	14.9
KORALL	.	5	54	68.3	13.6
MINARET	.	SG	32	60.6	15.4
ODESSA #63	.	SG	57	61.8	15.8
ODESSA #65	.	SG	42	62.9	15.2
ODESSA #66	.	5	54	68.9	14.6
ODESSA #69	.	SG	64	64.1	14.8
OR3880152	.	SG	45	64.7	14.8
OR3880158	.	5	63	66.3	14.9
OR3880181	.	SG	45	65.9	14.2
OR3910084	.	SG	72	60.4	16
OR3910085	.	SG	58	61.3	16
OR3910214	.	SG	7	64.0	14.1
PANNONDUR	.	4	66	71.9	14.4
Minimum[2]	250	2	75	74.6	12

[1]Sample grade

[2]Minimum specifications for pasta production

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Vita

Amanda S. Bullard was born in Cleveland, Ohio on April 4, 1974. She graduated magna cum laude from Virginia Polytechnic Institute and State University in December of 1997, with a Bachelor of Science in Crop and Soil Environmental Sciences, Biotechnology option. From 1997-1999, Amanda worked with durum in field, greenhouse, and laboratory settings as part of her research for her Master of Science degree. During this time, Amanda was elected to the agricultural honor society, Gamma Sigma Delta. Her research interests include crop improvement through selection for quality traits and the development of quality food products from small grains. Currently, Amanda is a Master of Science degree candidate in the Crop and Soil Environmental Sciences department at Virginia Polytechnic Institute and State University.