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Characterisation of grain quality of Syrian durum wheat genotypes affecting milling performance and end-use quality

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**Characterisation of grain quality of Syrian durum wheat
genotypes affecting milling performance and end-use
quality.**

JIHAD SAMAN

**A thesis submitted to the University of Plymouth
in partial fulfilment for the degree of**

DOCTOR OF PHILOSOPHY

**School of Biological Sciences
Faculty of Science**

June 2007

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Abstract:

Characterisation of grain quality of Syrian durum wheat genotypes affecting milling performance and end-use quality.

Jihad Samaan

Durum wheat is a strategic crop in Syria produced in high quantities and used mainly for the production of Arabic bread, bulgur and pasta. This investigation is the first known systematic study relating the grain quality of nine domestic cultivars to milling performance and pasta quality in order to map the Syrian durum wheat characteristics onto the world market requirements and hence determine the potential export development. Furthermore, it examines the influence of environment, genotype and their interaction on the physiochemical characteristics of five durum wheat cultivars grown in five different locations under rainfed and irrigated conditions in Syria.

AACC standard methods were principally used in this investigation.

Despite the soundness of grains revealed by elevated test weight ($83.1\text{--}85.9\text{ kg hl}^{-1}$), 1000 kernel weight (42.50–55.0 g) and falling number (433–597 sec), it is necessary to improve the kernel quality of Syrian durum wheat for the degree of vitreousness and total protein content (average quality data were 65% and 12.6% respectively) for better end-use product quality. In addition, irrigation demonstrated a significant effect on kernel quality traits, for example, irrigated samples showed the highest test weights. The importance of three physiochemical markers, namely total protein content, the degree of vitreousness and kernel hardness was substantiated and presented useful indicators for future development in Syrian durum wheat breeding programmes.

Optimum cooking time of pasta and cooked pasta firmness correlated significantly with final viscosity ($r = 0.51, 0.73$), dough development time ($r = 0.69$ and 0.63) and R_{\max} ($r = -0.64, -0.43$) which indicated that RVA, farinograph and extensograph techniques were useful indicators of the cooking properties of pasta.

Overall, this study revealed that to achieve the aim of improving the domestic production and expanding the potential export of durum wheat crop in Syria, both genetic and agronomic improvements are still required.

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Courses attended:

Modules

- SFAC511: Research and development project management.
- SFAC200: Quantitative methods.

Generic Skills Workshops

- Project Management
- Endnote Bibliographic Referencing – an introduction
- Introduction to PowerPoint 2002
- Intermediate PowerPoint 2002
- Preparing Effective Poster Presentation

Publications:

El-Khayat, G. H., Samaan, J. and Brennan, C. S. 2003. Evaluation of vitreous and starchy Syrian durum (*Triticum durum*) wheat grains: The effect of amylose content on starch characteristics and flour pasting properties. *Starch/ Starke*, 55, 358-365.

El-Khayat, G. H., Samaan, J., Manthey, F. A., Fuller, M. P. and Brennan, C. S. 2006. Durum wheat quality I: some physical and chemical characteristics of Syrian durum wheat genotypes. *International Journal of Food Science and Technology*, 41, 22-29.

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AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

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Director of study:

A handwritten signature in cursive script that reads "Michael Fuller". The signature is written in dark ink and is positioned to the right of the "Director of study:" label.A handwritten signature in cursive script, possibly reading "Michael Fuller" again, written in dark ink and positioned below the first signature.

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Chapter 1

1. The current situation and future development of wheat in Syria:

Wheat is one of seven crops that are considered by the Syrian government as strategic crops, with 75% of the 4.6 million hectares of cultivated land in Syria planted to these crops. These crops also comprise over 50% of the total income of crop production (Westlake 2003).

It was estimated that the Syrian wheat production in the crop year 2005 was approximately 4.3 million tonnes from 1.7 million hectares harvest area (Anon. 2005a). Two species of wheat are currently cultivated in Syria, hard durum wheat (*Triticum durum*) and soft wheat (*Triticum aestivum*) which comprise 60% and 40% of the total wheat production respectively and are grown on irrigated and rainfed lands during the winter season (the summer is too hot and dry for wheat production) as shown in Fig.1.1. Approximately 40% of the Syrian wheat crop is grown under irrigated conditions and wheat is the dominant irrigated crop in Syria accounting for approximately 50% of the total irrigated land. The irrigated wheat tripled between 1987 and 1998 whereas significant changes in the area planted to rainfed wheat have not been detected over the past 15 years (Westlake 2003).

Durum wheat is mainly grown in the north and north east of Syria. Table-1.1. illustrates the changes in durum wheat production, area and yield (Anon. 2005b). The area planted to durum wheat has shown a small but steady decrease since 1994 to a current production area of 0.83 million hectares and whilst average yield fluctuates it has stabilised somewhat recently at around 2.5 t ha^{-1} and realises an annual production of

some 2.3 million tonnes (Table-1.1). The yield per hectare of Syrian durum is low compared to world standards which frequently record yields twice or three-times this level (Anon. 2002; 2006a).

Durum wheat in the Middle East is mainly used for bread rather than pasta and in Syria durum and soft wheat classes are both milled into flour and subsequently this flour is used to form Arabic bread (two-flat leavened bread made of wheat flour, water, yeast, salt and sugar). Wheat is considered the main staple food by the Syrians as bread is widely consumed in large quantities (Westlake 2003; Anon. 2005a). The Syrian government planned to achieve the target of being self-sufficient in wheat production to meet the domestic requirements and achieved this goal in 1994. It was also a government economic intention to increase exports to external markets (Westlake 2003; Anon. 2005c).

Wheat marketing and processing in Syria is closely government controlled. It is almost exclusively marketed through a state enterprise known as The General Establishment for Cereal Processing and Trade (GECPT) under the supervision of the Ministry of Supply and Internal Trade (MSIT). Milling and baking of wheat is undertaken by two state companies called the General Company for Mills (GCM) and the General Company for Baking (GCB) under the GECPT, whilst wheat storage is carried out by the General Company for Silos, Feed Mills and Seed Plants (GESILOS), which is an establishment of the MSIT. Seventy percent of the wheat produced by farmers is sold to the GECPT and the rest is largely for own consumption. In 1991 a number of private mills were established in Syria and some farmers market a small amount of grains to these mills but this is considered as technically illegal (Westlake 2003). Wheat is milled either by the GCM or private mills to produce two types of flour, standard and high

quality. Standard flour is processed into standard bread, while high quality flour is used to make special bread, pastries and pasta. Bran and other by-products are sold to the General Establishment for Feed (GEF).

According to the world market requirements and the intention to improve domestic products, the Syrian government established the General Commission for Standards and Specifications in December 2005 as a part of the Ministry of Industry to identify and set the standards for all crop products and all enterprises have to comply with these standards. Currently there is a proposal to establish The National Commission for Export Development to replace the Foreign Trade Centre, with the following general objectives to: (reproduced directly from the published documentation, Anon. 2005c):

- “Develop national exports and help local producers, traders, and investors to benefit from export opportunities in international markets.
- Assist in improving the quality of Syrian commodities in order to achieve comparative advantages and competitiveness.
- Promote the exports of Syrian products and work with concerned authorities to remove domestic and foreign obstacles and barriers.

In order to achieve these objectives, this Commission has the following main assignments:

- Participating in the preparation of national export plans and the drawing of general export policies.
- Searching for foreign markets for Syrian commodities and studying the consumption patterns in these markets to guide producers and exporters to supply the most competitive products for these markets.

- Establishing a system for collecting and storing information and data related to national and international trade to serve exporters and producers.
- Preparing a training programme to improve the qualifications of technical staff working in domestic marketing and exporting to international markets.
- Conducting promotional activities for Syrian products and services in foreign markets through trade expeditions and specialized exhibitions, and preparing local and outside seminars and forums for marketing and export.
- Working to establish qualitative councils for the most important exported products.
- Developing bilateral, regional and international cooperation with domestic, regional and international organizations and groups in terms of stimulating Syrian exports and offering information about foreign markets.
- Establishing external trade centres to promote Syrian exports in coordination with Trade Commercial Offices (Supplements) in Syrian embassies.”

As a consequence, the Ministry of Economy and Trade (MET) has established a Directorate for the World Trade Organization (WTO) responsible for preparing Syria to join the WTO. Moreover, an agreement between Syria and the United Nations Development Program (UNDP) has been signed to support the Syrian procedures and preparations to join the WTO (Anon. 2005c).

Syria has shifted from a net wheat importer to a net wheat exporter since 1994, with soft wheat accounting for 76.3% of total wheat exports in 2004. Nevertheless, in 1999 private companies were granted permission to import wheat for special purposes, such as pasta processing for both domestic consumption and export (Westlake 2003).

It has been recorded that the annual exports of Syrian wheat were about 664,700 tonnes between 2002-2004 compared with 407,400 tonnes between 1995-1997 (Anon. 2005c). Algeria used to be the main country for Syrian wheat exports but in 2004 the Syrian wheat was mostly exported to Egypt (one third of exports) followed by Iraq, Algeria, Jordan, Lebanon, North Korea, Yemen, and Italy (Table-1.2). From the data provided in Table-1.2. it is possible to determine the average price per tonne for exported Syrian wheat and compare these to published world prices for these years (Table-1.3) and show that Syrian wheat has traded at a premium price. Prices obtained for exported Syrian wheat are generally lower than for internally marketed wheat but exportation is a sound economic goal for Syria as it attracts an income of "hard currency".

It is unlikely that the wheat acreage in Syria can increase much more than at present due to limitations on irrigation water availability and crop rotations but it is clear that yields could be improved. It can therefore be concluded that in order to meet the economic development goals for wheat exports as outlined above it is necessary to improve yield through both genetic (breeding) and environmental (agronomic) routes. However, it is imperative that in pursuing increased yields, breeders and growers must not sacrifice crop quality because it is this that commands premium world prices. Unfortunately there has been relatively little research on Syrian wheat to determine the relationships between grain qualities and end-use products particularly pasta and therefore it is important to determine these relationships to give indicators to breeders and growers for future improvement in the crop.

Year	Area million hectares	Production million tonnes	Yield tonnes hectare⁻¹
1994	1.10	1.95	1.77
1995	1.10	2.35	2.14
1996	1.20	2.45	2.04
1997	1.30	1.90	1.46
1998	1.30	2.60	2.00
1999	0.80	1.00	1.25
2000	0.90	1.10	1.22
2001	0.88	2.40	2.72
2002	0.83	2.30	2.76
2003	0.88	2.30	2.61
2004	0.83	2.10	2.53
2005	0.83	2.10	2.53
2006	0.83	2.10	2.53

Table-1.1. Durum wheat area, production and yield in Syria.

Source: Anon. 2005b.

Year	Exports		Main destination countries (%)
	Tonnes	Million US\$	
Av 95-97	407,367	89.8	Algeria (53.4), Tunisia (8.2), EU (7.2), Turkey (6.3), Iraq (5.2), Libya (5.1), South Korea (4.5)
Av 02-04	664,663	120.5	Algeria (49.5), Egypt (19.2), Iraq (9.4), South Korea (4.6), Italy (4.0), Jordan (3.9)
2000	0	0.0	
2001	35,615	8.5	Algeria (60.5), Armenia (39.4), S. Arabia (0.1), UAE (0.1)
2002	626,218	117.8	Algeria (82.4), South Korea (13.4), Egypt (4.1), Jordan (0.1)
2003	667,580	117.8	Algeria (54.2), Egypt (21.0), Italy (8.9), Iraq (7.9), Yemen (4.4), Ukraine (3.6)
2004	700,193	125.9	Egypt (31.7), Iraq (19.6), Algeria (14.2), Jordan (11.1), Lebanon (8.4), North Korea (4.6)

Table-1.2. Durum and soft wheat exports in Syria.

Source: Anon. 2005c.

Year	Average price per tonne of exported Syrian wheat	World price per tonne
Av 95-97	\$ 220	\$ 190
Av 02-04	\$ 181	\$ 175
2000	0	\$ 215
2001	\$ 239	\$ 205
2002	\$ 188	\$ 190
2003	\$ 176	\$ 175
2004	\$ 180	\$ 162

Table-1.3. Average value of exported Syrian wheat compared to world wheat prices.

Source: Anon. 2002; 2006a.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Algeria												
Argentina												
Australia												
Canada												
EU												
India												
Kazakstan												
Mexico												
Morocco												
Russia												
Syria												
Tunisia												
Turkey												
USA												

Plant	
Harvest	

Fig.1.1. Durum crop calendar.

Source: Anon. 2005b

Chapter 2

2. Literature Review:

Wheat is one of the most important crops in the world with the largest production of any crop. This is because it is highly adaptative to environmental conditions and because of its unique characteristics where it can be processed into various types of edible products (Shewry and Tatham 1997).

Traditionally, durum wheat (*Triticum durum*), which possibly was first cultivated around 10,000-15,000 BC (Bozzini 1988; Srivastava *et al.*, 1988), is used mainly for the production of pasta (Irvine 1971), couscous and in some countries, especially the Middle East and North Africa, for various types of bread (Quaglia 1988; Palumbo *et al.*, 2000) whereas the hexaploid modern day wheat (*Triticum aestivum*) is preferred for bread (Finney and Barmore 1948).

The different attributes of *T. durum* and *T. aestivum* are due to the differences in kernel physiochemical properties (Matsuo and Irvine 1970; Tipples and Kilborn 1974). Durum wheat grains are harder, larger and more vitreous than bread wheat grains. Moreover, durum wheat generally has higher protein content, double the amount of xanthophylls pigments (responsible for the bright yellow colour of semolina), and higher wet and dry gluten, but lower SDS sedimentation volume. This latter characteristic means that durum wheat gluten is softer than bread wheat gluten (Sims and Lepage 1968; Dick *et al.*, 1981; Finney *et al.*, 1987; Dick and Matsuo 1988; Boyacioglu and D'Appolonia 1994a) and is also more sticky. Furthermore, because there is a higher amount of gliadin in durum wheat gluten (rather than glutenin), it shows more extensibility and less elasticity than hard wheat gluten (Gilles 1967; Risdal 1971; Dick 1981; Feillet 1988). As durum wheat grain is very hard, more starch damage is generated when grains are

milled into flour and this is associated with higher water absorption in farinograph tests than bread wheat, but shorter dough development time and a higher mixing tolerance index (Bakhshi and Bains 1987; Boyacioglu and D'Appolonia 1994b; Sapirstein *et al.*, 2007).

Durum wheat is tetraploid (AABB), while bread wheat is hexaploid (AABBDD), and consequently, the absence of D genome is to some extent responsible for the reduction in durum wheat baking performance (Kerber and Tipples 1969; Ceoloni *et al.*, 1996; Pogna *et al.*, 1996; Redaelli *et al.*, 1997; Joppa *et al.*, 1998; Lafiandra *et al.*, 2000).

2.1. PHYSICAL PROPERTIES:

Wheat milling potential and end-use quality are highly determined by the physical properties of the grains which in turn are highly influenced by both genotype and the environmental conditions of the growing season (Dexter and Edwards 1998a; 1998b).

2.1.1. Specific (test) weight:

Specific weight (weight per unit volume) is an important quality aspect used in wheat grading systems as an indication of grain soundness. Low specific weight can reflect various unfavourable actions such as severe weather damage (Czarnecki and Evans 1986), insect infection (Buntin *et al.*, 1992), heat damage (Saadalla *et al.*, 1990), loading damage (Laude and Pauli 1956, Weibel and Pendleton 1964), or delay in harvesting (Pool *et al.*, 1958). Grains with low specific weight tend to have shrivelled appearance.

Numerous investigations have been conducted to determine the relationship between specific weight and milling potential (Mangels 1960; Shuey 1960; Johnson and Hartsing 1963; Baker *et al.*, 1965; Barmore and Bequette 1965; Finny and Yamazaki 1967; Shuey and Gilles 1972; Watson *et al.*, 1977a; 1977b; Matsuo and Dexter 1980a; Matsuo *et al.*, 1982a; Hook 1984). Work conducted on common wheat showed significant correlation between specific weight and flour yield for the four classes A - D (Baker *et al.*, 1965). On the other hand, Tkachuk and Kuzina (1979) revealed that specific weight was negatively correlated with moisture content and protein content. Hook (1984) in research on UK winter and spring wheats concluded that specific weight was influenced by year and location, but did not find strong correlations to grain or flour yield. In contrast, Matsuo and Dexter (1980a) reported that semolina yield of durum wheat was significantly correlated with specific weight and 1000-kernel weight ($r = 0.52, 0.69$ respectively), while specific weight and 1000-kernel weight showed a low but significant correlation ($r = 0.32$). Further work by Dexter *et al.*, (1987) demonstrated a highly significant correlation between specific weight, milling characteristics and pasta quality, where a linear decrease of 0.7% in semolina yield was associated with a 1 kghl^{-1} decrease in specific weight. Moreover, pasta brightness was related to specific weight, as semolina colour became duller when specific weight declined. More recently, Troccoli and Di Fanzo (1999), who investigated the relationship between specific weight and kernel size characteristics, detected negative correlations between specific weight and both kernel length and perimeter ($r = -0.61, -0.57$ respectively). Furthermore, kernel size features were not influenced by variety or location, while specific weight exhibited variations, which support previous findings by Stenvert and Moss (1974), and Hook (1984) who pointed out that specific weight was a cultivar and site determined character of grain.

2.1.2. Kernel hardness:

Wheat hardness is an important milling characteristic as it is related to conditioning of wheat before milling, energy consumption during milling, mill settings, flour particle size distribution, and milling yield (Hoseney *et al.*, 1987; Pomeranz and Williams 1990; Greffeuille *et al.*, 2007). Furthermore, hardness affects baking quality as it is related to starch damage leading to the absorption of more water during dough development and a greater effectiveness of α -amylase (Pomeranz *et al.*, 1984; Morris and Rose 1996; Sapirstein *et al.*, 2007).

Hard and soft wheats, even if they exhibit no morphological differences between them, tend to fracture differently when exposed to a mechanical force (Turnbull and Rahman 2002). Soft wheat kernels tend to crush randomly through the endosperm generating flour with irregular fine particles with a low level of starch damage, which is difficult to handle, and sticks in the sieves during milling. The characteristics of soft wheat tend to be preferred for biscuits and cake flour production. In contrast, hard wheat is ground to flour with high levels of damaged starch and the fractures occur along the walls of the endosperm cells producing flour with angular larger particles, which flow easily through the sieves. The characteristics of hard wheat tend to be preferred for breadmaking (Greer and Hinton 1950; Haddad *et al.*, 1998; 1999).

Extensive research has been dedicated to measure wheat hardness using different techniques. These techniques were reviewed by Anjum and Walker (1991) and classified the principles into four categories, grinding, crushing, abrasion, and indentation. In addition, Near-Infrared Reflectance (NIR) has been used in measuring wheat hardness as a simple technique requiring a short time (Williams 1979; Williams

and Sobering 1986a; Noriss *et al.*, 1989; Manley *et al.*, 1996). Particle size index (PSI), as a measurement of the percentage of flour passing through a specific sieve, has been performed by various authors (Cutler and Brinson 1935, Worzella and Cutler 1939; Symes 1961; Obuchowski and Bushuk 1980; Miller *et al.*, 1982; Yamazaki and Donelson 1983; Williams and Sobering 1986b) as an index to kernel hardness because of the relationship between hardness and granulation or particle size distribution (Wu *et al.*, 1990).

Early work on wheat hardness showed that kernel components, such as protein and starch of hard and soft wheat exhibited little difference in hardness. However, starch surfaces of hard wheat showed more adherent material than starch of soft wheat (Barlow *et al.*, 1973; Glenn and Johnston 1992a). Moreover, Simmonds *et al.*, (1973) established that the adhesive strength between starch granules and the surrounding protein matrix, which was attributed to the water soluble components, was responsible for the physical difference between hard and soft endosperm. Work conducted by Greenwell and Schofield (1986), Schofield and Greenwell (1987) showed that soft wheat had 15 kDa protein bands and hard wheat had faint or very faint 15 kDa bands, moreover these were completely absent in durum wheat. This protein was given the name “Friabilin” or Grain Softness Protein GSP (Greenwell and Schofield 1986; Jolly *et al.*, 1993; Morris *et al.*, 1994; Rahman *et al.*, 1994; Bettge *et al.*, 1996). This protein plays an important role in wheat endosperm texture as a non-stick substance and therefore reduces adhesion between the protein matrix and starch granules. This enables the main wheat endosperm components (starch and protein) to be separated more easily in soft wheat than hard wheat. Darlington *et al.*, (2000) isolated friabilin from the protein matrix in hard wheat, and showed that it was made up of two main polypeptides named puroindoline-a and puroindoline-b, in addition to a third minor component called

GSP-1 (Rahman *et al.*, 1994) and there may be other components in friabilin (Oda and Schofield 1997). Bechtel *et al.*, (1996) demonstrated that factors responsible for hardness were present in both mature and immature kernels. Furthermore, Greenblatt *et al.*, (1995) showed that starch granules isolated from soft wheat had tenfold more of the polar lipids, such as glycol and phospholipids, than hard wheat starch granules. These lipids were associated with puroindoline and were important in the interaction with starch. In other studies, pentosans or arabinoxylans have been shown to affect wheat hardness (Hong *et al.*, 1989; Kavitha and Chandrashekar 1992) where a highly significant correlation ($r = 0.58$) has been reported although only half of the variation was accounted for by the correlation. In contrast, Bettge and Morris (2000) demonstrated a trivial role of pentosans in relation to hard wheat hardness.

It has been well established that the inherited genotype of hardness is a single major gene (Symes 1965; Yamazaki and Donelson 1983; Miller *et al.*, 1984), which is associated with the alteration of puroindoline a and b (Giroux and Morris 1997; 1998), and softness is the dominant trait (Morrison *et al.*, 1989). This gene is located on chromosome 5D and is called the *Ha* (hardness) locus (Mattern *et al.*, 1973). It has been shown that the presence of the hardness gene imparts significant effects on wheat and flour qualities (Rogers *et al.*, 1993; Bergman *et al.*, 1998; Campbell *et al.*, 1999; Morris *et al.*, 1999). The relationship between environmental factors and hardness was investigated by Miller *et al.*, (1984) who concluded that environmental conditions had no influence on measured hardness, which supported the contention that hardness is an inherited character. Other studies however, have demonstrated that environmental conditions did affect wheat hardness (Stenvert and Kingswood 1977; Pomeranz *et al.*, 1985; Bushuk 1998) but the combined effects of genotype and the physiochemical

characteristics on wheat hardness have not been fully confirmed (Greenblatt *et al.*, 1995).

2.1.3. The degree of vitreousness:

Another physical property often associated with hardness is the degree of vitreousness of grains. However, hardness is not synonymous with vitreosity (Simmonds 1974). The vitreous character refers to the appearance of the kernel, related to air spaces between starch granules, and is defined as the degree of translucency shown by wheat kernels (Yamazaki and Donelson 1983), whilst hardness refers to the degree of compactness between starch granules and the surrounding protein matrix which can be defined as the resistance of the kernel to deformation (Hoseney 1986; Pomeranz and Williams 1990). Starchy kernels have a discontinuous endosperm with many air spaces and appear white in colour (Dexter *et al.*, 1989; Sadowska *et al.*, 1999).

It is well documented that environmental factors, such as temperature, light intensity, water availability and nitrogen fertilisation, during grain development can determine whether grains appear vitreous or starchy (Parish and Halse 1968; Hoseney 1986; Pomeranz and Williams 1990). However, the genetic effect on the degree of vitreousness has not been detected but it has been related to protein content (Zeleny 1971; Pomeranz and Williams 1990) as well as to the gliadin/ glutenin ratio (Dexter *et al.*, 1989; Samson *et al.*, 2005).

It has been verified that vitreous kernels are harder and with a higher protein content than starchy kernels (Stenvert and Kingswood 1977; Dexter *et al.*, 1988; Dexter *et al.*, 1989; Samson *et al.*, 2005) and as a consequence the degree of vitreousness affects

semolina yield as starchy kernels impart more flour when ground, which is undesirable (Menger 1973; Matsuo and Dexter 1980a; Dexter and Matsuo 1981; Sissons *et al.*, 2000). Furthermore, vitreous kernels have higher gluten content than starchy kernels as well as more gliadin, although no differences have been detected in their relative electrophoretic compositions (Dexter *et al.*, 1989). An important consequence is that the degree of vitreousness improves cooking quality and the colour of pasta (Matsuo and Dexter 1980a; Hoseney 1986; Blanco *et al.*, 1988).

Whilst a knowledge of the complete relationship between the degree of vitreousness and durum wheat hardness and milling characteristics is still limited (Dexter *et al.*, 1988) since the degree of vitreousness has no impact on gluten quality (Dexter and Matsuo 1981) protein content is generally considered a more reliable index to predict pasta quality than the degree of vitreousness.

2.2. CHEMICAL CHARACTERISTICS:

2.2.1. Ash content:

Ash content of durum wheat, which is under genetic control (Borrelli *et al.*, 1999), has been investigated as a quality characteristic because of its influence on pasta colour (Matsuo and Dexter 1980b). It has been reported that semolina subjected to a long extraction time had high ash content and an associated brown colour of the pasta (Kobrehel *et al.*, 1974; Taha and Sagi 1987; Cubadda 1988; Borrelli *et al.*, 1999), where ash content appears to affect pigment degradation during pasta processing (Borrelli *et al.*, 1999).

2.2.2. Lipids content:

It has been demonstrated that durum wheat semolina had more non-polar lipid but less polar lipids than common wheat flour (Lin *et al.*, 1974a; Greenblatt *et al.*, 1995).

However, polar and non-polar lipids did not show any effects on pasta quality (Lin *et al.*, 1974b).

It has been proposed that puroindoline polypeptides associate with lipid to perform their role as non-sticking components (Wilde *et al.*, 1993; Oda and Schofield 1997; Le Guerneve *et al.*, 1998; Turnbull and Rahman 2002; Konopka *et al.*, 2005). Moreover, a strong relationship has been detected between the locus controlling the amount of polar lipids (*Flp*) and the locus controlling kernel hardness (*Ha*), which indeed supported the association between lipids and puroindolines (Kooijman *et al.*, 1997) and hence interpreted previous findings that soft wheat exhibited higher polar lipid content on starch granule surfaces (Lin *et al.*, 1974a; Greenblatt *et al.*, 1995).

2.2.3. Starch quality and quantity:

Starch is the dominant component of wheat kernels and comprises approximately 70% of the endosperm (Dick 1981). Two types of wheat starch granules have been detected, large lenticular shaped starch granules (A-type), with an average diameter of approximately 18 μm , and small spherical granules (B-type), with an average diameter of approximately 5 μm (Lowy *et al.*, 1981), and these two types of starch granules exhibit different physical, chemical and functional properties (Manigat and Seib 1997). It has been found that an increase in A-type granules caused disruption in the protein

matrix and hence damage in gas cells (Hayman *et al.*, 1998). On the other hand, an increase in B-types granules improved dough viscosity (Lelievre *et al.*, 1987; Edwards *et al.*, 2002) as well as pasta cooking quality (Soh *et al.*, 2006) since small starch granules exhibit higher gelatinization temperature than large granules (Feillet 1984).

Starch is made up of two polymers, amylose and amylopectin in a ratio of approximately 1:3. Amylose content, which ranges between 21.6-30% in wholemeal wheat flour, is positively controlled by the presence of waxy protein (Yamamori *et al.*, 1992; Nakamura *et al.*, 1993; Yamamori and Quynh 2000). However, it has been illustrated that environmental conditions exhibited an influence on amylose content of starch (Sasaki *et al.*, 2002).

Upon heating with excess water wheat starch granules start to swell at 45-50°C and continue until 85°C resulting in gelatinization (Tester and Morrison 1990a). The swollen starch granules comprise amylopectin which loses its crystalline structure and amylose melts and diffuses out of the starch granules to form the continuous phase (Hermansson and Avegmark 1996). Upon cooling, amylose is re-associated in an organized structure to form a gel, whereas amylopectin forms a viscose matrix (Biliaderis *et al.*, 1980; Miles *et al.*, 1985a; 1985b; Atwell *et al.*, 1988). This process is called starch retrogradation (Fredriksson *et al.*, 1998) and it has been found to affect the quality of end-use products cooking properties (Biliaderis and Zawistowski 1990; Zeng *et al.*, 1997).

It is well established that the amylose/amylopectin ratio exhibits significant effects on starch gelatinization and retrogradation (Czuchajowski *et al.*, 1998; Fredriksson *et al.*, 1998; Yuryev *et al.*, 1998), and a minimum amylose/ amylopectin ratio of 0.43 was

reported to retain the gel structure during heating with water (Leloup *et al.*, 1991).

Amylose shows an adverse effect on starch swelling, where starch completes its swelling as amylose leaches out from the starch granules and hence starch swelling is an attribute of amylopectin (Tester and Morrison 1990a; 1992; Morrison *et al.*, 1993; Sasaki *et al.*, 2002) and therefore, waxy starch (amylose free starch) exhibits rapid swelling (Hermansson and Avegmark 1996; Bhattacharya *et al.*, 1999). Nevertheless, it has been found that damaged starch granules also exhibited an impact on starch swelling and gelatinization properties (Karkalas *et al.*, 1992; Morrison and Tester 1994a; 1994b; Tester and Morrison 1994). On the other hand, amylose exhibits an important role in starch gelatinization, where it maintains a firm gel by reducing the damage of swollen starch granules (Flipse *et al.*, 1996; Hermansson and Avegmark 1996; Mei-Lin *et al.*, 1997) and hence gives the resultant structure of the bread crumb (Lorenz 1995; Lee *et al.*, 2001).

Negative correlations have been reported between amylose content and peak viscosity as measured by the Rapid Visco Analyzer (RVA), where 1% reduction in amylose content was associated with 22 RVAU (Rapid Visco Analyzer Unit = 1/12 centipoises) increase in peak viscosity. This has been interpreted as a reduction in amylose content is associated with an increase in the swelling power of starch granules and hence a reduction in the amount of available water (Dengate 1984; Crosboie 1991; Ming *et al.*, 1997). Moreover, amylose content showed an impact on starch breakdown viscosity, which is an index of the susceptibility of cooked starch to disintegration. In addition, amylose exhibited an influence on setback viscosity, which is an index of re-crystallization of gelatinized starch when it is cooled (Lee *et al.*, 1995). Sasaki *et al.*, (2000) illustrated that enthalpy energy and final gelatinization temperature, as measured by Differential Scanning Calorimetry (DSC), were negatively correlated with amylose

content. However, onset and peak temperatures did not show any correlation with amylose content. Furthermore, highly positive correlations were detected between amylose content and final viscosity and setback ($r= 0.916, 0.801$ respectively), where starch with low amylose content exhibited less leached out amylose and hence less viscosity during cooling. On the other hand, it has been confirmed that amylopectin molecular characteristics such as crystallinity, weight and shape, also played a major role in starch swelling and gelatinization properties (Tester and Morrison 1990a). High gelatinization temperature and high enthalpy energy are associated with long amylopectin branch chain (Sanders *et al.*, 1990; Jane *et al.*, 1992; Yuan *et al.*, 1993; Shi *et al.*, 1994; Kasemsuwan *et al.*, 1995; Sasaki and Matsuki 1998; Jane *et al.*, 1999) and pasting properties of starch are affected by branch chain length of amylopectin (Jane *et al.*, 1992; Wang *et al.*, 1993; Jane *et al.*, 1999; Franco *et al.*, 2002).

Durum wheat starch shows lower gelatinization temperature (Medcalf and Gilles 1965; Berry *et al.*, 1971; Lii and Lineback 1977; Soulaka and Morrison 1985; Lintas 1988), higher peak viscosity (Rask and Alsberg 1924; Mangels 1934; 1936), and higher amylose content (Medcalf and Gilles 1965; Soulaka and Morrison 1985; Lintas 1988; Vansteelandt and Delcour 1998) than other wheat starches.

In general, research investigating the effect of durum wheat starch on end-use product quality is limited and much more research has been dedicated to the effect of protein (Lin and Czuchajowski 1997). Whilst protein is responsible for the cooking quality of pasta, starch determines its optimum cooking time (Marshall and Wasik 1974; Banasik *et al.*, 1976; Sheu *et al.*, 1976; Grzybowski and Donnelly 1977). Nonetheless, more research has demonstrated that starch appeared to exhibit less influence on the cooking properties of pasta (Sheu *et al.*, 1967; Walsh and Gilles 1971; Grzybowski and

Donnelly 1979; Damidaux *et al.*, 1980). Recently, Soh *et al.*, (2006) confirmed the importance of amylose content in durum wheat end-use quality, and they demonstrated that durum wheat with elevated amylose content between 32-44% imparted improvement in the firmness of cooked pasta, which supported previous research (Dexter and Matsuo 1979; Gianibelli *et al.*, 2005; Vignaux *et al.*, 2005), and hence they suggested plant breeders to develop durum wheat genotypes with elevated amylose content.

2.2.4. Total protein content:

It is well documented that protein quality and quantity are the most important factors affecting dough rheological properties and pasta cooking quality (Matsuo and Irvine 1970; Walsh and Gilles 1971; Matsuo *et al.*, 1972; Dexter and Matsuo 1977a; 1977b; 1978a; 1980; Grzybowski and Donnelly 1979; Dexter *et al.*, 1980; Matsuo *et al.*, 1982a; Autran *et al.*, 1986; Dick and Matsuo 1988; Autran and Galterio 1989; D'Egidio *et al.*, 1990; Boyacioglu *et al.*, 1991; Novaro *et al.*, 1993; Dexter *et al.*, 1994; Sissons *et al.*, 2005). It has been recommended that durum wheat cultivars should retain at least 13% protein content (dmb) in order to produce a high quality product and protein content less than 11% imparts poor quality (Liu *et al.*, 1996).

Bietz and Wall (1972) used the technique of SDS-PAGE (Sodium Dodecyl Sulfate Poly Acrylamide Gel Electrophoresis) to characterize the molecular weight of wheat proteins. They demonstrated that gliadins had molecular weights between 30,000 and 80,000 kDa where ω -gliadin showed the largest molecular weight 60,000-80,000, while α -, β -, and γ -gliadins had molecular weight between 30,000 and 40,000. The molecular weight of albumins and globulins was less than 40,000. On the other hand, high

molecular weight glutenin subunits showed molecular weights between 100,000-140,000, while the molecular weight of low molecular weight glutenin subunits was 30,000-50,000.

A large body of research on hard bread wheat has revealed that protein quality and quantity affect baking quality (Finney and Barmore 1948; Tipples and Kilborn 1974; Sozinov and Popereya 1980; Branlard and Dardevet 1985a; 1985b; Graybosch *et al.*, 1996) demonstrating that an increase in protein content is associated with an increase in bread loaf volume. Other studies however, have shown that the correlation between protein composition and breadmaking quality was restricted to certain proteins and even to certain subunits (Payne *et al.*, 1983; Payne and Lawrence 1983; 1987; Sontag *et al.*, 1986; Lawrence *et al.*, 1987; Uhlen 1990; Johansson *et al.*, 1993; Johansson and Svensson 1995; Johansson 1996). Khatkar *et al.*, (1995) pointed out that breadmaking quality was correlated with protein content, where it increased with increasing protein content for a given cultivar, however, for different cultivars with the same protein contents, breadmaking quality was affected by protein quality more than quantity.

There is less research on durum wheat and protein but Dexter and Matsuo (1977a) investigated the effect of protein content on quality characteristics of two durum wheat cultivars differing in pasta quality. In general, they demonstrated that durum wheat dough rheological properties and pasta cooking quality were significantly influenced by protein content and protein content increased semolina yellow pigment, farinograph maximum consistency tolerance index, cooking quality of pasta and tolerance to overcooking. Subsequently, Dick and Quick (1983) showed that protein content and mixograph measurements explained 65% of the variations in firmness of cooked pasta whilst other studies showed that protein content and SDS sedimentation volume

accounted for 40% of the variations in pasta cooking quality (Dexter *et al.*, 1980).

Recently, Sissons *et al.*, (2005) suggested that durum wheat cultivars with protein contents over 17% produced superior quality of pasta with high firmness and low stickiness and hence they proposed a useful indicator to wheat breeders regarding the importance of protein content.

As with proteins of bread wheat, protein fractions of durum wheat have been found to impart different effects on the quality traits of pasta (Ruiz and Carrillo 1995a; 1995b; Vazquez *et al.*, 1996; Carrillo *et al.*, 2000; Brites and Carrillo 2001; Martinez *et al.*, 2004; 2005).

Environmental factors, such as nitrogen fertilization, water and temperature, exhibit large influences on protein content (Sosulski *et al.*, 1963; Benizian *et al.*, 1983; Baenziger *et al.*, 1985; Peterson *et al.*, 1986; Stapper and Fischer 1990; Lukow and McVetty 1991; McDonald 1992; Mariani *et al.*, 1995). In contrast, protein quality is entirely under genetic control (Payne *et al.*, 1987; Johansson *et al.*, 1993). However, there are some quality attributes, such as specific protein and subunit contents and particle size distribution of glutenin, are influenced by both environmental factors (Wieser and Seilmeier 1998) and genotype (MacRitchie 1999).

2.2.5. Gluten content:

The wheat storage proteins, gliadin and glutenin, represent approximately 80% of total wheat flour protein (Hoseney *et al.*, 1969; Bietz and Wall 1975; Pritchard and Brock 1994; Tatham and Shewry 1995). As wheat flour is mixed with water, these storage proteins combine with other flour components, such as lipids, carbohydrates and other minerals, to form a viscoelastic mass called gluten (Feillet 1980). In this gluten, gliadin

is responsible for viscosity, while glutenin contributes to elasticity (Weegeles *et al.*, 1996; Khatkar and Schofield 1997). Hussain *et al.*, (1998) reported a highly significant correlation between gluten content and total protein content in hard bread wheat cultivars ($r = 0.98$).

It has been well documented that dough rheological properties and pasta cooking quality are influenced to a large extent by protein content (Irvine *et al.*, 1961; Matsuo *et al.*, 1972; Dexter and Matsuo 1977a), as well as gluten quality (Matsuo and Irvine 1970; Walsh and Gilles 1971; Wasik and Bushuk 1975a; Dexter and Matsuo 1977b). Moreover, variations in breadmaking quality between cultivars are attributed to the variation in gluten quality (Finney 1943; Booth and Melvin 1979; MacRitchie 1979; Sapirstein and Fu 1998), and the quality of the end-use product can vary for flours having the same total amount of protein (Bushuk *et al.*, 1969).

2.2.5.1. Gliadin:

Gliadins are considered as a family of prolamins, comprising single polypeptide chains (monomers) connected to each other by hydrogen and hydrophobic bonds and soluble in dilute acids or 70% ethanol (Caldwell 1979). It has been demonstrated that gliadins could be classified into four groups; α , β , γ , and π gliadins according to their mobilities at low pH (Jones *et al.*, 1959) and starch gel electrophoresis (Woychick *et al.*, 1961). Amino acid composition of gliadin shows a high content of glutamine and proline. Moreover, gliadins are amongst the smallest charged proteins that have ever been studied (Caldwell 1979).

It has been well documented that gliadin imparts weakening effects on dough properties of hard wheat (Branlard and Dardevet 1985a; Campbell *et al.*, 1987; MacRitchie 1987;

MacRitchie *et al.*, 1991; Fido *et al.*, 1997). Nevertheless, Weegels *et al.*, (1994) found that when added to the base flour purified gliadin fractions had a positive effect on loaf volume. An adverse effect of gliadin was detected in durum wheat, where high gliadin was associated with a decrease in pasta firmness (Edwards *et al.*, 2001; Rao *et al.*, 2001) and mixing strength (Dexter and Matsuo 1980; Edwards *et al.*, 2003).

The relationship between gliadin protein and durum quality was intensely investigated by Du Cros *et al.*, (1982), who employed the technique of gel electrophoresis to study the gliadin composition of 103 durum wheat lines. They demonstrated that 100% of durum wheat lines with weak gluten had the 42- γ -gliadin band, while 90% of lines with strong gluten had a 45- γ -gliadin band. Consequently, they suggested that 42- γ -gliadin and 45- γ -gliadin could be used as reliable indices for strong and weak gluten respectively to investigate durum wheat quality in early generations of durum wheat breeding programmes. These findings were also in agreement with Kosmolak *et al.*, (1980) and Pogna *et al.*, (1982). However, it has subsequently been found that the LMW-1 and LMW-2 glutenin subunits, which are associated with γ -gliadin 42 and 45 respectively, were responsible for variations in gluten strength and hence pasta quality (Payne *et al.*, 1984; Autran *et al.*, 1986; Pogna *et al.*, 1988, 1990; Autran and Galterio 1989; Carrillo *et al.*, 1990; Ruiz and Carrillo 1995b). Afterwards, Boggini *et al.*, (1995) claimed that LMW-2 was the major factor affecting dough strength as it existed in larger amounts than LMW-1 (Autran *et al.*, 1987; D'Ovidio *et al.*, 1999).

2.2.5.1. *Glutenin:*

Glutenins are polymeric proteins comprising subunits that form both intra- and inter-molecular bonds and the size of the glutenin molecule affects gluten quality (Shewry

and Tatham 1990; Gupta *et al.*, 1993; 1995; Sapirstein and Fu 1998; Singh and MacRitchie 2001). Two types of glutenin subunits have been detected (Shewry and Tatham 1990), high molecular weight glutenin subunits (HMW-GS) and low molecular weight glutenin subunits (LMW-GS). The total weight of LMW-GS is three times of that weight of HMW-GS (Gupta *et al.*, 1992; 1993). On the other hand, the average molecular size of LMW-GS is nearly half of the HMW-GS (40k, 85k respectively), so the molar ratio is 6:1 (Graveland *et al.*, 1982; 1985; Benedettelli *et al.*, 1992).

Many researchers have focussed their work on glutenin because of its relationship with variations in breadmaking quality (Field *et al.*, 1983; Schofield 1994; Weegels *et al.*, 1996; Toufeili *et al.*, 1999; Dupont and Altenbach 2003), where a variation in the composition of glutenin among wheat cultivars has been illustrated (Gupta *et al.*, 1996; Kuktaite *et al.*, 2000; Lindsay and Skerritt 2000; Johansson *et al.*, 2001; Singh and MacRitchie 2001; Kuktaite *et al.*, 2004). Moreover, it has been demonstrated that the total amount of glutenin subunits accounted for 55% of the variation in extensograph parameters (Gupta *et al.*, 1991a) and 68-80% of the variations in dough rheological properties (Gupta *et al.*, 1992). HMW glutenin subunits impart a positive effect on the dough of bread wheat by improving dough strength and stability (Bekes *et al.*, 1995; Kuktaite *et al.*, 2000; Johansson *et al.*, 2001), while dough extensibility is adversely affected by HMW glutenin subunits (Schropp and Wieser 1996) and positively by LMW glutenin subunits (Gupta *et al.*, 1989; 1991b).

Early studies on durum wheat quality revealed that the higher the glutenin fractions in the gluten mass the better the pasta quality (Walsh and Gilles 1971; Matsuo *et al.*, 1972; Wasik and Bushuk 1975a; 1975b; Dexter and Matsuo 1977b), and high glutenin to gliadin ratio is responsible for high pasta cooking properties (Wasik and Bushuk 1975a;

Dexter and Matsuo 1977a; 1977b). Furthermore, investigating the effect of protein solubility revealed that the proportion of insoluble glutenin in acetic acid solution is an important factor related to protein quality (Huebner and Wall 1976; Orth *et al.*, 1976; Wasik 1978; Dexter and Matsuo 1980; Moonen *et al.*, 1982), mixing properties (Orht and Bushuk 1972), gluten strength and cooking quality of pasta (Walsh and Gilles 1971; Matsuo *et al.*, 1972; 1982a; Dexter and Matsuo 1978a; 1980; Sgrulletta and De Stefanis 1989). Others reported a highly significant correlation between pasta cooking quality and 0.1 M acetic acid-insoluble protein semolina samples ($r = 0.796$), while the correlation with the total protein content was insignificant ($r = 0.269$). This suggested that acetic acid insoluble protein could be used as a good indicator for investigating pasta cooking quality in plant breeding programmes (Sgrulletta and De Stefanis 1989). However, in recent studies it has been documented that variations in durum wheat cultivars are strongly related to the variations in gluten protein (Carrillo *et al.*, 1990; 2000), where LMW glutenin subunits exhibit a more significant effect on durum wheat end-use product than HMW glutenin subunits (Carrillo *et al.*, 1990; Ruiz and Carrillo 1995b; Liu *et al.*, 1996), which is contrary to the status in bread wheat (Payne *et al.*, 1984). Nevertheless, Sapirstein *et al.*, (2007) recently demonstrated that gluten strength of durum wheat dough prepared for breadmaking and measured by different techniques was strongly related with insoluble glutenin fractions which comprised HMW polymeric glutenin subunits.

2.2.6. Gluten strength:

It has been found that dough strength is described as the balance status between dough elasticity and viscosity (MacRitchie 1990), where dough with long development time and high resistance to extension (high elasticity and low viscosity) is characterized as

strong dough. On the contrary, weak dough exhibits short development time and low resistance to extension (low elasticity and high viscosity). In general, high breadmaking quality requires strong dough, and pasta requires gluten with high elasticity, whilst cakes and biscuits require more extensibility (Shewry and Tatham 1997). Consequently, a durum wheat cultivar with high resistance to extension is the main aim of durum wheat breeders.

Gluten strength can be measured by different techniques, such as farinograph (Irvine *et al.*, 1961), mixograph (Bendelow 1967), SDS sedimentation test (Dexter *et al.*, 1980; Quick and Donnelly 1980), gluten index test (Cubadda *et al.*, 1992), alveograph (D'Egidio *et al.*, 1990), and extensograph (Edwards *et al.*, 2001).

It has been demonstrated that gluten strength had an important relationship with pasta cooking quality (Dexter and Matsuo 1980; Matsuo *et al.*, 1982a; Autran *et al.*, 1986; Mariani *et al.*, 1995; Feillet and Dexter 1996; Kovacs *et al.*, 1995), where strong gluten reduced the breakdown of pasta during cooking, and consequently granted a desirable firmness or *al dente* consistency to the consumer (Matsuo and Irvine 1970; Irvine 1971). However, this relationship is still doubtful and Matsuo (1993) demonstrated that high pasta cooking quality was not necessarily due to gluten strength. Furthermore, gluten strength does not have a significant influence on pasta quality when dried under high temperatures compared with low temperatures (D'Egidio *et al.*, 1990; Zweifel *et al.*, 2003).

2.2.7. Amino acids:

It has been detected that protein of common and durum wheats is rich in both amino acids glutamine and proline. However, it is deficient in the essential amino acids, such as lysine, threonine, tryptophan, methionine, and isoleucine (Wrigley and Bietz 1987).

Amino acid composition of wheat protein is restricted by the protein content (Mosse *et al.*, 1985; Martin del Molino 1989), where an increase in grain protein content is associated with a decrease in the essential amino acids, such as lysine (Mosse *et al.*, 1985). Furthermore, wheat storage proteins have variable amino acids composition among varieties and this composition changes according to the nitrogen fertilisation level (Mosse *et al.*, 1985).

Shewry *et al.*, (1986) demonstrated that ω -gliadins had large proportions of the amino acids glutamine, proline and phenylalanine (comprising about 80% of the total residues), while α , β , and γ -gliadins were characterised by less proline, glutamine and phenylalanine, but higher cysteine and methionine. On the other hand, glutenin had a higher content of glycine and lower content of proline compared with gliadins.

2.3. THE MILLING TECHNOLOGY OF DURUM WHEAT:

The wheat milling process is defined as the technique that involves the reduction of kernels into smaller particles that can be utilised and transferred into palatable products. More specifically, milling is the separation of the endosperm from the other parts of the

kernel (i.e., bran and germ), and the reduction of the endosperm to semolina and then to flour.

The separation principle of endosperm from the bran layer depends mainly on the difference in the mechanical properties between these two parts of the grain, which are enhanced by the conditioning process. The role of conditioning (addition of water prior to milling) has been well documented, where its function is to toughen the bran layer and improve its separation from the endosperm (Bass 1988). Many factors have been shown to affect the conditioning process of wheat including the grain characters of hardness (Stenvert and Kingswood 1977), protein content and initial moisture content (Moss 1977) the temperature of added water (Campbell and Jones 1955), and the quantity of added water and duration of soak (Moss 1973; Bass 1988; Perrin *et al.*, 2004). Conditioning has also been reported to exhibit an impact on the quality of wheat flour, where the increase in moisture content during tempering caused a decrease in extraction rate, improvement in flour colour, and decrease ash content (Butcher and Stenvert 1973a; 1973b; Hook *et al.*, 1982a; 1982b; 1982c; 1982d), as well as having an impact on protein characteristics (Gobin *et al.*, 1996).

It has been demonstrated that as wheat endosperm and bran are different in their mechanical properties, they exhibit differential breakage when exposed to the same physical stresses (Glenn *et al.*, 1991; Glenn and Johnston 1992b; Fang and Campbell 2002a; Peyron *et al.*, 2002a). Chaurand *et al.*, (1999) summarized the factors affecting the separation of the starchy endosperm of durum wheat from the bran layers and hence the milling efficiency and semolina yield into three groups. Firstly, peripheral factors, related to the growing conditions; secondly, interior factors, such as the ratio of semolina to bran as well as kernel hardness; finally, how easy the bran could be separated from the endosperm. In a further study Campbell *et al.*, (2001a) classified

factors affecting wheat breakage in the first break into two groups; firstly, factors related to the physiochemical properties of the wheat grains, such as hardness, moisture content and kernel size and secondly, factors related to the milling settings. Previous work on this by Pomeranz and Williams (1990) had proposed that hardness was the fundamental factor affecting wheat milling.

Research efforts have mainly been condensed to evaluate the efficiency of the separation of bran from the endosperm. Pomeranz (1987) suggested determining the chemical constituents in the kernel botanical parts, for instance, ash content. However, determining ash content as a method to investigate the efficiency of separation had a disadvantage as ash also exists in the starchy endosperm (Morris *et al.*, 1945). Another proposed technique was dependent on speck counting in the semolina but this method could not be used for comparative studies between wheat varieties (Evers 1993). Image analysis has been developed for variety discrimination (Fulcher *et al.*, 1972; Jensen *et al.*, 1982) and it was used for common wheat flour assessment (Symons and Dexter 1992; 1996). However, the crystalline appearance of the endosperm was an obstacle in using this method for durum wheat (Lempereur *et al.*, 1997). More recently, Peyron *et al.*, (2002b) suggested the use of phenolic acids, which are highly concentrated in the bran layers (MacCallum and Walker 1991; Onyeneho and Hettiarachchy 1992), as markers to evaluate the accurate separation of bran from the starchy endosperm and hence the milling efficiency of durum wheat.

Milling of durum wheat is significantly different to milling of hard and soft wheat, and it has been reviewed by Bizzarri and Morelli (1988), and Gonzalez (1995). They have stated that the durum wheat milling technique is distinguished from the flour bread milling technique by a long breaking stage, at least six passages with fine and coarse

corrugated rollers oriented sharp-to-sharp in order to reduce the amount of generated flour (Posner and Hibbs 1997; Manthey and Hareland 2001). The breaking stage is accompanied with equal number of detached passages with corrugated rollers.

Additionally, the durum wheat milling process comprises a short reduction stage with only one or two passages of smooth rollers. Differentiation is usually 1:1.5-1:3.0 and 1:1.05-1:1.5 for the corrugated and smooth rollers respectively.

The objective of durum wheat milling is to convert the grains to a coarsely ground endosperm particles known as semolina with a higher particle size than flour and where the entire product should pass through a No. 20 sieve (840 μm aperture size) but not more than 10% passes through a 180 μm sieve. A desirable range of semolina particle size is 150-350 μm , but 100-500 μm is a more realistic expectation. In contrast, 89-98% of flour particles milled from common bread wheat are distributed within the range 10-41 μm and 41-300 μm , while 2-11% of the particles are less than 10 μm (Hareland 1994). As durum wheat is very hard (Miller *et al.*, 1982), because of the absence of the starch granule protein on the surface of the starch granules (Greenwell and Schofield 1986), large particles are produced when it is ground. Therefore, a high force should be used when durum wheat is milled to fine particles (Mousa *et al.*, 1983). Moreover, durum wheat is only tempered to 16-16.5% moisture content for 4 hours to avoid softening the endosperm which would produce more flour.

The correlations between the physical characteristics, such as 1000-kernel weight, test weight (Halverson and Zeleny 1988) and kernel size (Shuey 1960) of wheat grains and milling potential have been widely studied. Test weight has been used for a long time as a grading factor for wheat varieties. A highly linear correlation between flour yield and test weight in the range of 40-64 lb bu⁻¹ (50-80 kg ha⁻¹) was detected (Barmore and Bequette 1965) but Halverson and Zeleny (1988) demonstrated no relation between test

weight and flour yield when the values were more than 57 lb bu⁻¹ (71.25 kg ha⁻¹). Hook (1984) demonstrated that test weight was insignificantly related to wheat milling potential but Marshall *et al.*, (1986) demonstrated a strong positive correlation between test weight and semolina yield. Another physical factor that has been shown to affect the milling performance is wheat hardness, where it has been found that hardness played a major role in determining the way that wheat grains fractured under pressure, the ease of separation of bran from the endosperm, granulation and starch damage (Stenvert 1972). Kilborn *et al.*, (1982) demonstrated that hardness had an impact on milling energy and Scanlon and Dexter (1986) reported that energy consumption during milling was dependent on the physical characteristics of the grains, such as hardness and vitreousness, as well as wheat kernel preparation and mill settings. A recent study conducted by Greffeuille *et al.*, (2007) explained the different influence of both kernel hardness and the degree of vitreousness on the particle size distribution of wheat flour. They illustrated that fine particles of flour were related negatively to the degree of adhesion between starch granules and surrounding protein matrix and hence to wheat hardness. On the other hand, coarse particles generated during the reduction stage were associated with the low degree of porosity and high compactness of wheat endosperm and subsequently to the elevated degree of vitreousness. Peyron *et al.*, (2003) investigated the effect of the aleurone layer, which is a one-cell layer surrounding the endosperm and it is removed through the milling process. Aleurone structure, especially thickness and irregularity had an effect on the milling behaviour of durum wheat cultivars with aleurone layer thickness affecting the ratio of bran to endosperm as its thickness is approximately half of the bran layer (Moss 1973; Simmons and Meredith 1979) and irregularity of the aleurone layer affected the adhesion between endosperm and bran (Bradbury *et al.*, 1956). It has been demonstrated that wheat genotype and environmental conditions had an impact on the thickness and irregularity of the

aleurone layer but kernel weight and morphology did not exhibit any effect on the structure of the aleurone layer. In conclusion despite these findings, the aleurone layer structure did not greatly influence the milling behaviour of durum wheat.

Mill settings, such as roll diameter (Niernberger and Farrell 1970), roll gap (Hsieh *et al.*, 1980), speed differential (Scanlon and Dexter 1986; Scanlon *et al.*, 1988; Hareland 1998; Manthey and Hareland 2001), and orientation (Hareland and Shi 1997; Fang and Campbell 2002b; 2003), are evaluated through semolina yield, appearance and granulation (Dick and Youngs 1988). The first break rolls, where wheat grains are open and the endosperm is separated through an exposure to shearing action, are important in the milling process since this determines the effective separation of the bran from the endosperm (Manthey and Hareland 2001). Corrugated rolls are used in the first break in order to improve the separation where the bran layer fractures into larger particles than the endosperm and hence it can be easily separated by plansifters to yield granular semolina (Posner and Hibbs 1997; Campbell *et al.*, 2001b; Owens 2001).

Fang and Campbell (2002b) demonstrated that the different orientations of corrugates in the break system had a significant effect on particle size distribution. Scanlon and Dexter (1986) and Scanlon *et al.*, (1988) showed that as the roll differential was increased flour yield of hard wheat increased. However, increased differential increased the damage starch which resulted in an adverse effect on flour quality. Regarding durum wheat, Hareland (1998) showed that changing break roll differential affected the total yield of semolina, the ease of separation of bran from the endosperm and semolina granulation. This work was furthered by Manthey and Hareland (2001) to investigate the effect of break roll differential, as an indicator of the shearing force required to remove bran from the endosperm, on semolina and pasta quality. They demonstrated that as the break roll differential was increased, bran speck, ash content and protein

content increased, while semolina starch damage decreased. The increase in protein content was attributed to the relationship between protein content and extraction rate, where protein content in wheat kernels increases from the centre towards the bran layers. On the other hand, semolina colour as expressed by L and b values decreased with increasing roll differential. Pasta cooking loss and firmness did not exhibit any influence with changing the break roll differential. These findings were consistent with previous studies (Dexter and Matsuo 1978b; Scanlon and Dexter 1986; Feillet and Dexter 1996; D'Egidio and Pagani 1997; Hareland 1998; Hsieh *et al* 1998).

2.4. PASTA QUALITY:

Pasta making involves several stages where first the durum semolina is mixed with water in a paddle mixer and then it is fed into an extrusion worm conveyor, where it is compressed and extruded through a die into a stiff dough. After that, the dough is cut and dried to the optimum moisture content, where it should not exceed 12.5% (Feillet and Dexter 1996). The amount of water that is added to the semolina is approximately 280 L.ton⁻¹ to give a final moisture content of 33% on a wet base or 49% moisture content on a dry base, assuming that the initial moisture content of semolina is 14% (Icard and Feillet 1999).

Dexter and Matsuo (1977c) investigated the changes that occurred in semolina proteins during pasta processing. Three durum wheat cultivars and one hard wheat cultivar were used in this investigation. They demonstrated a considerable decrease in sulfhydryl groups by the extrusion stage, while the disulfide bonds did not significantly change during processing for four wheat cultivars. A significant decrease in the amount of acetic acid extractable protein was detected corresponding with a decrease in the salt

soluble protein, while no change was found in the molecular weight distribution of the proteins during pasta processing, which was manipulated by the binding between salt soluble protein and insoluble components of the semolina. Many researchers have detected an increase in the amount of acetic acid extractable proteins during mixing (Mecham *et al.*, 1962; 1963; 1965; Tsen 1967; Chen and Bushuk 1970). Ummadi *et al.*, (1995) demonstrated that extrusion caused new disulphide bonds among insoluble glutenin fractions as an increase in these fractions was noticed during extrusion processes at 50 and 96 °C. Moreover, they observed that these changes were higher when the semolina was extruded at higher temperature. Pagani *et al.*, (1989) detected that the extrusion process imparted interruption to the protein matrix and hence this explained why poor quality flour was not suitable for pasta production. Lintas and D'Appolonia (1973) reported that the increase in starch damage in pasta was attributed to the mechanical damage during mixing and extruding and to the amylolytic enzyme activity during processing. Bañasik *et al.*, (1976) found that as durum dough was extruded, starch was partially gelatinized, while the completed gelatinization occurred during cooking and hence the gelatinized starch and the network of protein were responsible for pasta firmness. Abecassis *et al.*, (1994) found that deterioration in pasta cooking properties could be related to the increase in dough temperature during extrusion. Furthermore, the temperature of extrusion and semolina water absorption have been found to exhibit effects on brightness, yellowness, firmness, cooked weight and cooking loss of pasta (Walsh *et al.*, 1971; Debbouz and Deotkott 1996). The hydration level of semolina particles along with gluten strength were found to affect pasta strength (Abecassis *et al.*, 1994; Ames *et al.*, 2003). Additionally, deficient hydration of semolina caused white specks and cracks in the resultant pasta, while excess hydration resulted increased in pasta stickiness, decrease in the mechanical strength of dried pasta and deterioration in colour (Levine 2001; Manthey *et al.*, 2004).

These findings have recently been confirmed by Yalla and Manthey (2006) that factors other than gluten strength and protein content, such as semolina type, semolina hydration and processing conditions, imparted significant effects on pasta quality. Subsequently, it has been concluded that achieving high quality pasta demands high quality semolina as well as optimum processing conditions (Debbouz and Deotkott 1996).

It is well recognised that pasta appearance, texture and flavour are the principal factors that determine the quality of pasta (D'Egidio *et al.*, 1982; 1993a; 1993b; Dexter *et al.*, 1983; Feillet 1984; Autran *et al.*, 1986; Autran and Feillet 1987). These factors could be defined throughout pasta translucency, bright yellow colour, high firmness and elasticity “*al dente*” eating properties (Antognelli 1980; Hosenev 1986; Pomeranz 1987). In addition, high quality pasta should sustain firm texture during cooking, exhibit minimum water loss, increase cooked weight, and show tolerance to overcooking (Cole 1991; D'Egidio *et al.*, 1993a). Afterwards, Grant *et al.*, (1993) reported that pasta cooking quality could be assessed by firmness, elasticity, surface stickiness, cooking tolerance, water absorption, the degree of swelling, and cooking water loss.

Feillet (1984), who comprehensively reviewed the topics related to the effects of protein, starch, lipids, enzymes, and macromolecules on pasta cooking quality, concluded that good pasta cooking quality was principally influenced by protein quality, quantity, and its ability to form an insoluble network capable of entrapping the swollen and gelatinized starch granules. Cubadda (1989) specified the factors related to obstacles in defining the variations in the quality of semolina of different cultivars. These factors were firstly related to the abundant chemical constituents of grain and the interaction between them, which exhibited difficulties in achieving absolute separation. Secondly, related to the protein composition of high molecular weight subunits with

inadequate solubility. Troccoli *et al.*, (2000) reviewed all the topics related to durum wheat quality and demonstrated that it was difficult to have an accurate definition for durum wheat quality as it varied among farmers, millers, and end-users. However, in pasta processing technique, factors, such as ash content, semolina colour and protein quality, must be considered because of their relation with the quality of the end-use product.

The effect of total protein content, gluten content and quality on pasta cooking properties have been comprehensively investigated (D'Egidio *et al.*, 1990; Boyacioglu *et al.*, 1991; Novaro *et al.*, 1993; Dexter *et al.*, 1994; Sissons *et al.*, 2005, Cubadda *et al.*, 2007) and demonstrated that protein content and gluten quality were the dominant variables to influence the cooking quality of pasta.

The factors that are responsible for pasta colour have been well defined as firstly the original kernel pigment content, which is under genetic control, and secondly the remaining amount of pigment after grain milling and pasta processing as well as the general pasta processing conditions (Irvine and Winkler 1950; Irvine and Anderson 1953; Borrelli *et al.*, 1999; 2003). Other factors have been shown to be involved in pasta colour, such as lipoxygenase activity (LOX), which is responsible for the oxidation of fatty acids (Siedow 1991) and plays a major role in carotenoid pigment degradation giving bleached pasta (Irvine and Winkler 1950; Irvine and Anderson 1953; Borrelli *et al.*, 1999). LOX also causes loss of sulfhydryl groups (Siedow 1991). Peroxidase (POD) and polyphenoloxidase (PPO) can also affect pigment degradation (Kobrehel *et al.*, 1974; Taha and Sagi 1987; Iori *et al.*, 1995; Fraignier *et al.*, 2000). Importantly, semolina ash content has been shown to affect pasta colour (Kobrehel *et al.*, 1974; Taha and Sagi 1987; Cubadda 1988; Borrelli *et al.*, 1999) and hence ash

content of semolina has been advocated as a quality characteristic (Matsuo and Dexter 1980b). In addition, pasta brownness has been revealed to be influenced by protein content (Walsh and Gilles 1971; Matsuo *et al.*, 1972; Dexter and Matsuo 1977a; Taha and Sagi 1986; Feillet *et al.*, 2000).

Dexter and Matsuo (1978b) demonstrated that pasta cooking quality did not correlate noticeably with semolina extraction rate. Moreover, cooking quality of pasta made from coarse semolina did not significantly differ from pasta made from fine semolina. These findings were in agreement with those reported by Seyam *et al.*, (1974). However, the latter stated that cooking loss increased with decreasing semolina granulation. In a further study by Matsuo and Dexter (1980b) it was demonstrated that reducing semolina granulation was associated with a number of negative effects, where it increased starch damage, as durum wheat is very hard, and hence this caused an increase in water absorption of semolina, cooking loss and stickiness of pasta, and reduction in pasta firmness. These findings were verified latter by Grant *et al.*, (1993). Nevertheless, it has been demonstrated that these disadvantages in pasta quality caused by reducing semolina granulation could be overcome by drying pasta under high temperature (Dexter *et al.*, 1981; 1983; Ibrahim 1982; Wyland and D'Appolonia 1982; D'Egidio *et al.*, 1990; Grant *et al.*, 1993; Malcolmson *et al.*, 1993; Novaro *et al.*, 1993; Zweifel 2001; Zweifel *et al.*, 2003), where the extractability of starch decreases and hence adhesion strength between starch and protein increases (Vansteelandt and Delcour 1998). Moreover, starch pasting properties have been noticed to be modified under high temperature (Yue *et al.*, 1999; Zweifel *et al.*, 2000). Nonetheless, Resmini *et al.*, (1996) claimed that pasta dried under high temperature affected pasta colour and flavour due to the Maillard reaction, where the Maillard reaction could be initiated when pasta with high starch damage and low moisture content (< 16%) was dried under high temperature

producing pasta with a red colour and low nutritional value. Furthermore, very recent research verified that the high drying temperature of pasta revealed a significant positive effect on pasta cooking properties only in durum wheat cultivars with weak gluten (Cubadda *et al.*, 2007).

Troccoli *et al.*, (2000) claimed in their review that high extraction rate of durum wheat grains into semolina with minimum flour was the main criterion required by the millers. However, semolina subjected to longer extraction time had higher ash content, which associated with pasta with brown colour (Kobrehel *et al.*, 1974; Taha and Sagi 1987; Cubadda 1988; Borrelli *et al.*, 1999). Furthermore, increasing semolina extraction rate was associated with increasing pigment loss during pasta processing, as the LOX which is responsible for pigment loss, was concentrated in the germ (Bhirud and Sosulski 1993), and also POD and PPO, which are responsible for pasta browning, are concentrated in the bran layers (Fraignier 2000), and hence that would yield pasta with brown colour (Matsuo and Dexter 1980b).

The effects of grain sprouting on pasta quality are contradictory, it has been found that kernel sprouting caused a decrease in pasta firmness and an increase in cooking loss (Kruger and Matsuo 1982; Matsuo *et al.*, 1982b; Grant *et al.*, 1993) whereas a previous study showed that sprouting did not have an influence on cooking loss, cooked weight or firmness (Dick *et al.*, 1974).

Recently, there has been an interest to incorporate non-traditional ingredients, such as buckwheat, wholemeal flour, wheat bran, flaxseed and dietary fiber, to pasta dough as nutritional and healthy objectives (Carter 1993; Kritchevsky 1997; Marconi and Carcea 2001; Manthey and Schorno 2002; Tudorica *et al.*, 2002; Manthey *et al.*, 2004).

However, it has been demonstrated that such incorporation causes disruption in the

gluten network and hence deterioration in pasta quality (Zhang and Moore 1997; Manthey and Schorno 2002; Manthey *et al.*, 2004; Sinha *et al.*, 2004).

Manthey and Schorno (2002) studied the physical and cooking quality of pasta made from wholemeal durum wheat flour. They demonstrated that the whole wheat dough was weak and had poorer stability than dough made from semolina, as bran and germ interfered with the continuity of the protein starch matrix causing weakness in dough development (Bruinsma *et al.*, 1978; D'Appolonia and Youngs 1978; Ozboy and Koksel 1997; Zhang and Moore 1997). Furthermore, pasta made from wholemeal flour had a reddish brown colour and exhibited lower mechanical strength and firmness and greater cooking loss compared with pasta made from semolina. This was consistent with previous studies (Kordonowy and Youngs 1985; Sahlstrom *et al.*, 1993; Edwards *et al.*, 1995). Further studies investigated the effect of genetically modified durum wheat, such as waxy durum wheat, on pasta quality. It has been hypothesised that pasta made from waxy durum wheat could exhibit less cooking loss and consequently higher cooking quality, as amylose, which is free in waxy starch wheat (Grant *et al.*, 2001), was lost during pasta processing (Grant *et al.*, 1993). However, reducing amylose starch caused an increase in water swelling during cooking in excess water, and hence the resultant pasta was softer (Crosbie 1991; Morris *et al.*, 1997; Grant *et al.*, 2001), and supported previous research by Dexter and Matsuo (1979) that cooked pasta firmness was positively correlated with starch amylose content. Grant *et al.*, (2004) compared the quality characteristics of waxy durum wheat grains, semolina and cooked pasta, with those of non-waxy durum wheat. They demonstrated that quality attributes of waxy grains were similar to those of non-waxy grains apart from kernel hardness. Semolina of waxy wheat had higher ash content, lipid content, starch damage, swelling values, and stronger mixograph curve, but lower speck count, wet gluten than non-waxy wheat, while no difference was detected in protein content. On the other hand, pasta processed

from waxy semolina exhibited shorter cooking time, as well as exhibiting the same cooking loss and cooked weight, but had lower firmness. Colour measurements of uncooked pasta showed that samples made from waxy semolina were brighter (higher L values) but less yellow (lower b values) than samples made from non-waxy semolina. A former study by Dexter and Matsuo (1978b) interpreted that lower b values were associated with lower vitreousness; waxy durum grains are opaque, while higher L values could be interpreted by lower speck count. In contrast, durum wheat with elevated amylose content showed desirable effects on pasta quality (Soh *et al.*, 2006).

2.5. THE EFFECT OF ENVIRONMENT AND GENOTYPE ON WHEAT QUALITY:

The effects of environment, genotype and their interaction ($G \times E$) on wheat physiochemical properties have been extensively studied and this interaction has a significant influence on wheat quality in the Mediterranean area (Borghi *et al.*, 1982; Sinclair *et al.*, 1993).

Protein content, quality and chemical composition have received more attention comparing with other quality attributes due to the significant influence imparted by protein on end-use product quality. It has been well documented that total protein content was fundamentally influenced by environmental factors and the effect of the $G \times E$ was insignificant. In contrast, protein quality has been reported to be mainly related to genotype variations, with an insignificant $G \times E$ effect (Baenziger *et al.*, 1985; Peterson *et al.*, 1986; Lukow and McVetty 1991; Mariani *et al.*, 1995; Ames *et al.*, 1999; Lerner *et al.*, 2006; Rogers *et al.*, 2006). Kolster *et al.*, (1991) demonstrated significant differences in the amount of individual HMW glutenin subunits of hard

wheat varieties through different locations, where 66% of this variation was attributed to the variations in the total protein content. Peterson *et al.*, (1992) however, demonstrated that the quality attributes, such as protein content, mixing properties and SDS sedimentation volume, were influenced by genotype, environment, and by $G \times E$ although environmental factors had the largest effects. Recently, Labuschagne *et al.*, (2006), in their investigation of the influence of different nitrogen treatments on protein quality of hard and soft wheat, supported previous research by Graybosch *et al.*, (1996) and revealed that different environmental conditions could affect protein quality. As a consequence, it has been suggested that the environmental effects should be taken into account in breeding programmes of common wheat. Mikhaylenko *et al.*, (2000) demonstrated that environmental factors exhibited the dominant influence on hard wheat grain quality and moreover, the growing location had a significant influence on the end-use quality with strong negative effects detected when cultivars were grown in inappropriate environments. Zhu and Khan (2001) found that total protein content and SDS soluble glutenin fraction were greatly affected by environmental factors more than genetic factors, while SDS-insoluble glutenin fraction was under greater genetic control. In a further study, Zhu and Khan (2002) demonstrated that environmental factors significantly influenced the quantitative variation of the total amount of HMW glutenin subunits, which in turn affected the size distribution of glutenin polymers and hence breadmaking quality.

In general, it has been reported that increased temperature and reduced rainfall during the grainfill stage caused an increase in grain nitrogen concentration (Halverson and Zeleny 1988; Blumenthal *et al.*, 1993; Borghi *et al.*, 1995; Corbellini *et al.*, 1997; 1998), and consequently increased the degree of vitreousness, gluten quantity and sedimentation volumes (Schipper 1991) leading to reduced gluten strength because of

the higher proportion of bran in shrivelled grains than in well-filled grains. The positive effect of temperature on wheat protein content during the early stage of grainfilling has also been well documented (Johnson *et al.*, 1972; Kolderup 1975; Spiertz 1977; Rao *et al.*, 1993; Blumenthal *et al.*, 1994; Corbellini *et al.*, 1997; Uhlen *et al.*, 1998).

Blumenthal *et al.*, (1994) proposed that high temperature during grainfilling affected starch particle size distribution, where large A-starch granules were increased but starch chemical composition was not modified. These changes in starch distribution have been reported to affect flour water absorption and hence dough mixing properties (Pomeranz 1988; Stone and Nicolas 1994). Borghi *et al.*, (1995) found that wheat kernels exposed to a temperature range 30-35°C for a long time exhibited an increase in dough strengthening measured by alveograph but when the temperature exceeded 35°C a decline in dough strength was experienced. Corbellini *et al.*, (1997) investigated the effect of heat shock during grain-filling stage on protein quality and dough rheological properties of hard and durum wheat. The selected wheat varieties were exposed to 13 heat treatments up to 40 °C for different periods, which was representative for the Mediterranean climate. They demonstrated that dough rheological properties were significantly affected by the heat exposure during grain filling as it was noticed by the adequate reduction in dough mixing tolerance. This was interpreted as a change in protein quality, where gliadin protein and soluble glutenin were increased while insoluble glutenin was decreased. Uhlen *et al.*, (1998) also reported that flour protein and polymeric protein fraction increased as the temperature increased. These findings are not surprising but are of importance to wheat grown in the eastern Mediterranean where temperatures during the grainfilling stage are frequently in the low 30's °C and soil moisture availability is often low.

Nitrogen fertilization, as an agricultural practice, has been found to increase protein content and affect the ratio of HMW to LMW glutenin subunits (Doekes and Wennekes 1982; Lasztity *et al.*, 1984; Wieser and Seilmeier 1998), which sequentially affects breadmaking quality (Hamada *et al.*, 1982; Uthayakumaran *et al.*, 1999). In durum wheat, nitrogen fertilization increases protein content, which is associated with an increase in gluten strength (Abad *et al.*, 2000; Johansson *et al.*, 2001). A comprehensive study related to the effect of nitrogen fertilization on durum wheat varieties of different gluten strength under different locations and crop years was carried out by Ames *et al.*, (2003). It has been demonstrated that nitrogen fertilizer positively affected protein content and gluten strength, as measured by SDS sedimentation volume.

2.6. AIMS AND OBJECTIVES OF THE THESIS:

It has been mentioned that it is difficult to propose a comprehensive definition for wheat quality as this differs between growers, millers and end-use processors (Troccoli *et al.*, 2000). However, wheat quality or functionality, as defined by Williams (1998), “is the suitability of the wheat for the manufacture of the products for which it is to be purchased”. Consequently, the question that emerged at the beginning of this study was “are the Syrian durum wheat functionalities suitable for the manufacture of high quality pasta?”. Reviewing the research that has been published on durum wheat grain quality, milling performance, pasta cooking properties and the variation of quality due to the effects of environment, genotype and their interaction revealed a distinct lack of information regarding Syrian durum wheat, where only a few articles have been published so far (Williams *et al.*, 1983; Williams and El-Haramein 1985; Williams *et al.*, 1988; Elings., 1991; Elings and Nachit 1991; Vanhintum and Elings 1991; Elings 1993; Elings and Nachit 1993; Elharamein and Adleh 1994; Ali 1995; Annicchiarico *et al.*, 1995; Elias 1995; Kayyal *et al.*, 1995; Nachit *et al.*, 1995, Al-Oudat *et al.*, 1998; Paulley *et al.*, 1998; Vargas *et al.*, 1998; Oweis *et al.*, 1999; Arabi and Jawhar 2002; Berlin *et al.*, 2003; El-Khayat *et al.*, 2003; Kaddour and Fuller 2004; Pala *et al.*, 2004; El-Khayat *et al.*, 2006; Samaan *et al.*, 2006; Shoaib and Arabi 2006) even though Syria is considered as one of the top durum wheat producers in the world (Lennox 2003; Anon. 2005b). Moreover, the milling potential of Syrian durum wheat into semolina and the resultant cooking quality of pasta have never been investigated as the majority of the Syrian wheat is ground into flour used mainly for the production of bread. Recently, there has been an increased expectation to expand the export of Syrian durum wheat into the local and external world markets as an economic issue (Anon. 2005c).

Consequently, to fulfil this demand and to answer the previous question three critical aims emerged in the current thesis:

- I. Comprehensively define the overall quality of selected Syrian durum wheat cultivars.
- II. Test the projected compatibility of Syrian durum wheat in the world market.
- III. Determine the stability and variability of the measured traits.

These aims have been tested through the following objectives:

1. Select the dominant grown durum wheat cultivars on fully irrigated plots in Syria.
2. Determine the physiochemical composition, milling potential and pasta cooking properties of the selected cultivars.
3. Investigate the interrelationship between the measured variables and hence present a clue to select the most fundamental traits that could be used later as genetic indicators in breeding programmes.
4. Test the consequence of elevated vitreousness on the kernel quality attributes.
5. Illuminate whether starch quality, quantity and chemical composition demonstrate a significant role in durum wheat quality.
6. Compare the Syrian durum wheat characteristics with the counterpart top durum wheat exporters (the Canadian and American grade No 1 cultivars) and map the Syrian cultivars onto the world market requirements to define suitability and shortfalls.
7. Determine the stability of the most important physiochemical characteristics by evaluating the variability across the major growing zones in Syria and under two different agricultural practices, irrigation and rainfed. Consequently, present other potential agronomic indicators to improve durum wheat farming in Syria.

These objectives are detailed more thoroughly in the relevant chapters of the thesis.

Chapter 3

3. Materials and Methods:

3.1. MATERIALS:

3.1.1. Seeds Set-1:

Nine spring durum wheat cultivars (SHAM-1, SHAM-3, SHAM-5, BOHOUTH-5, BOHOUTH-7, DOUMA-1105, DOUMA-18861, DOUMA-26827 and DOUMA-29019) were selected for analysis (Table-3.1). The first five cultivars are commercially available and currently used on farms, whereas the DOUMA lines are experimental lines in the process of accreditation. The samples were obtained from the Ministry of Agriculture Research Station at Al-Raqqa in northeast of Syria, which is one of the main durum wheat provinces in Syria (Latitude: 35°37'N, Longitude: 39°0'E, Altitude: 249.9 m). All cultivars were grown at the same location and under the same agroecological conditions in the crop year 2001/ 2002 in a medium clay soil type. The crops were from an irrigated agricultural practice and were not exposed to drought conditions. The land was previously cropped with vegetables and had high initial soil fertility (Nitrogen 18.4 ppm, Phosphorus 12 ppm and Potassium 220 ppm). Total rainfall for the 2001-2002 season was 184 mm with 13 recorded days where the field temperatures was below 0°C, and no days were recorded where the temperature exceeded 30°C. The field plots received 4500 m³ha⁻¹ of water during the growing season (450 mm, i.e. approximately 2.5 times of normal rainfall) and was applied after 20 days of sowing, tillering stage, and early grain filling stage. Nitrogen and phosphorus fertilisers were applied as well (138 and 69 units.ha⁻¹ respectively, equal to 300 kg.ha⁻¹

of 46% Urea and 150 kg.ha⁻¹ of 46 % Super-phosphate respectively), where half the amount of nitrogen fertiliser and the total amount of phosphorous fertiliser were added before sowing while the other half of nitrogen was added during the tillering stage.

Samples of 50 g from each cultivar were analysed as whole samples and 2 fractions comprising vitreous and starchy grains sorted visually. These fractions were ground to wholemeal flour using a laboratory mill (Micro Hammer mill C680, Glen Creston Ltd., Stanmore, UK) and the flour sieved through precision sieves 500 and 250 µm to obtain semolina-like flour particle size of 250 µm for subsequent chemical determinations.

Furthermore, samples of 2 kg from each cultivar were cleaned and tempered then milled in a Buhler laboratory mill into semolina which was then used to determine the quality characteristics of semolina and end-use product.

3.1.2. Seed Set-2:

In this set of samples, two sub-sets of samples were selected:

3.1.2.1. Seed sub-set-1:

Three spring durum wheat cultivars (SHAM-1, BOHOUTH-5 and DOUMA-29019) were selected (Table-3.1). Each cultivar was grown in five different locations in Syria in a complete-block design with four replications, and the crops were from irrigated agricultural practices and were not exposed to drought conditions. These locations are as shown in Table-3.2. All cultivars in each area were grown at the same location and under the same agroecological conditions in the crop year 2004/ 2005. The field plots received 4500 m³ha⁻¹ of water during the growing season (450 mm) and nitrogen and

phosphorus fertiliser (138 and 69 units.ha⁻¹ respectively, which is equal to 300 kg.ha⁻¹ of 46% Urea and 150 kg.ha⁻¹ of 46 % Super-phosphate respectively), and were applied as mentioned before.

Treatment	Growing season					
	2002/2003			2004/2005		
	Location	Cultivar	Code	Location	Cultivar	Code
Irrigation	Site-3 Abou-Rassen/ Al-Raqqa	SHAM-1	1	Site-1 Amer/ Al-Hassakah	SHAM-1	10
		SHAM-3	2		BOHOUTH-5	11
		SHAM-5	3		DOUMA-29019	12
		BOHOUTH-5	4	Site-2 Saalo/ Deir Ezzor	SHAM-1	13
		BOHOUTH-7	5		BOHOUTH-5	14
		DOUMA-1105	6		DOUMA-29019	15
		DOUMA-18861	7	Site-3 Abou-Rassen/ Al-Raqqa	SHAM-1	16
		DOUMA-26827	8		BOHOUTH-5	17
		DOUMA-29019	9		DOUMA-29019	18
				Site-4 Khan-Shehon/ Edleb	SHAM-1	19
					BOHOUTH-5	20
					DOUMA-29019	21
				Site-5 Homs/ Homs	SHAM-1	22
					BOHOUTH-5	23
					DOUMA-29019	24
Rainfed				Site-6 Tal-Sandal/ Edleb	SHAM-1	25
					SHAM-3	26
					DOUMA-18861	27
				Site-7 Almalkia/ Al-Hassakah	SHAM-1	28
					SHAM-3	29
					DOUMA-18861	30
				Site-8 Yahmol/ Aleppo	SHAM-1	31
					SHAM-3	32
					DOUMA-18861	33
				Site-4 Khan-Shehon/ Edleb	SHAM-1	34
					SHAM-3	35
					DOUMA-18861	36
				Site-5 Homs/ Homs	SHAM-1	37
					SHAM-3	38
					DOUMA-18861	39

Table-3.1. Codes for the durum wheat samples used throughout the study.

	Location	Latitude	Longitude	Altitude m	Rainfall mm	Soil Type	Total days temperature below 0°C	Total days temperature exceeded 30°C
Site-1	Amer/ Al-Hassakah	37°1'N	41°11'E	451.1	196.1	Medium Clay	69	34
Site-2	Saalo/ Deir Ezzor	35°19'N	40°9'E	211.8	155	Medium Clay	1	30
Site-3	Abou-Rassen/ Al-Raqqa	35°37'N	39°0'E	249.9	121	Medium Clay	41	30
Site-4	Khan-Shehon/ Edleb	36°12'N	36°12'E	100	371	Medium Clay	20	13
Site-5	Homs/ Homs	35°1'N	36°43'E	309.1	435	Heavy Clay	15	7

Table-3.2. Sites properties of the irrigated cultivars.

3.1.2.2. Seed sub-set-2:

Three spring durum wheat cultivars (SHAM-1, SHAM-3 and DOUMA-18861) were selected (Table-3.1). Each cultivar was grown in five different locations in Syria in a complete-block design with four replications, and the crops were from rainfed agricultural practices. These locations are as shown in Table-3.3. All cultivars in each area were grown at the same location and under the same agroecological conditions in the crop year 2004/ 2005. The field plots received nitrogen and phosphorous fertiliser during the growing season (92 and 46 units.ha⁻¹ respectively, which is equal to 200 kg.ha⁻¹ of 46% Urea and 100 kg.ha⁻¹ of 46 % Super-phosphate respectively).

	Location	Latitude	Longitude	Altitude m	Rainfall mm	Soil Type	Total days temperature below 0°C	Total days temperature exceeded 30°C
Site-6	Tal-Sandal/ Edleb	36°10'N	37°13'E	392.9	392	Heavy Clay	18	13
Site-7	Almalkia/ Al-Hassakah	36°6'N	40°12'E	398.1	331.8	Heavy Clay	9	24
Site-8	Yahmol/ Aleppo	36°11'N	37°13'E	392.9	404	Heavy Clay	23	9
Site-4	Khan-Shehon/ Edleb	36°12'N	36°12'E	100	371	Medium Clay	20	13
Site-5	Homs/ Homs	35°1'N	36°43'E	309.1	435	Heavy Clay	15	7

Table-3.3. Sites properties of the rainfed cultivars.

3.2. METHODS:

The seeds were analysed for various characters related to grain quality, semolina production and pasta cooking properties.

3.2.1. Physical characteristics:

3.2.1.1. *The degree of vitreousness:*

The degree of vitreousness is related to the degree of compactness of the kernel (Yamazaki and Donelson 1983), and it has been linked to the hardness of the kernel, and the amount of protein and starch within the kernel (Stenvert and Kingswood 1977).

The degree of vitreousness was ranked visually and samples hand sorted. Vitreous kernels were defined as whole sound kernels that exhibited the natural amber colour of durum wheat with no starchy white flecks. In contrast, starchy samples were defined as kernels with 100% starchy endosperm and no vitreous flecking. The vitreous kernels from 50 g of wheat were hand sorted, weighed and reported as percent vitreous kernels.

3.2.1.2. *Test weight:*

Test weight or specific weight is an important quality aspect used in wheat grading systems, and it is used as an index of the soundness of wheat grain, plumpness, maturity and freedom from damage.

Test weight was determined as of the AACC method 55-10 (AACC 2000), where the weight of grains is measured using a standard 0.5-litre cell and the weight converted to weight per unit volume (kg hl^{-1}). Care is taken to drop the grains into the volumetric cell in a standard manner so as not to affect packing density unduly.

3.2.1.3. Thousand Kernel weight:

Thousand kernel weight (or Thousand Grain Weight – TGW), which is a measurement of the weight in grams of a 1000 grain sample of wheat, is linked with both semolina yield and test weight. Small grains retain lower ratio of endosperm to bran than large kernels and hence would yield less semolina.

1000-Kernel weight was determined using an electronic seed counter, where the number of kernels in a 10 g clean wheat sample was determined. Results were adjusted to reflect the weight of 1000 kernels.

3.2.1.4. Kernel hardness:

Wheat hardness is an important milling characteristic as it is related to the conditioning requirements of wheat before milling, the energy consumption during milling, mill settings, flour particle size distribution, and milling yield (Hoseney *et al.*, 1987; Pomeranz and Williams 1990). Moreover, hardness is used to classify wheat grains into different types, such as hard and soft.

Wheat grain hardness was measured by recording the force required to crush the wheat kernels using a Texture analyzer TA.XT2 (Stable Micro Systems, Reading, UK),

calibrated for a load cell of 25 kg and force and time were recorded for individual grains with the same size, and mean levels recorded for a 10 grain sample.

3.2.1.5. Kernel size distribution:

Kernel size distribution was determined according to the procedure described by Shuey (1960), which used a kernel sizer consisting of two sieves, Tyler No. 7 with a 2.92 mm aperture and Tyler No. 9 with a 2.24 mm aperture. A 100 g sample of clean wheat was placed on the top (No. 7) and shaken for three minutes. Kernels remaining on the top sieve were classified as large kernels, while kernels passing through the top sieve and remaining on the second one were classified as medium kernels. Kernels passing through the second sieve were classified as small. Each fraction was weighed and the weight reported as a percentage of the total.

3.2.1.6. Single kernel characteristics:

Single kernel characteristics were determined using Single Kernel Characterisation System SKCS 4100 (Perten Instruments, ND, USA), using a 300 kernel sample (conditioned to 11% moisture). The SKCS had previously been calibrated using hard wheat samples. Means and standard deviation for kernel weight, diameter, hardness index and moisture were recorded.

3.2.1.7. Scanning Electron Microscopy:

The difference in vitreous and starchy grains structure was examined using Scanning Electron Microscopy (SEM).

Vitreous and starchy kernels were cut with a razor blade, air dried, and mounted on 10 mm aluminium stubs with carbon tabs and silver paint (Agar Scientific Ltd., Stansted, UK). Samples were sputter coated in an EMITECH K550 gold coating unit (EM Technologies Ltd., Ashford, UK) and scanned in a JEOL 5600 LV Scanning Electron Microscope (Jeol Ltd., Welwyn Garden City, UK) at x500, x1000 and x2000 resolutions. The resulting micrographs were then assessed by eye.

3.2.2. Chemical characteristics:

3.2.2.1. *Moisture content:*

It has been confirmed that moisture content has an influence on the tempering process in wheat (Moss 1977). Early research by Tkachuk and Kuzina (1979), studying hard red spring wheat, illustrated that an increase in grain moisture content caused a decrease in test weight and density, but an increase in kernel weight. Moreover, moisture content exhibited a significant effect on hardness scores measured by NIR, and it was postulated that as kernel moisture content increased the particle size increased, because of higher bran particles, and hence the hardness scores of hard and soft wheats increased (Gaines and Windham 1998).

Moisture was determined by the approved AACC method 44-15A (AACC 2000) using a 2-3 g of wholemeal sample or semolina placed in a dish and heated for 60 min at 103°C and moisture content is calculated as:

$$\text{Moisture \%} = \frac{\text{loss in moisture (g)}}{\text{original weight of sample (g)}} \times 100$$

3.2.2.2. Ash content:

Ash content is regarded as a quality characteristic for durum wheat kernels as it has an influence on pasta colour that may be due to high extraction rates (Cubadda 1988). This can impart an undesirable brown colour in the resulting pasta (Borrelli *et al.*, 1999; Taha and Sagi 1987). Premium-grade semolina generally has ash content lower than 0.9% on a dry matter basis (Cubadda 1988).

Ash content was determined using the Approved AACC method 08-01 (AACC 2000) and expressed on a dry matter basis. Wholemeal flour or semolina (3-5 g) was weighed into a crucible and then incinerated at 575-590 °C until a light grey ash was obtained and ash content calculated:

$$\text{Ash \% (as is)} = \frac{\text{weight of residue (g)}}{\text{sample weight (g)}} \times 100$$

$$\text{Ash \% (dmb)} = \frac{\text{Ash (as is)\%}}{100 - \text{moisture content\%}} \times 100$$

3.2.2.3. Falling number:

Falling number or Hagberg falling number is used as an industry standard method to reflect α -amylase activity in a ground sample and reflects adverse weather conditions during harvest that causes premature grain sprouting. This is particularly damaging in bread wheat but is also relevant to durum wheat quality. Donnelly (1980) observed that semolina with falling number values less than 120 sec would produce pasta with high checking and cracking. Matsuo *et al.*, (1982) concluded that low falling number values

which associated with high α -amylase activities tended to increase the amount of residue in pasta cooking water as well as reduce the firmness of cooked pasta.

Falling number was determined by the AACC approved method 56-81B (AACC 2000), using Perten Falling Number instrument (Perten Instruments AB, Sweden). The falling number is defined as the time in seconds for a stirrer (plunger) to fall through a hot pre-incubated slurry of ground wheat. When the amount of alpha-amylase in the wheat flour is high premature hydrolysis of the gelatinized starch paste occurs, the paste becomes thinner and hence the plunger falls through the slurry more quickly. High falling number values (more than 300 sec) indicate that the wheat is acceptable.

3.2.2.4. Protein content:

Protein content is one of the most important quality characteristic of durum wheat kernels in relation to determining pasta quality (Dexter and Matsuo 1977c; Dexter and Matsuo 1980; Autran and Galterrio 1989). It has been confirmed that protein content is highly influenced by environment much more than genotype (Mariani *et al.*, 1995), and protein content increases with increasing temperature and reduced moisture availability during ripening.

There are several methods of determining the protein content of wheat grains which have all been cross-correlated. In this work protein analysis was conducted by the DUMAS method using a Leco model FP-428 C/N analyser (Leco Corp., Stockport, UK) corresponding to the AACC approved methods 46-30, protein crude combustion method (AACC 2000). A wholemeal flour sample or semolina sample is burned in an oxygen-rich atmosphere and the amount of nitrogen gas measured. The total protein present is calculated from the nitrogen content using the standard conversion factor $N \times 5.7$.

Protein content was reported on a dry mater basis as follows:

$$\text{Protein\% (dmb)} = \frac{\text{protein (as is)\%}}{100 - \text{moisture content\%}} \times 100$$

3.2.2.5. *Gluten quality and quantity:*

Although total protein content is a major factor in final pasta quality, research has also investigated the importance of the gluten component of the protein in determining the rheological and cooking quality of pasta (Damidaux *et al.*, 1980; Du Cros *et al.*, 1982; Carrillo *et al.*, 1990). Gluten is the visco-elastic mass formed through the interaction between the wheat storage proteins glutenin and gliadin, and the other wheat components such as wheat lipids and water under the effect of mixing. The starch fraction of the flour sticks to the gluten to form a dough which can be extruded to form raw pasta.

Assessment of the wet gluten content was performed according to the approved AACC method 38-12A (AACC 2000) using a glutomatic instrument (Perten Glutomatic 2200 with double washing chambers), which washes out the starch components of the flour with a 2% sodium chloride solution. The remaining gluten mass was then centrifuged (2015 bench-top centrifuge) for one minute at 6000 ± 5 rpm using a 600 μm aperture size metal sieve. The gluten fraction remaining on the top of the sieve was collected and weighed. The gluten which passed through the sieve was scraped off with a spatula and was added to the top fraction and reweighed to calculate the total wet gluten. Total wet gluten content was calculated as a percentage out of 10 g flour.

The Gluten index was calculated as following:

$$\text{Gluten index} = \frac{\text{gluten remained on sieve (g)}}{\text{total gluten (g)}} \times 100$$

The extracted wet gluten was dried in a Glutork 2020 at 150 °C for 4 min. The weight of dried gluten is multiplied by 10 to calculate dry gluten as a percent.

3.2.2.6. Starch content:

Wheat starch, which is concentrated in the endosperm (Dick 1981), is the dominant component of kernels comprising approximately 70% (by weight) of the endosperm.

Total starch content was determined using a Megazyme starch assay kit (Megazyme Int., Wicklow, Ireland) which conformed to the AACC approved method 76-13 (AACC 2000) based on the use of thermostable α -amylase and amyloglucosidase (McCleary *et al.*, 1997). Starch is first partially hydrolysed into dextrins by the thermostable α -amylase, then the dextrins are completely hydrolysed into glucose units by the amyloglucosidase. A glucose determination reagent (GOPOD) is used to develop a colour with the glucose units and the absorbance is measured using a spectrophotometer set at 510 nm wavelength.

Starch is calculated using the following formula:

$$\text{Starch \%} = \Delta E \times \frac{F}{W} \times 90$$

Where:

ΔE = Absorbance (reaction) read against the reagent blank.

$$F = \frac{100}{\text{absorbance of glucose}}$$

W = weight (as is) of flour sample in milligrams.

3.2.2.7. Amylose content:

Starch is made up of two polymers, amylose and amylopectin. Amylose, which comprises between 21.6- 30% of wholemeal wheat flour starch (Yamamori *et al.*, 1992), is a linear molecule of 100-10000 glucose units connected by 1-4 α bonds, and exhibits an amorphous order. In contrast, amylopectin, which has the same basic structure as amylose, is a branched chain of glucose units, where its degree of polymerization is approximately 2 million units and this forms a crystalline structure (Hermansson and Avegmark 1996). The amylose content in wheat starch is strongly linked to the presence of waxy protein in the grain (Yamamori *et al.*, 1992; Nakamura *et al.*, 1993; Yamamori and Quynh 2000) but environment also has an influence on amylose content of starch (Sasaki *et al.*, 2002).

The apparent amylose content was determined using a Megazyme amylose/ amylopectin ratio assay kit, which depends on forming complexes with amylopectin using the following procedure as described by Gibson *et al.*, (1997):

1. Disperse starch samples (20-25 mg) completely by heating in dimethyl sulphoxide (DMSO).
2. Discard lipids by ethanol 95%, where starch will precipitate.
3. Total starch in separate aliquots is hydrolyzed into glucose by the addition of fungal α -amylase and amyloglucosidase mixture, and form colour complex with a glucose determination reagent (GOPOD), where it is measured colourimetrically by a spectrophotometer set at 510 nm wave-length.
4. Denature amylopectin by the addition of Con A (lectin concanavalin A), and then removed by centrifugation (20,000 g for 10 min).

5. The amylose in aliquots is hydrolysed by the enzyme mixture into glucose, which is measured the same as total starch in step-3.
6. Apparent amylose content is calculated as following:

$$\text{Amylose \%} = \frac{\text{Absorbance Con A Supernatant}}{\text{Absorbance Total Starch Aliquot}} \times 66.8$$

3.2.2.8. Pasting properties of wheat starch:

The Rapid Visco Analyser (RVA) has recently been used to measure starch pasting properties since it requires small sample size as well as only taking a short time (Ravi *et al.*, 1999).

Flour pasting properties were evaluated using a Rapid Visco Analyser (RVA-4) and data analysed using Thermocline software (Newport Scientific Pty. Ltd., Warriewood, NSW 2102, Australia), which depends on exposing a wheat starch suspension to heat and shear and recording the viscosity during the process. A total weight of 28 g per canister was maintained with the amount of wholemeal flour added based on 3 g dry matter basis (Grant *et al.*, 2001). Total run time was 13 minutes with conditions using the AACC approved method 76-21 (AACC 2000), where onset temperature was 50°C. The temperature was increased to 95°C and held for approximately 3 min before declining again to 50°C (Fig.3.1). Peak viscosity (PV), holding strength or hot paste viscosity (HPV), breakdown (PV-HPV), final paste viscosity (FV), and setback (FV-HPV), were recorded (Fig.3.2).

3.2.4. Dough rheological measurements:

3.2.4.1. *Farinograph*:

The farinograph technique is used to measure dough water absorption along with the mixing tolerance indices.

Farinographs were determined according to the approved AACC method 54-21 (AACC 2000), with the large bowl 300 g. Measurements recorded were water absorption, dough development time, and stability (Fig.3.6).

Water absorption: The amount of water in millilitres required to centre the highest portion of the farinograph curve on the 500-Brabender unit (BU) line, where it is adjusted by adding or deducing 0.4 ml for each square. It is expressed as a percentage of the flour weight on a 14 % moisture basis, and calculated as following:

$$\text{Absorption \%} = (X - Y + 300) / 3$$

X: the amount of water (ml) to produce a curve with maximum consistency centred on the 500-BU line.

Y: weight of flour (g) used equivalent to 300 g on 14 % moisture basis.

Mixing Peak Time (Development time): The time interval, in minutes, required from the first addition of water until the curve reaches its maximum height.

Stability Time: The time in minutes where the top of the curve remains above the 500 unit line.

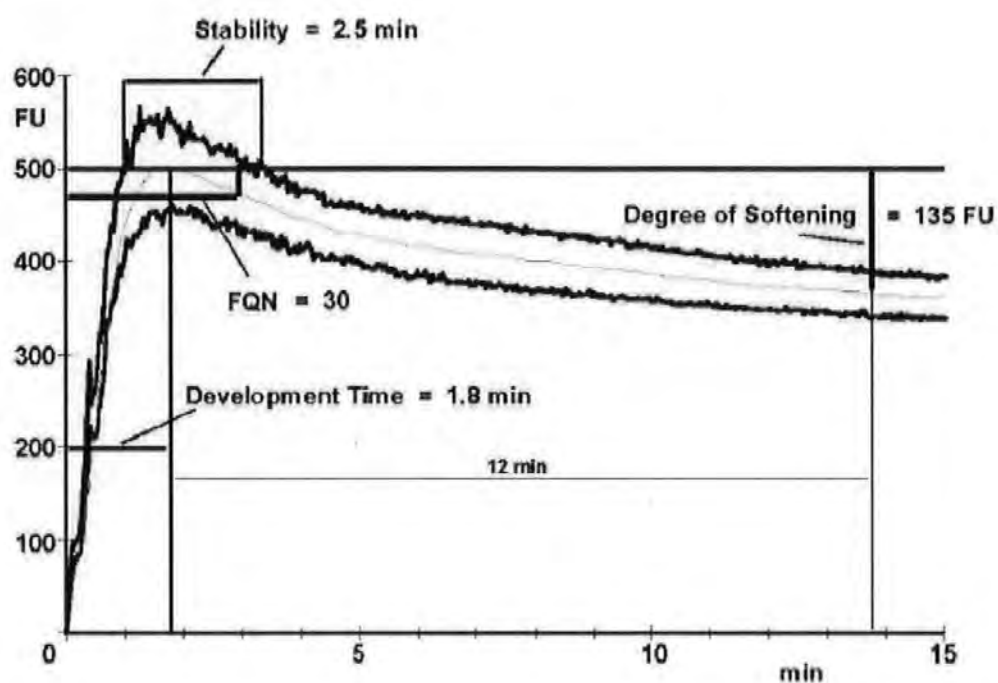


Fig.3.6. Farinograph curve showing the measured parameters.

Source:

http://www.brabender.com/typo3conf/ext/nf_downloads/pi1/passdownload.php?downloadaddata=304&pid=96

3.2.4.2. Extensograph:

The extensograph technique is used to study the stretching behaviour of dough, such as the resistance to extension and the extensibility as well as the baking characteristics of flour.

Extensographs were determined according to the approved AACC method 54-10 (AACC 2000) and the measurements recorded were extensibility and resistance to extension (Fig.3.7).

Resistance to extension (R_{\max}): the height of the curve in BU at maximum height or at 5 cm where test starts on chart.

Extensibility (E): the total length of the curve on the horizontal line in mm.

Ratio of R_{\max}/E : refers to dough elasticity.

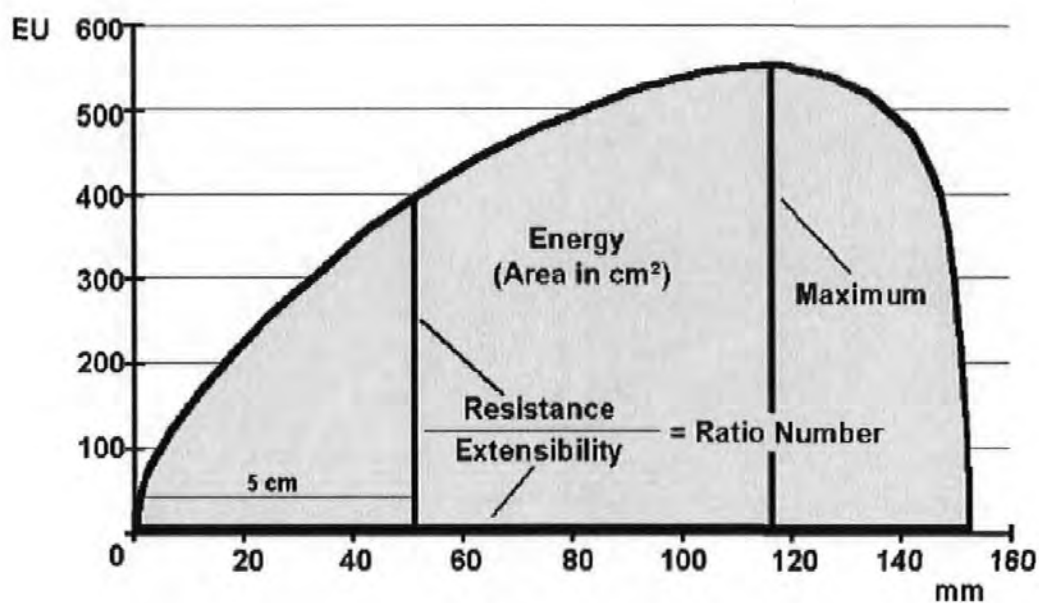


Fig.3.7. Extensograph curve with the measured parameters.

Source:

http://www.brabender.com/typo3conf/ext/nf_downloads/pi1/passdownload.php?downloaddata=305&pid=94

3.2.4.3. *Mixograph:*

The Mixograph is used to evaluate dough mixing properties and gives a visual evaluation of gluten strength as a Mixogram.

Mixograph assessments of semolina were achieved according to the approved AACC method 54-40A (AACC 2000), where 10 g of semolina (on a 14% moisture basis) were mixed for 8 min at constant water absorption of 5.8 ml using a spring setting of 8. The Mixograms were compared to reference Mixograms with a scale of 1 to 8 (Fig.3.8), the higher the number the stronger the mixing characteristics and hence the stronger the flour.

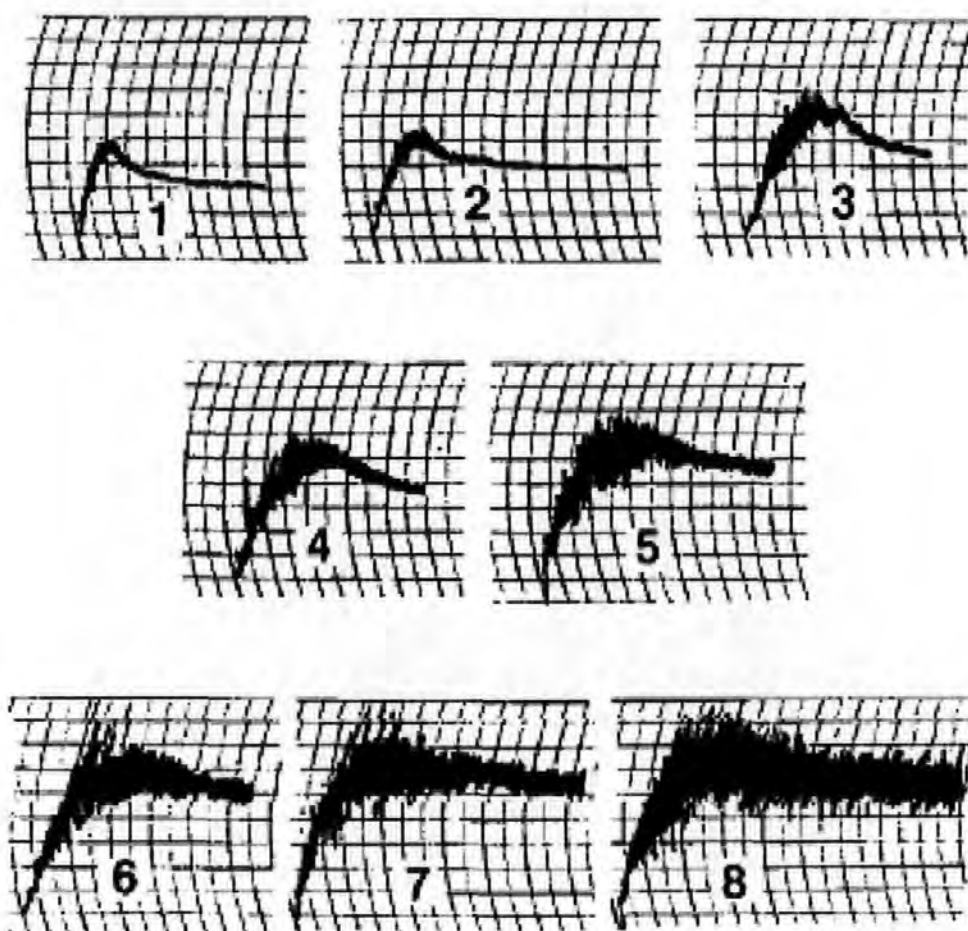


Fig.3.8. Mixograms to show the 1 to 8 scale (1 = low, 8 = high).

Source: (Anon. 2006b).

3.2.5. Pasta quality evaluation:

3.2.5.1. *Pasta production:*

Pasta samples were processed according to the procedure described by Walsh *et al.*, (1971) and in the approved AACC method 66–41 (AACC 2000). Semolina (1 kg) was mixed with water to reach 32% absorption. The hydrated semolina was mixed at high speed in a Hobart mixer (Hobart Corporation, Troy, OH, USA) for 4 min, placed in a mixing chamber under vacuum, and extruded as spaghetti through an 84-strand Teflon-coated die with 0.157 cm openings using a DeMaCo semi-commercial laboratory extruder (DeFrancisci Machine Corp., Melbourne, FL, USA). The extruder was operated under the following conditions: extrusion temperature of 45 °C, mixing chamber vacuum with 46 cm of Hg, and auger extrusion speed of 25 rpm. Extruded spaghetti samples were dried at high temperature 73 °C for 12 h at a relative humidity of 83%.

3.2.5.2. *Pasta colour:*

The colour of pasta has been related mainly to the pigment content of wheat kernels. Consequently, factors affecting pigment degradation, such as lipoxygenase, peroxidase and ash content have been shown to affect pasta colour (Siedow 1991; Borrelli *et al.*, 1999; 2003; Fraignier *et al.*, 2000).

Pasta colour scores were determined according to the approved AACC method 14-22 (AACC 2000) using a Minolta Colour Difference Meter (Model CR 310, Minolta Camera Co., Japan). Reflectance percent is read on the green and blue scales, Y and Z

respectively. Y and Z values are converted to measure the colour parameters, L% which refers to brightness, and b% which refers to yellowness using the following equations:

$$L = 10\sqrt{Y}$$

$$b = \frac{7(Y - Z\%) }{Y}$$

The colour scores were calculated using the colour map designed by Debbouz (1994) with the two measured parameters L* and b*. Colour scores of 8.0 or higher refer to pasta with good colour.

3.2.5.3. Cracks:

Cracks or checks appear in dry pasta as the result of moisture equilibrium between the centre and surface of the pasta strands.

Dry pasta strands were cut to 10 cm long, and placed in a humidity chamber at 80% RH for 2 hours and the resultant number of cracks were counted from the centre 5 cm of 10 strands.

3.2.5.4. Cooked weight:

Pasta cooked weight was determined according to the approved AACC method 66-50 (AACC 2000) with some modifications as described by Dick *et al.*, (1974), where 10 g of dry pasta, broken into approximately 5 cm length, were boiled in 300 ml of distilled water. Each pasta sample was cooked to its optimal cooking time, which was defined as the time required for the white core in the centre of the pasta strand to disappear. This

was determined by removing a strand from the cooking water every 30 sec and cut between two plexiglass plates. Then the cooked pasta was rinsed with distilled water 25°C and drained for 2 min and weighed and reported in grammes.

3.2.5.5. *Cooking loss:*

Cooking loss was conducted by the approved method AACC 66-50, where the cooking water and rinse water were dried in an air-forced oven at 110°C for approximately 20 hours, and the residue weighed and reported as a percentage of the total dry sample weight (Dick *et al.*, 1974).

3.2.5.6. *Firmness of cooked pasta:*

Pasta firmness has been linked to protein quality and quantity (Dick and Quick 1983). Pasta firmness was determined as of Tudorica *et al.*, (2002) using a Stable Microsystems TA.XT2 Texture Analyser (Stable Microsystems, Reading, UK) according to the approved AACC method 66-50 (AACC 2000). Results were recorded in gcm^{-1} .

3.2.5.7. *Mechanical strength of dried pasta:*

It has been demonstrated that the mechanical strength of dry pasta is considered as a quality attribute because of the association with the gluten content of semolina (Matsuo *et al.*, 1982a; D'Egidio *et al.*, 1982) and the drying process (Donnelly 1991). Moreover, the mechanical strength measurement can provide practical information for the packing design (Guinea *et al.*, 2004).

The mechanical strength of dried pasta was determined by placing 10 strands from each sample (10 cm long) on the heavy duty stage of the Texture Analyser TA.XT2 (Stable Micro Systems, Reading, UK), calibrated for a load cell of 25 kg, and the samples cut with a craft knife. Force and area were recorded.

3.2.6. Statistical analysis:

All measured characteristics were conducted in triplicate and expressed as means, apart from farinograph analysis which was performed in duplicate. Correlation coefficients were run between the different variables using the Microsoft Excel. Analysis of variance (ANOVA) was performed using Minitab 1332 software package (Minitab Inc., USA). Differences between means were tested for significance using the Tukey test and results were reported on significant level 5% ($P < 0.05$).

Chapter 4

4. Syrian durum wheat characterisation:

4.1. INTRODUCTION:

The highly degree of tolerance of wheat to environmental conditions as well as its unique properties to be processed into palatable products have made it a worldwide crop (Shewry and Tatham 1997). Durum wheat however, which is processed mainly into pasta, compromises only 8% of global wheat production.

Syria was ranked fourth in durum wheat production in the crop year 2002-2003 (Lennox 2003), and this reflects the important role of this crop in the domestic market as well as its importance as an export commodity. Despite its prominent role only limited research has been dedicated to investigate the characterisation of the Syrian durum in order to determine whether the Syrian varieties could compete on the world market.

Durum wheat end-use product quality or pasta cooking property is determined to a large extent by the physical and chemical characteristics of kernels (Mariani *et al.*, 1995). It has been well established that these characteristics are influenced by both genotype (Troccoli *et al.*, 2000), and environment (Kovacs *et al.*, 1995; Sharma *et al.*, 2002) and their interaction.

In durum wheat, the degree of vitreousness of the kernel is often used, in conjunction with kernel hardness, to predict the quality of the crop. The degree of kernel translucency, and hence the apparent degree of vitreousness, is related to the degree of compactness of the kernel (Yamazaki and Donelson 1983). The degree of vitreousness

of kernels has been linked to the hardness of the kernel, and the amount of protein and starch within the kernel (Stenvert and Kingswood 1977). Moreover, the degree of vitreousness is used as a critical character in the Canadian and US durum grading systems. Consequently, it is advantageous to determine the influence of the degree of vitreousness on Syrian durum quality.

Starch is the dominant component of wheat and its characteristics contribute to the utilization of flour and semolina (Boyacioglu and D'Appolonia 1994b). Most of the functional attributes of starch can be related to the temperature interaction of starch with water in the processes known as gelatinization, pasting, gelation and retrogradation (Dengate 1984; Atwell *et al.*, 1988). Amylose and amylopectin ratio affects the physicochemical properties of starch (Fredriksson *et al.*, 1998). The amylose content of starch appears to be under genetic control and appears to vary over a limited range (16-28%) within durum wheat (Leloup *et al.*, 1991, Yamamori *et al.*, 1992, Miura and Tanll 1994). Consequently, it is of interest to utilise published research on *Triticum aestivum* starch composition to indicate some of the functional base of variations in amylose content, starch pasting and thermal properties of different durum wheat cultivars.

4.2. AIMS:

The aims of this study were:

1. Determine the physiochemical composition of selected Syrian durum wheat cultivars.
2. Investigate whether Syrian durum wheat cultivars are comparable in the durum wheat market.

3. Test whether the degree of vitreousness is a fundamental character in Syrian durum wheat quality assessment.
4. Illuminate the effect of amylose content on starch characteristics and flour pasting properties.

4.3. OBJECTIVES:

1. Determine the physical characteristics of Syrian durum wheat cultivars, test weight, the degree of vitreousness, hardness, 1000-kernel weight.
2. Determine the chemical characteristics of Syrian durum wheat cultivars, moisture, protein, starch, amylose, falling number, wet and dry gluten, and ash content.
3. Compare these characteristics with grade NO. 1 varieties grown in the USA and Canada.
4. Investigate the effect of elevated degree of vitreousness on protein content, starch content, amylose content and hardness.
5. Determine amylose and starch content of whole-sample, vitreous and starchy grains of durum wheat cultivars.
6. Determine the starch pasting and thermal properties of kernel fractions by the techniques of RVA and DSC.
7. Investigate the correlation between amylose content and starch pasting and thermal properties of each grain fraction.

4.4. RESULTS AND DISCUSSION:

4.4.1. Characteristics of durum wheat cultivars:

The physical properties of durum kernels are considered very important in the overall assessment of durum wheat quality for its significance contribution to milling potential and end-use products quality.

In view of the fact that the growing conditions of the cultivars were practically consistent with regards to field plot experiments, the variation in traits is likely to be a result of the genotypic variation within the cultivars examined, but it is recognised that these characteristics could change if the varieties were to be grown at other locations.

Table-4.1. shows that the test weight values of the samples in this study were high and showed no significant difference between the cultivars, although values ranged from 83.1 kg^{hl}⁻¹ for Sham-3 to 85.9 kg^{hl}⁻¹ for Douma-29019. All tested cultivars had higher values for test weights and 1000-Kernel weights than previously reported for Syrian durum wheat varieties (Al-Raad 1992; and Kayyal *et al.*, 1995), and were within the high range of durum wheat grown elsewhere (Dexter and Matsuo 1981; Dexter *et al.*, 1988; Boyacioglu *et al.*, 1991; and Sissons *et al.*, 2000). Sham-3 and Bohouth-5 had the highest 1000-kernel weight (55.0 g) whilst the lowest was Douma-26827 (42.50 g).

The degree of vitreousness is an important international quality-grading factor for countries marketing durum wheat. For example, the Australian grading system has three grades: ADR1 \geq 90%, ADR2 80-89% and ADR3 <79%, (Sisson *et al.*, 2000). Applying this parameter to Syrian durum cultivars, only Sham-1 (93 %) and Douma-18861 (94

%) fell within the first range. Fig.4.1. and Fig.4.2. illustrate the structural difference between vitreous and starchy kernels as determined by SEM. As can be seen, the vitreous kernel shows a continuous structure where the starch granules are embedded in the protein matrix. On the other hand, the starchy kernel exhibits discontinuous endosperm with many air spaces and appears white in colour. Starchy grains render the appearance of the grains to become chalky, which is less desirable as it often adversely affects the end use of the durum wheat (Dexter and Matsuo 1981). Previous results for a range of Syrian durum wheat cultivars (Shehadeh *et al.*, 1999; ICARDA 1998/1999) showed difference in vitreousness/ starchiness for the same and different cultivars between locations. It is well established that soil fertility, weather and other inherent susceptibility of varieties influence the incidence of starchiness (Dexter *et al.*, 1989). Results from Table-4.1. indicated that variation in the degree of vitreousness is cultivar based and has a genetical background supporting the research of Shehadeh *et al.*, (1999).

Research conducted by Donnelly (1980) on durum wheat kernels indicated that falling number values less than 120 are an indication of some degree of sprouting and may be related to poor quality attributes. However, all of the tested cultivars showed high falling number values, indicating low α -amylase activities (Table-4.1), in contrast to previously recorded durum wheats (Boyacioglu *et al.*, 1991). Nevertheless, a degree of variability was observed between samples of Sham-1, Douma 1105 and Douma 26827 all showing lower values compared to the other samples.

Table-4.1. also shows low moisture content values, and this attribute is important for prolonged storage periods and for increasing the milling yield, two important factors for wheats grown in semi-arid areas.

Some significant differences were observed in the ash content of the cultivars ranging between 1.453-1.743% (on a dry basis). Douma-29019 showed the lowest ash content of all cultivars and it was significantly different to all cultivars except Douma-18861 and Douma-1105. This is likely to be due to the genetic similarity of the Douma samples compared to the Sham and Bohouth samples. The ash values for whole grain are at levels typically observed elsewhere (Cubadda 1988).

Protein content exhibited significant variations among the cultivars and ranged between 11.69-14.10% (on a dry basis), and generally showed lower values than durum wheat reported elsewhere (Autran and Galterrio 1989; Carrillo *et al.*, 1990, Ames *et al.*, 1999). The low protein contents of the cultivars may be an indication of the low nitrogen contents of the gypsiferous soils in which the crops were grown. Wet gluten and dry gluten contents of the kernels did not show any variations between cultivars, and varied between 27.77-22.73% and 9.36-7.60% for wet and dry gluten respectively.

Cultivars	TKW g	Test weight kg hl ⁻¹	Vitreousness %	Moisture %	Ash (dm) %	Falling No. Sec.	Protein (dm) %	Wet gluten %	Dry gluten %
Sham-1 (1)	50.3 ^a	84.9 ^a	93.00 ^a	8.46 ^a	1.638 ^a	433 ^a	12.73 ^a	24.63 ^a	8.55 ^a
Sham-3 (2)	55.5 ^b	83.1 ^a	45.00 ^b	8.20 ^a	1.743 ^a	528 ^b	12.01 ^b	23.86 ^a	8.37 ^a
Sham-5 (3)	50.4 ^a	84.9 ^a	45.00 ^b	8.30 ^a	1.693 ^a	502 ^b	12.93 ^a	24.93 ^a	9.30 ^a
Bohouth-5 (4)	55.1 ^b	84.1 ^a	50.00 ^c	8.17 ^a	1.705 ^a	505 ^b	12.57 ^{a,b}	23.15 ^a	8.43 ^a
Bohouth-7 (5)	49.6 ^a	85.5 ^a	85.00 ^d	8.30 ^a	1.660 ^{a,c}	597 ^c	12.71 ^a	23.97 ^a	7.77 ^a
Douma-1105 (6)	50.7 ^a	84.2 ^a	57.00 ^e	9.09 ^a	1.545 ^{a,b,c}	472 ^d	12.76 ^a	23.60 ^a	7.89 ^a
Douma-18861 (7)	50.8 ^a	83.7 ^a	94.00 ^a	8.06 ^a	1.469 ^b	524 ^b	14.10 ^c	27.77 ^a	9.36 ^a
Douma-26827 (8)	42.5 ^c	85.5 ^a	47.00 ^{b,c}	8.08 ^a	1.687 ^{a,c}	485 ^d	11.69 ^b	22.73 ^a	7.60 ^a
Douma-29019 (9)	50.4 ^a	85.9 ^a	65.00 ^f	8.23 ^a	1.453 ^b	501 ^b	13.14 ^a	26.73 ^a	9.13 ^a
SE	0.52	0.62	0.91	0.24	0.06	4.85	0.10	1.10	0.51

Table-4.1. Some physiochemical characteristics of durum wheat grains.

Means values in the same column, followed by different letters are significantly different ($p < 0.05$).

Samples numbers are indicated in the table.

TKW: 1000-kernel weight.

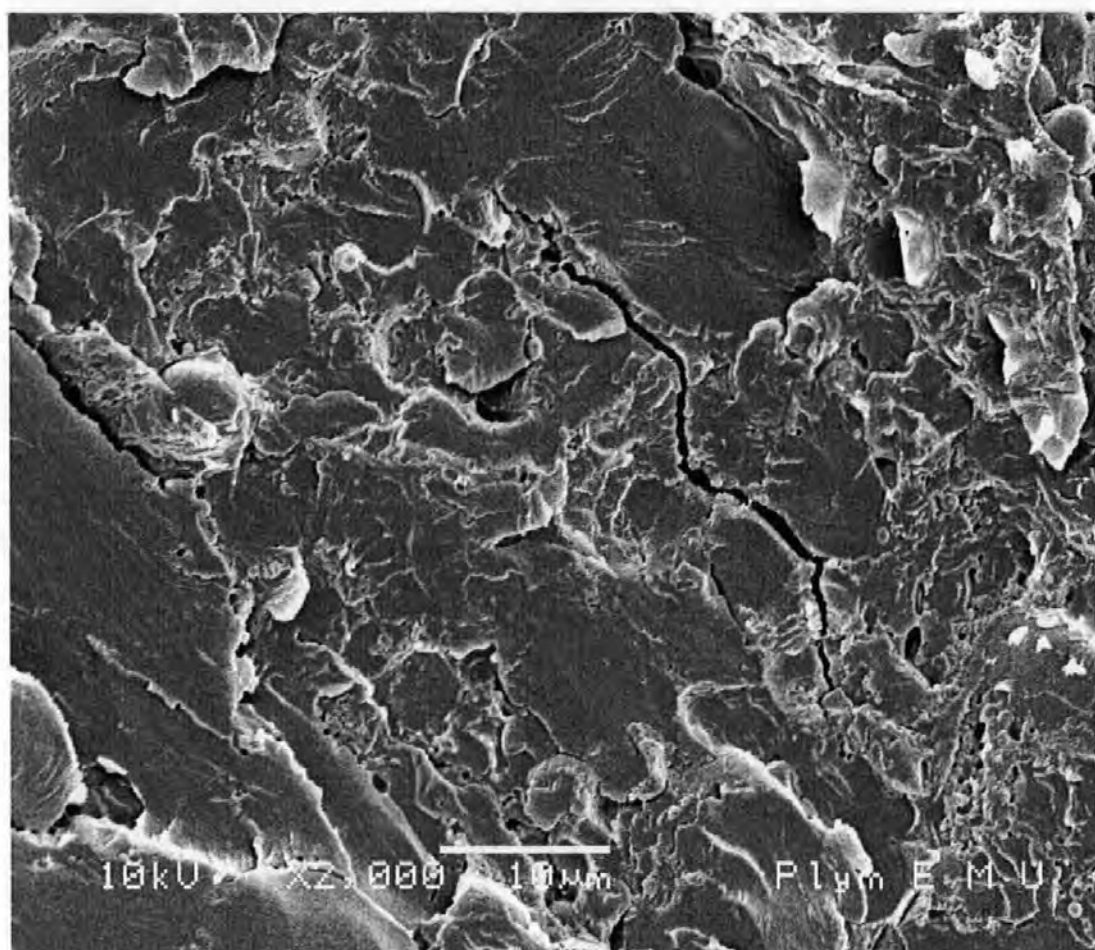


Fig.4.1. Micro structure of vitreous kernel.

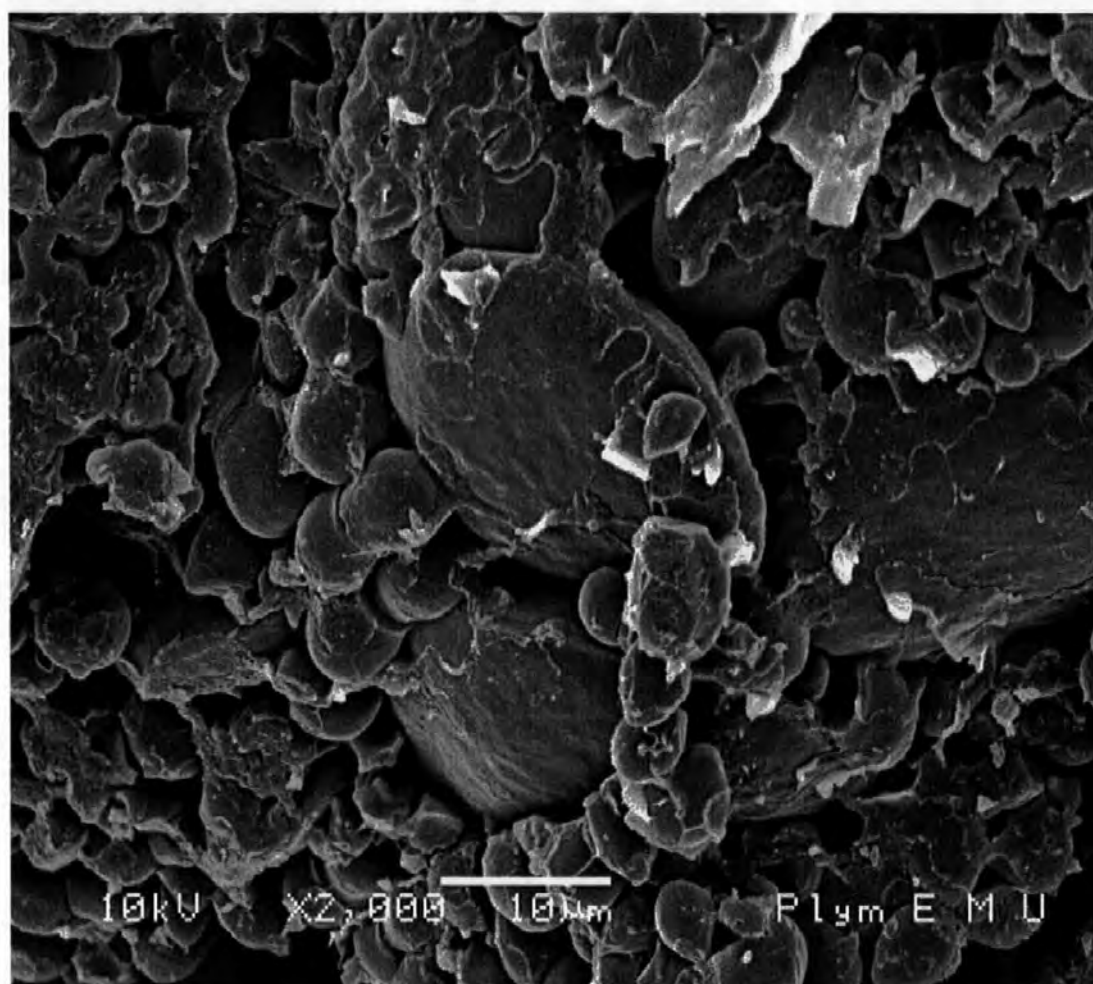


Fig.4.2. Micro structure of starchy kernel.

4.4.2. Comparison of the quality characteristics of Syrian, Canadian and American durum wheats:

The global world production of durum wheat for the crop year 2002/ 2003 as estimated by the International Grains Council (IGC) was 33.5 million tonnes (Lennox 2003). The European Union, represented by Italy, Spain, France and Greece, was ranked first in production with 9.3 mt (Fig.4.3). However, the majority of this wheat was for domestic use as the EU is the largest consumer of durum wheat with only 1.2 mt for export. Canada was number two in production but was ranked first for export (3.7 mt, 3.1 mt respectively). Turkey, with a production of 3.0 mt was the third but only 0.2 mt of its wheat was for export. Interestingly, Syria was ranked fourth in durum wheat production in the 2002/ 2003 crop year and produced 2.8 mt, which represents 8.36% of the durum global production. Syrian durum export was low at around 0.6 mt. The USA production of durum wheat was 2.15 mt with 0.8 mt for export.

It is of interest to compare the quality of the Syrian durum wheat in terms of both the Canadian and US grading systems, especially in relation to market export potential. The Canadian Grain Commission (CGC) specification of durum wheat grades classifies durum wheat into three grades according to the degree of vitreousness and test weight; grade No. 1, grade No. 2, and grade No. 3, where the minimum of vitreous kernels required are 80, 60, and 40% and the minimum test weight values are 79 kg hl^{-1} , 77 kg hl^{-1} and 74 kg hl^{-1} respectively (CGC 2001). On the other hand, The US grading system categorizes durum wheat into five grades depending on a numerical grading system based on test weight and content of damaged kernels, foreign material, shrunken and broken kernels, and wheat of contrasting classes. The grades for this system are 1 (minimum of 78.2 kg hl^{-1}); 2 (minimum of 75.6 kg hl^{-1}); 3 (minimum of 73.0 kg hl^{-1}); 4

(minimum of 70.4 kghl⁻¹); 5 (minimum of 66.5 kghl⁻¹). Moreover, the American grading system operates a sub-classification system for durum wheat. Thus, under the US grading system durum wheat with over 75% vitreous kernel content is classified as Hard Amber Durum (HAD), wheat with less than 75% but greater than 60% vitreous kernel content is classified as Amber Durum (AD), and with wheat with less than 60% vitreous kernel content is classified as Durum (D), so that two categories of grading based on vitreousness and test weight exist (Anon. 2003b).

The test weight values of the studied Syrian durum cultivars would satisfy requirements for No. 1 grade for both the Canadian and US grading systems. Nevertheless, applying the degree of vitreousness (Table-4.2) only three of the wheat cultivars studied would satisfy the Canadian grade No. 1 and the US Hard Amber Durum sub-classification requirement (Sham-1, Bohouth-7, and Douma-18861), while (Douma-29019) would be classified as Canadian grade No. 2 or 1 AD in the American system. The rest of the samples would be graded in No. 3 or as 1D.

The average quality data of the nine selected Syria durum wheat cultivars tested, represented by test weight, 1000-kernel weight, the degree of vitreousness, protein content, ash content and falling number, were compared with the same quality data for both the No.1 Canadian and American durum wheat in the crop year 2002 as standards (Table-4.3). It has been demonstrated that test weight and 1000-kernel weight are significant quality characters affecting durum milling potential and semolina yield (Matsuo *et al.*, 1978; Matsuo and Dexter 1980a; Dexter *et al.*, 1987). The average test weight and 1000-kernel weight of the studied Syrian cultivars exhibited higher values than the Canadian and US Wheats (Table-4.3), and hence theoretically, the studied cultivars would produce higher semolina yield. Moreover, the Syrian cultivars showed

higher falling numbers than the two standards. These findings are expected, because of the dry weather in Syria during the growing season compared with wet weather in Canada and the USA, which would generate low α -amylase activities in the former while high activities in the latter. On the other hand, the averages of the degree of vitreousness and protein content of the Syrian cultivars were significantly lower than the averages of the Canadian and the US wheat. The role of vitreousness and protein in durum properties and pasta quality has been confirmed in many studies (Menger 1973; Matsuo and Dexter 1980a; Dexter and Matsuo 1981; Hosney 1986; Blanco *et al.*, 1988; D'Egidio *et al.*, 1990; Boyacioglu *et al.*, 1991; Novaro *et al.*, 1993; Dexter *et al.*, 1994; Sissons *et al.*, 2000), and consequently, this would predict that the resultant pasta from the selected Syrian cultivars would exhibit lower cooking properties. This issue is presented in the following chapters. Average ash content of the three sites did not show significant difference.

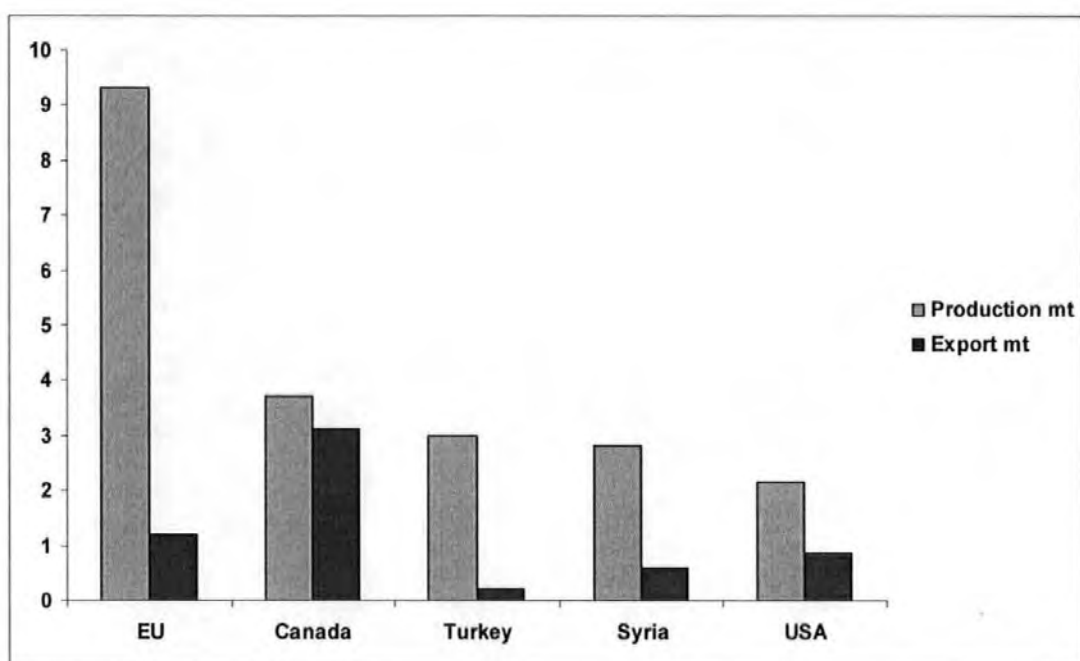


Fig.4.3. Durum wheat production and export 2002/2003 as estimated by the IGC.

Source: (Lennox 2003).

Cultivars	Test weight kg hl ⁻¹	Vitreousness %	Canadian grades	American grades
Sham-1 (1)	84.90	93.00	1	1HAD
Sham-3 (2)	83.10	45.00	3	1D
Sham-5 (3)	84.90	45.00	3	1D
Bohouth-5 (4)	84.10	50.00	3	1D
Bohouth-7 (5)	85.50	85.00	1	1HAD
Douma-1105 (6)	84.15	57.00	3	1D
Douma-18861(7)	83.70	94.00	1	1HAD
Douma-26827 (8)	85.50	47.00	3	1D
Douma-29019 (9)	85.90	65.00	2	1AD

Table-4.2. Syrian durum wheat mapped onto the Canadian and USA grades.

Samples numbers are indicated in the table.

Traits	Canada [*]	USA ^{**}	Syria
Test weight kg hl ⁻¹	81.8	77.7	84.6
1000-kernel weight g	44.4	36.6	50.2
Vitreousness %	85	90	65
Protein % (dm)	16.4	16.1	12.6
Ash % (dm)	1.60	1.59	1.62
Falling No. sec	330	266	505

Table-4.3. Average quality data of durum wheat in Canada, USA and Syria for the crop year 2002.

Sources: * (Anon. 2003a), ** (Anon. 2003b)

4.4.3. Effect of the degree of vitreousness on quality characteristics:

The degree of vitreousness has been used as a grade quality factor of durum wheat because of its important role in durum wheat milling potential (Menger 1973; Matsuo and Dexter 1980a; Dexter and Matsuo 1981; Sissons *et al.*, 2000) as well as on pasta cooking properties (Matsuo and Dexter 1980a; Hoseney 1986; Blanco *et al.*, 1988).

It was shown in the previous section that the average of the selected Syrian durum wheat cultivars regarding the degree of vitreousness was significantly lower than both the Canadian and American grads. Consequently, it is of interest to investigate whether elevated vitreousness would impart a fundamental impact on the quality of the Syrian durum wheat kernels.

In this study the selected durum wheat cultivars were divided into three fractions; fraction 1, represents the whole sample as is, fraction 2, corresponds to the fully vitreous kernels, while fraction 3 characterises the fully starchy kernels. The three fractions of each cultivar were analysed for hardness, protein content, total starch content, amylose content, and wet and dry gluten content.

Wheat kernel hardness is an important physical character affecting milling performance as it is related to the conditioning process of wheat before milling, energy consumption during milling, mill settings, flour particle size distribution, and milling yield (Hoseney *et al.*, 1987; Pomeranz and Williams 1990). Furthermore, hardness affects baking quality as it is related to starch damage leading to the absorption of more water during dough development and a greater effectiveness of α -amylase (Pomeranz *et al.*, 1984; Morris and Rose 1996). Fig.4.4. shows the measured force (Texture Analyzer) required

to crush wheat kernels of each fraction under controlled conditions of kernel size. All vitreous fractions demonstrated higher required force or hardness than the other fractions (whole sample and starchy). This supports previous research that vitreous kernels are harder than starchy kernels (Stenvert and Kingswood 1977; Dexter *et al.*, 1988; Dexter *et al.*, 1989; Samson *et al.*, 2005). Within each fraction, whole samples and vitreous kernels did not demonstrate any significant variation in hardness among the cultivars. However, Sham-5 and Douma-18861 in the starchy fraction exhibited significant lower values than the other cultivars ($P < 0.05$). On the other hand, no significant differences were observed between cultivars for hardness of whole sample and vitreous fractions but all the vitreous fractions were significantly higher than the starchy fractions. Comparing the whole samples with the starchy fractions, only Sham-3 and Douma-29019 showed no significant variations.

It is well established that protein content is the most important factor affecting dough rheological properties and pasta cooking quality (Dexter *et al.*, 1980; Matsuo *et al.*, 1982a; Autran *et al.*, 1986; Dick and Matsuo 1988; Autran and Galterio 1989; D'Egidio *et al.*, 1990; Boyacioglu *et al.*, 1991; Novaro *et al.*, 1993; Dexter *et al.*, 1994; Sissons *et al.*, 2005). Moreover, it appears to be more reliable than the degree of vitreousness to predict pasta quality (Dexter and Matsuo 1981). Table-4.4. shows the protein content of durum divisions for the selected cultivars. It can be seen that there are similar trends as for hardness in that vitreous kernels are of higher protein content than both whole sample and starchy fractions, verifying previous work (Dexter *et al.*, 1988; 1989). All the studied cultivars within each fraction showed variations in protein content (Table-4.5), indicating a strong effect of genotype. Studying the variations among the fractions revealed that the whole fraction exhibited significant variation for each cultivar, apart from Bohouth-7 and Douma-18861 where the protein content of the whole sample

fraction did not significantly differ from the vitreous fraction (Table-4.6). These findings would support the importance of vitreous kernel percentage in durum wheat quality.

Mean values of whole sample total starch (Table-4.4) ranged from 64.29% to 68.28%, while starchy kernel meal showed higher total starch (70.50-76.06%), compared to vitreous kernel meal (63.84-66.41%). Analysis between cultivars (Table-4.5), showed significant variation in starch content ($P<0.05$) between whole sample Douma-26827 and Douma-29019 compared with the rest of the cultivars and only vitreous Sham-1 verses Douma-26827, while all the starchy samples did not exhibit any significant difference between the cultivars. No significant differences in total starch were found between whole sample and vitreous fractions for any cultivar (Table-4.6). However, significant within cultivar variation ($P<0.05$) in total starch was found between vitreous and starchy kernel meals as well as whole sample and starchy fractions apart from Douma-29019.

Table-4.4. illustrates the variation in amylose content both between and within cultivars for whole sample, vitreous and starchy grains. The main variation in composition of starches has previously been attributed to the relative proportions of amylose and amylopectin in the starch granules (Hermansson and Svegmarm 1996). Results from this study indicated that there was a general trend (although not significant) of flour samples from starchy grains containing less amylose than vitreous kernel flours. The mean amylose values for the starchy grains were in the range 25.1-31.3%, while for vitreous grains ranged from 27.0 to 32.1%. Between cultivar analysis (Table-4.5) showed significant variation in whole flour amylose content ($P<0.05$) of Douma-1105 compared to Sham-3, Sham-5, Douma-26827 and Douma-29019, together with variation for

starchy grains, between Sham-1, Sham-3 and Sham-5 compared to Douma-1105, while only vitreous Sham-5 and Douma-1105 showed significant variation. The high amylose content of Syrian durum wheat cultivars confirmed the results of previous work that durum wheat generally had elevated amylose levels than other wheat starches (Medcalf and Gilles 1965; Soulaka and Morrison 1985; Lintas 1988; Vansteelandt and Delcour 1998). It is this high amylose content (sometimes up to 30%) which gives optimum product quality for pasta and noodles. In particular, the resulting gelatinised gel structure is reported to be less susceptible to enzymatic degradation, rendering these slowly hydrolysed foods of potential medical interest for diabetic control and reduction of serum lipid levels (Leloup *et al.*, 1991).

Gluten quality and quantity of wheat grain have been shown to exhibit a significant effect on dough rheological properties and pasta cooking quality (Matsuo and Irvine 1970; Walsh and Gilles 1971; Wasik and Bushuk 1975a; Dexter and Matsuo 1977b). Mean values of wet gluten ranged between 27.77-22.73%, 28.16-23.97%, and 20.38-10.48% for whole sample, vitreous and starchy fractions respectively. On the other hand, mean values of dry gluten for wholemeal flour, vitreous, and starch fractions ranged between 9.36-7.60%, 9.82-7.94%, and 7.05-3.34% respectively (Table-4.4). Furthermore, wet and dry gluten of vitreous fractions showed higher values than both the wholemeal and starchy fractions. Investigating the variation among the cultivars revealed that wet and dry gluten for the wholemeal flour did not show any variation for the studied cultivars. However, vitreous grains exhibited some significant variations among the samples in wet gluten, while only vitreous sham-1 and Bohouth-7 showed significant difference in dry gluten. Starchy flour showed significant difference in wet and dry gluten for the studied cultivars (Table-4.5). Table-4.6. demonstrates the variations among the fractions. It can be seen that wet and dry gluten of vitreous grains

significantly varied with starchy grains, apart from the dry gluten of Sham-5. These findings are consistent with previous results that vitreous kernels are of higher gluten content than starchy kernels (Dexter *et al.*, 1989). However, wholemeal samples did not show significant variations with vitreous samples apart from Douma-26827.

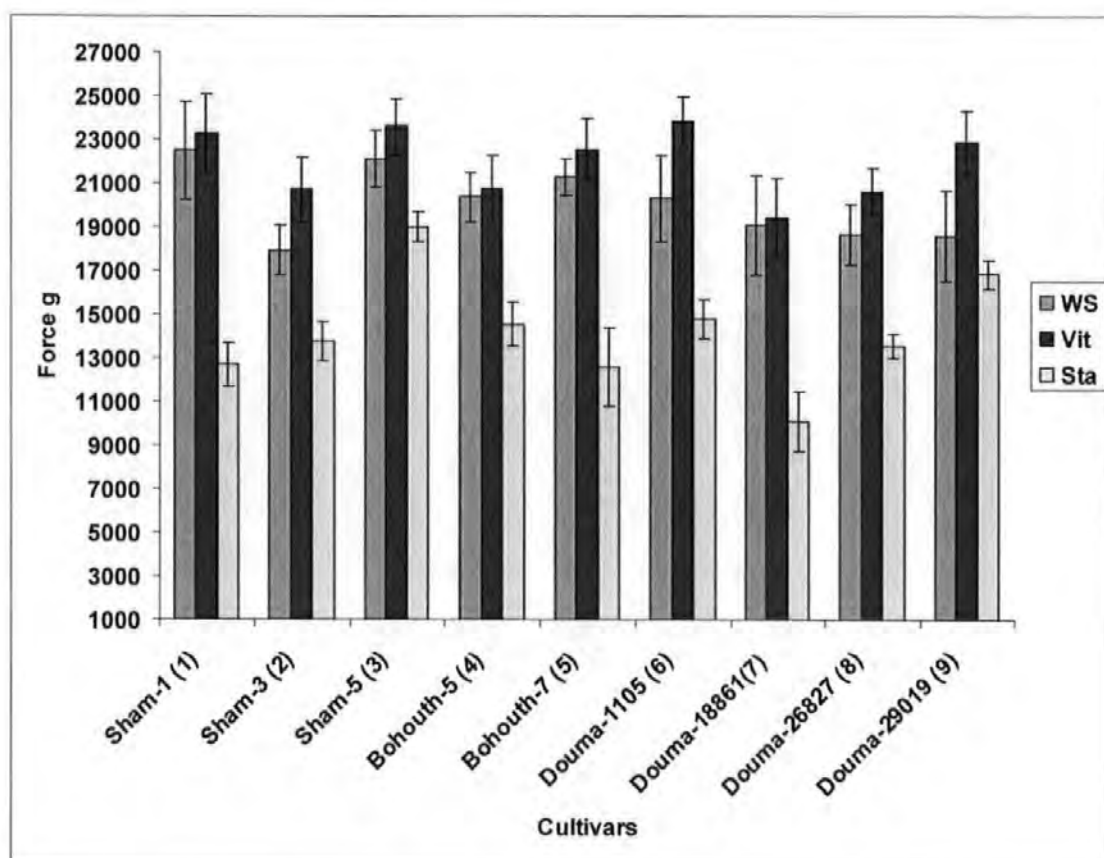


Fig.4.4. Kernel hardness of durum wheat fractions.

WS: whole sample kernels, Vit: vitreous kernels, Sta: starchy kernels.
Sample numbers are indicated in the graph.

Cultivars	Protein content (dm) %			Total starch (dm) %			Amylose %			Wet gluten %			Dry gluten %		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
Sham-1 (1)	12.73	13.64	9.93	64.43	63.84	72.51	28.3	28.0	26.9	24.63	27.61	17.61	8.55	9.82	6.61
Sham-3 (2)	12.01	13.54	10.09	64.29	65.03	71.89	27.6	27.0	25.1	23.86	24.52	14.86	8.37	8.82	5.16
Sham-5 (3)	12.93	13.85	10.71	65.01	66.17	71.83	27.8	27.9	26.1	24.93	26.65	20.38	9.30	9.08	7.05
Bohouth-5 (4)	12.57	13.67	10.68	66.24	66.17	71.87	29.0	29.1	27.6	23.15	24.83	19.15	8.43	9.03	5.70
Bohouth-7 (5)	12.71	13.79	9.93	66.82	66.13	73.06	29.8	29.7	28.3	23.97	23.97	10.48	7.77	7.94	3.34
Douma-1105 (6)	12.76	13.64	10.80	64.39	64.12	71.14	30.4	32.1	31.3	23.60	25.10	14.97	7.89	8.34	4.89
Douma-18861(7)	14.10	14.54	10.59	64.42	65.37	70.50	28.7	28.6	27.9	27.77	27.35	10.77	9.36	9.42	4.30
Douma-26827 (8)	11.69	13.17	10.43	68.24	66.41	72.36	28.0	28.7	27.7	22.73	27.28	17.72	7.60	8.70	5.92
Douma-29019 (9)	13.14	14.07	10.55	68.28	65.67	71.95	27.8	29.1	27.4	26.73	28.16	18.70	9.13	9.53	6.19
SE	0.10	0.15	0.05	0.56	0.45	0.58	0.44	0.82	0.69	1.10	0.52	0.65	0.51	0.31	0.20

Table-4.4. Characteristics of durum wheat fractions.

WS: Whole sample, Vit: Vitreous, Sta: Starchy.
Sample numbers are indicated in the table.

Comparison	Hardness			Protein			Starch			Amylose			Wet gluten			Dry gluten		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
S1- S3				S										S				S
S1- S5			S			S												
S1- B5						S												
S1- B7														S	S		S	S
S1-D11						S						S						S
S1-D18				S	S	S									S			S
S1-D26				S		S	S	S										
S1-D29						S	S											
S3- S5			S	S		S									S			S
S3-B5						S									S			
S3-B7				S											S			S
S3-D11				S		S				S	S	S						
S3-D18				S	S	S									S			
S3-D26						S	S											
S3-D29				S		S	S							S	S			
S5-B5																		S
S5-B7			S			S									S			S
S5-D11										S		S			S			S

Table-4.5. Hardness, protein, starch, amylase, and wet and dry gluten content statistical comparisons (Tukey) between durum wheat cultivars (samples 1 to 9).

Table-4.5. Contd.

S5-D18			S	S											S			S
S5-D26			S	S			S											S
S5-D29							S											
B5-B7						S									S			S
B5-D11															S			
B5-D18				S	S										S			S
B5-D26				S														
B5-D29														S				
B7-D11						S									S			S
B7-D18				S		S									S			
B7-D26				S		S									S	S		S
B7-D29						S									S	S		S
D11-D18				S	S										S			
D11-D26				S		S	S			S								
D11-D29							S			S					S	S		S
D18-D26				S	S		S								S			S
D18-D29			S	S			S								S			S
D26-D29				S	S													

S1: Sham-1, S3: Sham-3, S5: Sahm-5, B5: Bohouth-5 B7: Bohouth-7, D11: Douma-1105, D18: Douma-18861, D26: Douma-26827, D29: Douma-29019. S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

Comparison	Hardness	Protein	Starch	Amylose	Wet gluten	Dry gluten
S1	WS-Vit	I	S	I	I	I
	WS-Sta	S	S	I	S	I
	Vit-Sta	S	S	I	S	S
S2	WS-Vit	I	S	I	I	I
	WS-Sta	S	S	I	S	I
	Vit-Sta	S	S	I	S	S
S5	WS-Vit	I	S	I	I	I
	WS-Sta	I	S	I	S	I
	Vit-Sta	S	S	I	S	I
B5	WS-Vit	I	S	I	I	I
	WS-Sta	S	S	I	I	S
	Vit-Sta	S	S	I	S	S
B7	WS-Vit	I	I	I	I	I
	WS-Sta	S	S	I	S	S
	Vit-Sta	S	S	I	S	S
D11	WS-Vit	I	S	I	I	I
	WS-Sta	S	S	I	S	S
	Vit-Sta	S	S	I	S	S
D18	WS-Vit	I	I	I	I	I
	WS-Sta	S	S	I	S	S
	Vit-Sta	S	S	I	S	S
D26	WS-Vit	I	S	I	S	S
	WS-Sta	S	S	I	S	S
	Vit-Sta	S	S	I	S	S
D29	WS-Vit	I	S	I	I	I
	WS-Sta	I	S	I	S	S
	Vit-Sta	S	S	I	S	S

Table-4.6. Hardness, protein, starch, amylose, and wet and dry gluten content statistical comparisons between the durum wheat fractions.

S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

4.4.4. Effect of Amylose content on starch properties:

4.4.4.1. Starch pasting properties:

Table-4.7. shows gelatinisation properties of whole samples and vitreous and starchy fractions determined using the Rapid Visco Analyser (RVA). Parameters recorded were peak viscosity (PV), trough (Tr), breakdown (BD) and final viscosity (FV). Wholemeal flour was used throughout this study. Research conducted by Bhattacharya *et al.*, (1997) demonstrated a high correlation between the properties of purified starch and the corresponding wholemeal flour, providing α -amylase was inactivated. There was no need to conduct enzyme inactivation in this study as all samples showed low levels of α -amylase activities derived from the high falling number values (Table-4.1).

Table-4.8. and Table-4.9. draw the variations ($p < 0.05$) in pasting properties between the Syrian durum wheat cultivars and fractions, which indicates differences in starch composition and properties among the Syrian varieties. Previously Loney *et al.*, (1974; 1975) found that genetic factors (*i.e.* difference among cultivars) were a significant source of variation for peak viscosity of prime starch. Comparing the pasting properties of each cultivar fractions in this study revealed significant trends where the starchy grains of cultivars appeared to have elevated peak viscosity, trough, breakdown and final viscosity when compared to the vitreous grains (except the peak viscosity, trough and final viscosity of Sham-1 and trough final viscosity of Douma-18861). Nonetheless, these trends may be more related to high total starch composition in the starchy grains rather than any variation in amylose content. Bohouth-7 and Douma-1105 showed lower peak viscosity, trough, and breakdown than the other tested cultivars. According to Bhattacharya *et al.*, (1997) diversity in starch properties could be useful in breeding

programmes for improving quality of specific products, such as various types of noodles.

Results from this study indicated negative correlations between amylose content and both peak viscosity (Fig.4.5) and breakdown (Fig.4.6). Fig.4.5. shows the trends for peak viscosity in whole samples, vitreous sample and starchy sample with respective correlation coefficients of $r = -0.673$, -0.653 , -0.575 ; $p < 0.05$). Fig.4.6. shows the trends for breakdown in similar samples (respectively $r = -0.836$, -0.728 , -0.780 ; $p < 0.05$). However no significant correlation was found between amylose content and final viscosity and trough. This may indicate that differences in amylose content have a greater effect on the swelling and disruption of the starch granules, rather than the subsequent realignment of the starch components during retrogradation.

Lii and Lineback (1977) demonstrated that durum wheat starches start to gelatinize at a slightly lower temperature than starches of other wheat classes. This property appears to be related to the presence of amylose lowering the crystallinity of starch (Kruger *et al.*, 1987). Therefore, vitreous grains which had amylose contents ranging from 27.0 to 32.1% potentially required less energy to start swelling than the starchy grains (25.1-31.3% amylose). This may also account for the variations in pasting properties observed between the samples. Research conducted by Ming *et al.*, (1997) and Sasaki *et al.*, (1998) indicated that as the amylose content decreased, swelling increased, reducing the amount of free water and that was associated with higher peak viscosity. The negative correlations obtained in the current study support these observations.

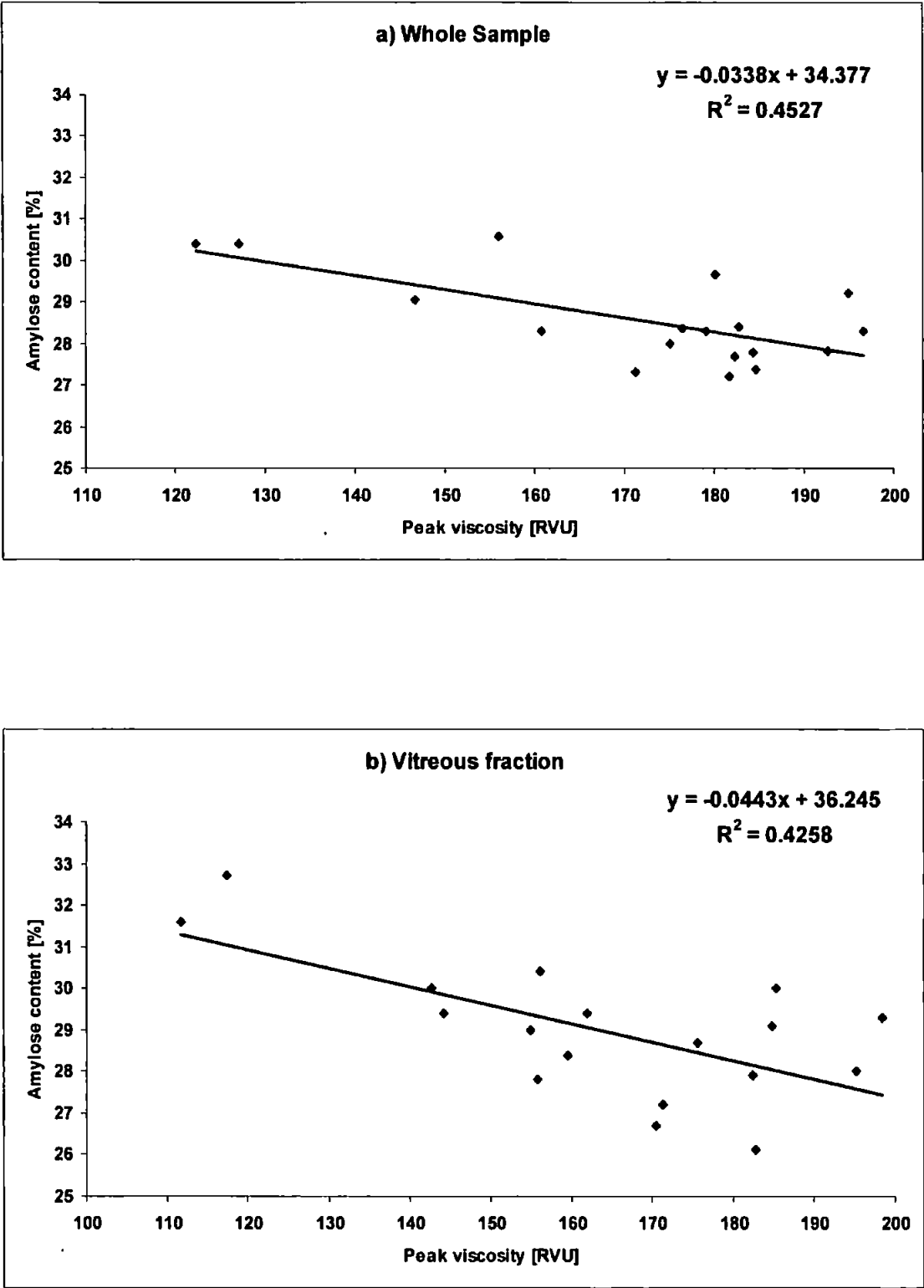
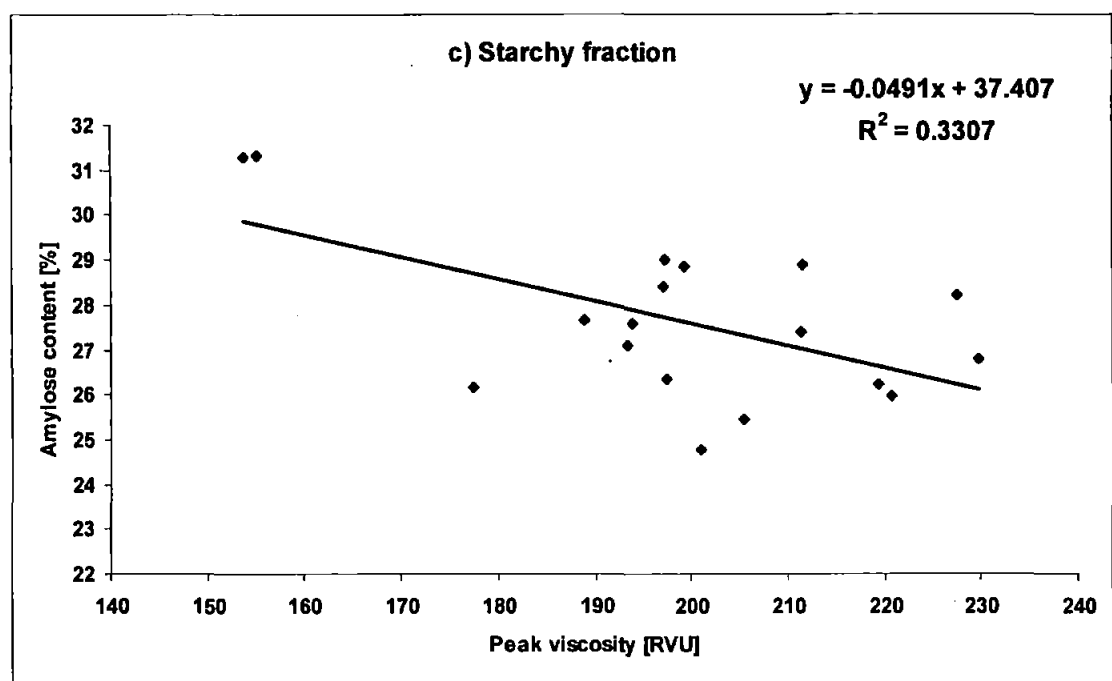


Fig.4.5. Regression analysis of amylose content and peak viscosity.

Fig.4.5. Contd.



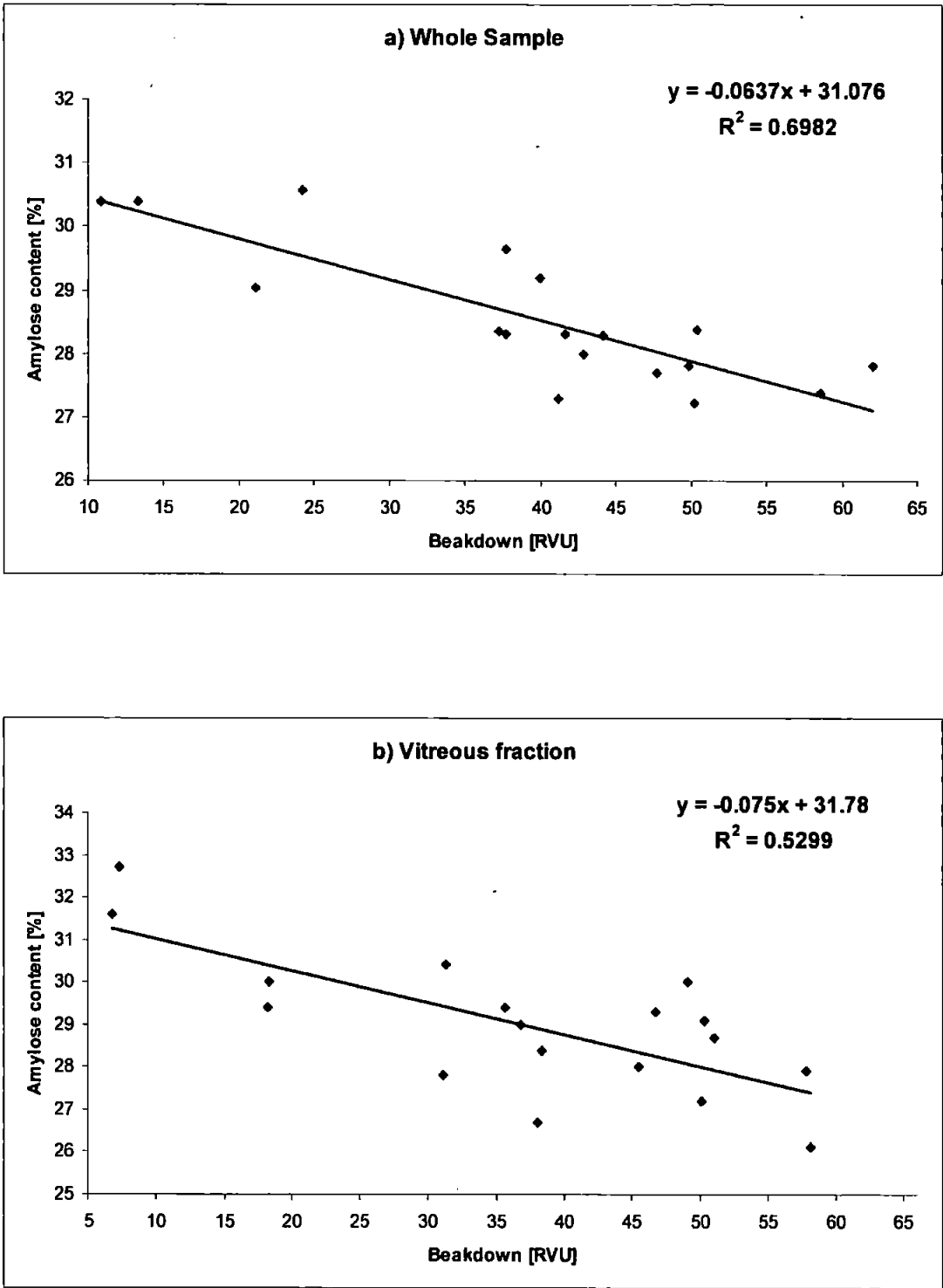
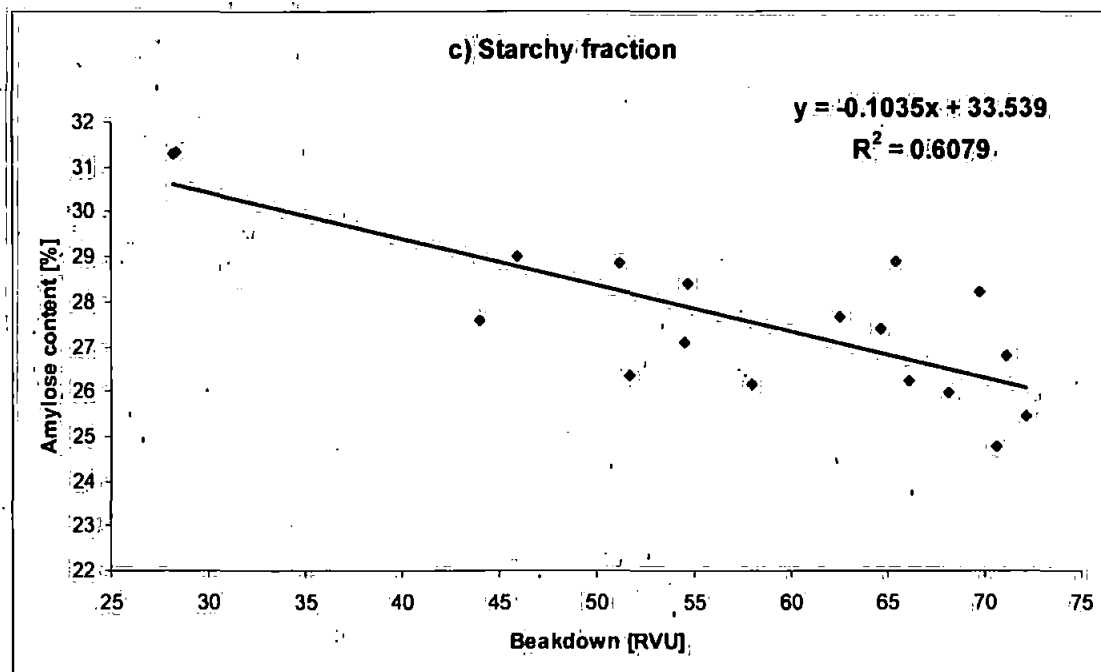


Fig.4.6. Regression analysis of amylose content and breakdown.

Fig.4.6. Contd.



Cultivars	Peak Viscosity [RVU]			Trough [RVU]			Breakdown [RVU]			Final viscosity [RVU]		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
Sham-1 (1)	169.96	166.21	183.13	129.04	129.33	122.88	40.92	36.88	60.25	261.75	260.04	249.04
Sham-3 (2)	188.58	182.67	203.17	128.29	124.67	131.83	60.29	58.00	71.33	255.71	253.79	259.13
Sham-5 (3)	182.29	173.46	220.08	131.96	122.83	152.96	50.33	50.63	67.13	256.96	244.75	284.04
Bohouth-5 (4)	178.29	155.96	198.33	140.83	124.75	146.92	37.46	31.21	51.42	280.25	259.21	288.71
Bohouth-7 (5)	151.29	143.46	195.58	128.58	125.17	150.63	22.71	18.29	44.96	270.71	271.00	295.54
Douma-1105 (6)	124.67	114.58	154.50	112.63	107.58	126.17	12.04	7.00	28.33	244.63	241.04	263.08
Douma-18861(7)	195.75	196.83	228.67	155.00	150.71	158.25	40.75	46.13	70.42	306.38	302.79	298.29
Douma-26827 (8)	173.13	157.21	195.21	131.13	119.67	140.63	42.00	37.54	54.58	265.50	252.42	272.88
Douma-29019 (9)	183.25	185.00	211.46	134.88	135.29	146.42	48.75	49.71	65.04	273.38	274.92	282.88
SE	3.89	2.09	2.29	2.47	1.61	1.49	1.50	0.59	0.96	4.32	2.45	2.70

Table-4.7. Pasting properties of durum wheat cultivars.

WS: Whole Sample, Vit: Vitreous, Sta: Starchy.
Sample numbers are indicated in the table.

Comparison	Final viscosity			Trough			Breakdown			Final viscosity		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
S1- S3	I	S	S	I	I	S	S	S	S	I	I	I
S1- S5	I	I	S	I	I	S	S	S	S	I	S	S
S1- B5	I	I	S	I	I	S	I	S	S	I	I	S
S1- B7	I	S	I	I	I	S	S	S	S	I	I	S
S1-D11	S	S	S	S	S	I	S	S	S	I	S	I
S1-D18	S	S	S	S	S	S	I	S	S	S	S	S
S1-D26	I	I	I	I	S	S	I	I	S	I	I	S
S1-D29	I	S	S	I	I	S	I	S	I	I	S	S
S3- S5	I	I	S	I	I	S	S	S	I	I	I	S
S3-B5	I	S	I	I	I	S	S	S	S	S	I	S
S3-B7	S	S	I	I	I	S	S	S	S	I	S	S
S3-D11	S	S	S	S	S	I	S	S	S	I	I	I
S3-D18	I	S	S	S	S	S	S	S	I	S	S	S
S3-D26	I	S	I	I	I	S	S	S	S	I	I	I
S3-D29	I	I	I	I	S	S	S	S	S	I	S	S
S5-B5	I	S	S	I	I	I	S	S	S	I	S	I
S5-B7	S	S	S	I	I	I	S	S	S	I	S	I
S5-D11	S	S	S	S	S	S	S	S	S	I	I	S
S5-D18	I	S	I	S	S	I	S	S	I	S	S	I
S5-D26	I	S	S	I	I	S	I	S	S	I	I	I
S5-D29	I	I	I	I	S	I	I	I	I	I	S	I
B5-B7	S	S	I	I	I	I	S	S	S	I	I	I
B5-D11	S	S	S	S	S	S	S	S	S	S	S	S
B5-D18	I	S	S	S	S	S	I	S	S	S	S	I
B5-D26	I	I	I	I	I	I	I	S	I	I	I	S
B5D29	I	S	S	I	S	I	S	S	S	I	S	I
B7-D11	S	S	S	S	S	I	S	S	I	S	S	S
B7-D18	S	S	S	S	S	I	S	S	I	S	S	I
B7-D26	S	S	I	I	I	S	S	S	S	I	S	S
B7-D29	S	S	S	I	S	I	S	S	I	I	I	I
D11-D18	S	S	S	S	S	S	S	S	S	S	S	S
D11-D26	S	S	S	S	S	S	S	S	S	I	I	I
D11-D29	S	S	S	S	S	S	S	S	S	S	S	S
D18-D26	S	S	S	S	S	S	I	S	S	S	S	S
D18-D29	I	S	S	S	S	S	I	S	S	S	S	S
D26-D29	I	S	S	I	S	I	I	S	S	I	S	I

Table-4.8. RVA statistical comparison between the durum wheat cultivars (samples 1 to 9).

S1: Sham-1, S3: Sham-3, S5: Sahm-5, B5: Bohouth-5 B7: Bohouth-7, D11: Douma-1105, D18: Douma-18861, D26: Douma-26827, D29: Douma-29019. S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

Comparison	PV	Tr	BD	FV
S1	WS-Vit	I	I	I
	WS-Sta	I	S	I
	Vit-Sta	I	S	I
S3	WS-Vit	I	I	I
	WS-Sta	I	S	I
	Vit-Sta	S	S	I
S5	WS-Vit	S	S	S
	WS-Sta	S	S	S
	Vit-Sta	S	S	S
B5	WS-Vit	S	S	S
	WS-Sta	S	I	I
	Vit-Sta	S	S	S
B7	WS-Vit	I	I	I
	WS-Sta	S	S	S
	Vit-Sta	S	S	S
D11	WS-Vit	I	I	I
	WS-Sta	S	S	S
	Vit-Sta	S	S	S
D18	WS-Vit	I	S	I
	WS-Sta	S	I	S
	Vit-Sta	S	S	I
D26	WS-Vit	S	S	I
	WS-Sta	S	S	I
	Vit-Sta	S	S	S
D29	WS-Vit	I	I	I
	WS-Sta	S	S	S
	Vit-Sta	S	S	S

Table-4.9. RVA statistical comparison between the durum wheat fractions.

S1: Sham-1, S3: Sham-3, S5: Sahm-5, B5: Bohouth-5 B7: Bohouth-7, D11: Douma-1105, D18: Douma-18861, D26: Douma-26827, D29: Douma-29019. S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

4.4.4.2. Starch thermal properties:

Table-4-10. shows the DSC parameters T_o , T_p , T_c , and ΔH (Tester and Karkalas 1996) that correspond to the onset, peak, conclusion temperatures and enthalpy of gelatinization (Muenzing 1991). Overall T_o varied between 57.30-59.65 °C, 56.90-59.50 °C, 58.15-59.95 °C for the whole sample, vitreous and starchy grains respectively.

Examining the variations among the cultivars revealed that a larger number of between cultivar variations were observed in the starchy grain samples (Table-4.11). Peak gelatinisation temperature (T_p) of whole grain samples ranged between 63.00-64.20 °C and exhibited variation between cultivars, while the vitreous and starchy grains had peak temperature ranges of 62.70-64.35 °C, 63.35-64.40 °C respectively, and did not demonstrate significant variations apart from vitreous Sham-1 comparing with Bohouth-5, Sham-5 with Douma-18861 and Bohouth-5 with Douma-18861, and starchy Bohouth-5 with Bohouth-7. In general, the cultivars exhibited very few significant differences in their conclusion temperature with T_c values of 69.00-71.05 °C, 68.95-70.35 °C and 69.80-71.10 °C for the whole sample, vitreous and starchy grains respectively. Significant differences in ΔH were observed between the starchy grains of the variety Douma-1105 compared with the rest of the samples (mean range of starchy grain ΔH being 3.81-4.78 Jg⁻¹). On the other hand, vitreous grains had ΔH between 3.34-4.29 Jg⁻¹ and showed some significant differences between the studied cultivars. Similarly, little significant difference was observed between whole samples of cultivars (ΔH of the whole sample grains between 3.56-4.67 Jg⁻¹). Moreover, no relationship could be established between either elevated total starch or amylose content and increased enthalpy of gelatinisation.

Little significant variation was observed within cultivars when investigating the DSC parameters between vitreous and starchy grains (Table-4-12). Only vitreous and starchy

grains of Douma-18861 had variance in T_o , T_p , T_c and ΔH . Bohouth-5 showed variation between the vitreous and starchy for T_o only. Sham-3 and Sham-5 exhibited difference in T_c , while Sham-3, Sham-5 Bohouth-7 and Douma-26827 showed significant variation between the starchy and vitreous kernels for ΔH . This lack of variation may be due to the relatively small differences in amylose content between starchy and vitreous grains within a sample (Table-4.4). Furthermore, there was a general trend to elevated thermal gelatinisation values in starchy kernels compared to vitreous kernels of the same cultivar. This may either be associated with the increase in starch content of the kernels or the decrease in amylose content of the starch from starchy kernels.

Although previous research by Fredriksson *et al.*, (1998) found negative correlation between amylose content and gelatinisation onset and peak temperature of the tested starches, no such correlation could be found either between or within the tested Syrian durum wheat cultivars, this may indicate that other factors can contribute to swelling and gelatinisation behaviour of starches (Tester and Morrison 1990a).

Cultivars	Onset temperature °C			Peak temperature °C			Conclusion temperature °C			Gelatinisation enthalpy Jg ⁻¹		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
Sham-1 (1)	57.30	56.90	58.15	63.20	63.00	63.60	69.70	69.85	69.85	3.58	3.97	4.68
Sham-3 (2)	58.30	59.15	58.65	63.90	63.85	63.80	71.00	69.85	70.70	4.67	3.58	4.44
Sham-5 (3)	59.65	59.50	59.75	64.10	64.15	64.35	71.05	70.10	71.10	4.19	3.85	4.78
Bohouth-5 (4)	59.00	59.40	59.95	64.10	64.35	64.40	70.90	70.35	70.35	4.27	4.07	4.43
Bohouth-7 (5)	58.10	58.35	58.30	63.00	63.30	63.35	69.70	70.25	70.05	3.85	3.37	4.57
Douma-1105 (6)	58.60	58.55	59.00	64.20	63.50	63.80	70.80	70.30	70.20	4.14	3.34	3.81
Douma-18861(7)	58.60	58.00	59.00	63.30	62.70	63.65	69.00	68.95	70.75	3.89	3.56	4.51
Douma-26827 (8)	59.00	58.30	58.70	63.45	63.55	63.45	69.95	70.00	69.80	3.56	4.29	4.70
Douma-29019 (9)	58.65	58.85	59.30	63.75	63.65	63.85	70.30	70.15	70.70	4.17	4.17	4.35
SE	0.30	0.27	0.20	0.13	0.22	0.19	0.35	0.23	0.17	0.14	0.12	0.11

Table-4.10. Thermal properties of durum wheat cultivars.

WS: Whole Sample, Vit: Vitreous, Sta: Starchy.
Sample numbers are indicated in the table.

Comparison	T _o			T _p			T _c			ΔH		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
S1- S3	I	S	I	I	I	I	I	I	I	S	I	I
S1- S5	S	S	S	S	I	I	I	I	S	I	I	I
S1- B5	S	S	S	S	S	I	I	I	I	I	I	I
S1- B7	I	I	I	I	I	I	I	I	I	I	I	I
S1-D11	I	S	I	S	I	I	I	I	I	I	I	S
S1-D18	I	I	I	I	I	I	I	I	I	I	I	I
S1-D26	S	I	I	I	I	I	I	I	I	I	I	I
S1-D29	I	S	S	I	I	I	I	I	I	I	I	I
S3- S5	I	I	I	I	I	I	I	I	I	I	I	I
S3-B5	I	I	S	I	I	I	I	I	I	I	I	I
S3-B7	I	I	I	S	I	I	I	I	I	S	I	I
S3-D11	I	I	I	I	I	I	I	I	I	I	I	S
S3-D18	I	I	I	I	I	I	S	I	I	I	I	I
S3-D26	I	I	I	I	I	I	I	I	I	S	S	I
S3-D29	I	I	I	I	I	I	I	I	I	I	I	I
S5-B5	I	I	I	I	I	I	I	I	I	I	I	I
S5-B7	I	I	I	S	I	I	I	I	S	I	I	I
S5-D11	I	I	I	I	I	I	I	I	I	I	I	S
S5-D18	I	I	I	S	S	I	S	I	I	I	I	I
S5-D26	I	I	I	I	I	I	I	I	S	I	I	I
S5-D29	I	I	I	I	I	I	I	I	I	I	I	I
B5-B7	I	I	S	S	I	S	I	I	I	I	S	I
B5-D11	I	I	I	I	I	I	I	I	I	I	S	I
B5-D18	I	I	I	S	S	I	I	S	I	I	I	I
B5-D26	I	I	S	I	I	I	I	I	I	I	I	I
B5D29	I	I	I	I	I	I	I	I	I	I	I	I
B7-D11	I	I	I	S	I	I	I	I	I	I	I	S
B7-D18	I	I	I	I	I	I	I	S	I	I	I	I
B7-D26	I	I	I	I	I	I	I	I	I	I	S	I
B7-D29	I	I	I	S	I	I	I	I	I	I	S	I
D11-D18	I	I	I	S	I	I	I	S	I	I	I	S
D11-D26	I	I	I	S	I	I	I	I	I	I	S	S
D11-D29	I	I	I	I	I	I	I	I	I	I	S	I
D18-D26	I	I	I	I	I	I	I	I	S	I	S	I
D18-D29	I	I	I	I	I	I	I	I	I	I	I	I
D26-D29	I	I	I	I	I	I	I	I	I	I	I	I

Table-4.11. Tukey statistical comparison between the durum wheat cultivars for DSC (Samples 1 to 9).

S1: Sham-1, S3: Sham-3, S5: Sahm-5, B5: Bohouth-5 B7: Bohouth-7, D11: Douma-1105, D18: Douma-18861, D26: Douma-26827, D29: Douma-29019. S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

Comparison		T _o	T _p	T _c	ΔH
S1	WS-Vit	I	I	I	I
	WS-Sta	I	I	I	S
	Vit-Sta	I	I	I	I
S3	WS-Vit	I	I	S	S
	WS-Sta	I	I	I	I
	Vit-Sta	I	I	S	S
S5	WS-Vit	I	I	S	I
	WS-Sta	I	I	I	I
	Vit-Sta	I	I	S	S
B5	WS-Vit	S	I	I	I
	WS-Sta	S	I	I	I
	Vit-Sta	S	I	I	I
B7	WS-Vit	I	I	I	I
	WS-Sta	I	I	I	S
	Vit-Sta	I	I	I	S
D11	WS-Vit	I	I	I	I
	WS-Sta	I	I	I	I
	Vit-Sta	I	I	I	I
D18	WS-Vit	I	I	I	I
	WS-Sta	I	I	S	S
	Vit-Sta	S	S	S	S
D26	WS-Vit	I	I	I	S
	WS-Sta	I	I	I	S
	Vit-Sta	I	I	I	S
D29	WS-Vit	I	I	I	I
	WS-Sta	I	I	I	I
	Vit-Sta	I	I	I	I

Table-4.12. Tukey statistical comparison between the durum wheat fractions for DSC.

S1: Sham-1, S3: Sham-3, S5: Sahm-5, B5: Bohouth-5 B7: Bohouth-7, D11: Douma-1105, D18: Douma-18861, D26: Douma-26827, D29: Douma-29019. S: Significant, I: Nonsignificant ($p > 0.05$). WS: Whole Sample, Vit: Vitreous, Sta: Starchy.

4.5. CONCLUSION:

Determining the quality attributes of selected Syrian durum wheat cultivars revealed the variations in the degree of vitreousness, hardness, protein content and falling number among the cultivars. It is of interest to realise the significant progress in durum wheat production where Syria was ranked fourth in the crop year 2002/ 2003. However, it is still not clear whether this production could fulfil the requirements of a durum wheat export market. Comparing the average quality parameters of the selected varieties with the Canadian and US grade-1 durum wheat exposed the highly elevated test weight, 1000-kernel weight and falling number which refers to the soundness of the produced wheat kernels. Moreover, all the tested cultivars would fit to grade No 1 of the Canadian and American grading systems in relation to test weight evaluations. Nevertheless, the reduction in the degree of vitreousness and protein content would restrict Syrian wheat compatibility to the world durum wheat market. Consequently, improvements in kernel quality are needed to enable the majority of the cultivars to reach the highest grade standards in relation to the degree of kernel vitreousness and protein content.

Examining the effect of the degree of vitreousness on durum wheat quality, assuming that the degree of vitreousness is 100% through simulated samples with 100% vitreous kernels and compare them with the actual as is samples and samples with 0% degree of vitreousness (starchy kernels) illustrated that the vitreous kernels are harder and of higher protein content and amylose content than starchy kernels, so these results support the fundamental role of vitreousness in durum wheat quality. Hypothetically, increasing the degree of vitreousness would result in improvement in the overall quality of the Syrian durum wheat to fulfil the first aim of this study.

Variation in apparent amylose content existed on a genetical basis between whole grain samples of Syrian durum wheat cultivars. Within cultivar variation between vitreous and starchy grains of the same cultivars illustrated that grain samples classified as starchy had an increased total starch content but a generally lower amylose content when compared to grain classified as vitreous. This difference in starch characteristics may explain the increased visco-gelatinisation properties (peak viscosity, trough, breakdown and final viscosity) in starchy grains compared to vitreous grains coupled to a similar trend to elevated onset temperatures (T_o) and total enthalpy (ΔH).

The negative correlation observed between amylose content and peak viscosity and breakdown illustrates the importance of amylose content when evaluating the potential use of durum wheat cultivars. The lack of clear correlation between amylose content and final viscosity or the thermal properties (T_o , T_p , T_c , ΔH) of the cultivars examined may indicate that grain protein and lipid quantity and quality, may be as important in regulating these properties as starch quality.

Although recent progress has been made in understanding the functional properties of gluten protein, the importance of starch in pasta-making and other durum wheat products needs further investigation.

Chapter 5

5. Milling performance of Syrian durum wheat cultivars:

5.1. INTRODUCTION:

Wheat milling is the technique which involves the reduction of grains into fine particles, from where it can then be processed and utilized to produce various types of palatable products, such as bread and pasta.

Durum wheat milling however, is notably different from the milling of hard and soft bread wheat since durum kernels are milled to a coarser material known as semolina, which should sustain a bright yellow colour, low speck count and consistent granulation in order to provide high quality end-product (Matsuo and Dexter 1980a). There are numerous factors influence durum wheat milling performance which according to Campbell *et al.*, (2001b), can be divided into two categories; interior factors related to the physiochemical properties of the wheat grains, such as hardness, the degree of vitreousness, kernel size and moisture content, and external factors associated with the mill settings, such as roll speed, gap, orientation and speed differential.

In this section, a study of the effects of kernel physiochemical composition on milling potential of Syrian durum wheat cultivars under steady milling settings was undertaken. The physical and chemical kernel characteristics were firstly determined and then the interrelationship among them was investigated in order to draw a preliminary link to milling performance.

The selected cultivars were tempered and then ground in a Bühler laboratory mill designed for durum wheat under controlled conditions of temperature and humidity as

well as at regulated settings. The relationship between the physiochemical composition and milling potential was examined with the intention of determining the factors responsible for milling performance.

5.2. AIMS:

The aims of this part of the study were:

1. Investigate the interrelationship among durum wheat physiochemical composition.
2. Determine factors responsible for milling performance in Syrian durum.

5.3. OBJECTIVES:

1. Determine the physical and chemical characteristics of selected cultivars.
2. Examine the correlation coefficients among the physical and chemical characteristics.
3. Verify semolina yield under controlled conditions.
4. Investigate the correlation between the physiochemical composition and semolina yield.

5.4. RESULTS AND DISCUSSION:

5.4.1. Interrelationship among the physiochemical composition of Syrian durum wheat cultivars:

The physical and chemical characteristics of the selected durum wheat cultivars have been discussed thoroughly in chapter 4 (see Table-4.1).

Kernel size distribution (Table-5.1) as measured by the procedure of Shuey (1960) showed that the durum wheat kernels tested were relatively large with cultivars having over 85% of the kernels tested being greater than 2.92 mm (No 7 sieve). The percentage of the medium-sized kernels (between 2.92 mm and 2.24 mm) ranged from 4.3% for Sham-3 and Sham-5 to 12% for Douma-26827. Small kernels (less than 2.24 mm) ranged between 1.0-2.7% amongst the cultivars. The high percentage of the large kernels agrees with the observations of high 1000-kernel weight and test weight values indicating that the kernels from the majority of the cultivars were plump, unbroken and sound, and should produce high milling yields.

Cultivars	Large grains > 2.92 mm	Medium grains < 2.92 and >2.24mm	Small grains <2.24mm and >1.70mm
Sham-1 (1)	91.0 ^{a,b}	7.7 ^{a,c}	1.3 ^a
Sham-3 (2)	94.0 ^b	4.3 ^b	1.3 ^a
Sham-5 (3)	94.6 ^b	4.3 ^b	1.0 ^a
Bohouth-5 (4)	91.6 ^{a,b}	5.7 ^{a,b}	2.6 ^a
Bohouth-7 (5)	89.0 ^{a,b}	9.7 ^c	1.3 ^a
Douma-1105 (6)	91.3 ^{a,b}	7.0 ^a	1.6 ^a
Douma-18861(7)	88.3 ^{a,b}	9.6 ^c	2.0 ^a
Douma-26827 (8)	85.3 ^a	12.0 ^c	2.7 ^a
Douma-29019 (9)	92.0 ^b	6.7 ^{a,b}	1.3 ^a
SE	1.22	0.55	0.44

Table-5.1. Kernel size distribution (% of grains).

Sample numbers are indicated in the table.

Single kernel characteristics, representing by kernel hardness index, moisture, diameter and weight, were measured by SKCS 4100 (Table-5.2). All tested cultivars exhibited hard grains with the hardness index ranging between 86.7 for Sham-3 to 100.9 for Bohouth-7. Six of the cultivars, Sham-5, Bohouth-5, Bohouth-7, Douma-1105, Douma-18861, and Douma-26827 were classified as extra hard, while three cultivars (Sham-1, Sham-3 and Douma-29019) were classified as very hard. Sham-5, Bohouth-7, and Douma-18861 had a significantly higher hardness index than Sham-1, Sham-3, and Douma-29019. The average diameters of grains ranged between 2.9-3.2 mm which confirms the measurement of kernel size distribution (Table-5.1), where the diameters of more than 85% of the grain were bigger than 2.92 mm. Kernel weight ranged between 43.4 mg (Douma-26827) and 53.6 mg (Douma-29019).

Cultivars	Mean Hardness (n = 300)	SD	Mean Moisture Content (%) (n = 300)	SD	Mean Diameter (mm) (n = 300)	SD	Mean Weight (g) (n = 300)	SD	Class
Sham-1 (1)	89.1	17.9	11.6	0.5	3.1	0.6	51.1	12.4	Very hard
Sham-3 (2)	86.7	17.0	10.8	0.5	3.2	0.6	52.0	12.0	Very hard
Sham-5 (3)	95.7	16.4	10.9	0.5	3.2	0.5	51.9	10.5	Extra hard
Bohouth-5 (4)	94.3	16.5	10.5	0.5	3.1	0.8	52.3	15.2	Extra hard
Bohouth-7 (5)	100.9	15.8	10.8	0.5	3.1	0.5	51.3	12.5	Extra hard
Douma-1105 (6)	91.5	17.1	10.7	0.5	3.1	0.7	53.2	15.6	Extra hard
Douma-18861 (7)	96.1	13.9	10.9	0.5	3.0	0.6	51.4	13.1	Extra hard
Douma-26827 (8)	90.6	22.2	11.1	0.5	2.9	0.6	43.4	12.3	Extra hard
Douma-29019 (9)	89.3	15.9	11.0	0.5	3.2	0.6	53.6	13.1	Very hard

Table-5.2. Single Kernel Characteristics of several durum wheat cultivars.

Sample numbers are indicated in the table.

The relationships between the physical and chemical traits of the selected cultivars were investigated by correlation (Table-5.3). The degree of vitreousness correlated but insignificantly with kernel hardness ($r = 0.33$). Previous observation demonstrated that vitreous kernels were harder than starchy kernels (Stenvert and Kingswood 1977; Dexter *et al.*, 1988; Samson *et al.*, 2005). The degree of vitreousness exhibited significant correlations with total protein content and both wet and dry gluten ($r = 0.58$, 0.74 , and 0.79 respectively), which support the findings of Dexter *et al.*, (1989) that vitreous kernels showed higher protein content than starchy kernels. The weak negative correlation between the degree of vitreousness and starch content ($r = -0.19$) accompanied with a weak positive correlation with amylose content ($r = 0.28$) have been proved in our previous investigation (El-Khayat *et al.*, 2003). It has been reported that durum wheat kernels showed elevated amylose content compared to bread wheat (Lintas 1988; Vansteelandt and Delcour 1998) as well as higher degree of vitreousness. This explained to some extent the correlation reported in our study.

1000-Kernel weight had a positive correlation with kernel diameter ($r = 0.69$) and large kernel content ($r = 0.74$). However, 1000-kernel weight showed a strong negative correlation with test weight ($r = -0.66$). Matsuo and Dexter (1980a) similarly reported weak correlation between test weight and 1000-kernel weight.

Despite the finding that protein content was significantly correlated to kernel vitreousness ($r = 0.58$), correlation between protein content of the kernel and hardness was weak in this investigation ($r = 0.37$).

A negative correlation between starch and protein ($r = -0.42$) was observed which was expected as starch and protein levels (based as a percentage of kernel weight) are intrinsically linked.

Protein content and test weight were not significantly correlated ($r = -0.19$). Previous correlations by Tkachuk and Kuzina (1979) and Matsuo and Dexter (1980a) have illustrated that low test weight is an indication of shrunken kernels and higher protein content. The lack of correlation here is probably because kernels were generally plump, with more than 85% of the kernels classified as large.

Significant positive correlations between protein content and the degree of vitreousness and the kernel weight ($r = 0.75$) emphasise the role that protein has on these characters.

Test weight, 1000-kernel weight, hardness and the degree of vitreousness have been used widely by wheat millers to predict the milling potential along with total protein content because of its high influence on end-use properties. The correlations among these traits in this study revealed their importance within the selected durum wheat cultivars. As a consequence, the effect of these factors on milling performance was investigated.

	TKW	TW	Hard.	Diam.	Weight	Large kernel	Medium kernel	Small kernel	Moist.	Ash	FN	Protein	Wet gluten	Dry gluten	Starch	Amylose
Vit.	-0.06	0.12	0.33	-0.20	0.17	-0.33	0.44	-0.19	-0.02	-0.50*	0.08	0.58*	0.74***	0.79***	-0.19	0.28
TKW		-0.66**	-0.09	0.69**	0.79***	0.74***	-0.79***	-0.28	0.07	0.12	0.16	0.45	-0.03	0.17	-0.54*	0.04
TW			0.20	-0.11	-0.29	-0.32	0.42	-0.08	-0.07	-0.19	0.00	-0.19	0.04	-0.14	0.78***	-0.06
Hardness				-0.16	0.06	-0.23	0.27	0.01	-0.11	-0.03	0.65**	0.37	0.20	-0.01	0.07	0.50*
Diameter					0.80***	0.94***	-0.88***	-0.77***	0.20	0.05	0.10	0.36	-0.03	0.01	-0.25	-0.19
Weight						0.75***	-0.70***	-0.59**	0.38	-0.33	0.11	0.75***	0.43	0.47*	-0.43	0.24
Large k.							-0.98***	-0.66**	0.24	0.18	-0.07	0.32	-0.12	-0.05	-0.45	-0.23
Medium k.								0.50*	-0.19	-0.24	0.10	-0.25	0.22	0.12	0.44	0.24
Small k.									-0.31	0.09	-0.11	-0.40	-0.30	-0.24	0.35	0.11
Moisture										-0.18	-0.36	0.10	0.37	0.30	-0.39	0.65**
Ash											0.10	-0.64**	-0.88***	-0.78***	-0.09	-0.20
FN												0.14	-0.08	-0.22	0.20	0.20
Protein													0.77***	0.75***	-0.42	0.22
Wet gluten														0.92***	-0.27	0.41
Dry gluten															-0.39	0.30
Starch																-0.17

Table-5.3. Interrelationship among the physiochemical composition in 9 varieties of durum wheat (n = 27).

Statistical significance* = 5%, ** = 1%, *** = 0.1%. Vit: Vitreousness. TW: Test weight. TKW: 1000 kernel weight, Diam: Diameter. Moist: Moisture. FN: Falling number. K: kernel

5.4.2. Factors affecting milling performance of durum wheat cultivars:

The analysis of semolina yield of the selected durum cultivars is presented in Table-5.4.

Semolina extraction was expressed as a percent of the total semolina out of total product, where total semolina was calculated as the total sum of particles passing through the purifiers. The weight of flour (particles of small diameter) was added to total semolina yield to calculate the total extraction rate.

Extraction rates for semolina varied between cultivars from 62.7 % (Douma-1105) to 65.5 % (Bohouth-5 and Bohouth-7). Although the semolina extraction rate is important from a commercial basis, research conducted by Dexter and Matsuo (1978b) indicated that the extraction rate of semolina did not exhibit a significant effect on pasta cooking quality. Thus extraction rate is a characteristic important to the economics of milling rather than quality of end product.

Cultivars	Milling time min	P1 g	P2 g	P3 g	P4 fine g	P4 inter g	P4 coarse g	Flour g	Bran g	Shorts g	Total dust g	Total semo. g	Total ext. g	Total product g	Semo ext. %	Total ext. %	Flour %
Sham-1 (1)	9.45	574.6	167.0	66.7	6.2	11.0	114.4	106.0	322.3	62.8	32.9	939.9	1045.9	1463.9	64.2	71.4	7.2
Sham-3 (2)	11.00	535.1	183.8	70.2	6.7	11.2	111.5	106.9	338.2	62.2	35.6	918.5	1025.4	1461.4	62.9	70.2	7.3
Sham-5 (3)	9.15	572.5	212.4	74.0	8.0	13.3	126.9	103.1	348.3	55.4	36.1	1007.1	1110.2	1550.0	65.0	71.6	6.7
Bohouth-5 (4)	9.35	544.1	200.5	70.0	7.4	11.7	113.8	91.1	306.7	62.4	37.9	947.5	1038.6	1445.6	65.5	71.8	6.3
Bohouth-7 (5)	9.15	548.7	192.3	69.9	7.3	10.8	118.8	84.1	315.2	63.1	36.0	947.8	1031.9	1446.2	65.5	71.4	5.8
Douma-1105 (6)	10.15	527.1	185.7	68.9	7.7	10.8	106.9	112.2	330.4	58.8	37.7	907.1	1019.3	1446.2	62.7	70.5	7.8
Douma-18861(7)	9.45	546.4	188.5	66.8	7.3	11.3	121.0	91.3	323.2	63.2	36.9	941.3	1032.6	1455.9	64.7	70.9	6.3
Douma-26827 (8)	8.45	521.5	183.6	61.3	6.8	11.3	117.9	125.4	311.7	62.2	33.9	902.4	1027.8	1435.6	62.9	71.6	8.7
Douma-29019 (9)	9.55	531.2	179.5	63.3	7.0	11.1	117.4	111.7	306.2	57.2	35.5	909.5	1021.2	1420.1	64.0	71.9	7.9

Table-5.4. Semolina yield of Syrian durum wheat cultivars.

P = purifiers (sieves, see Fig.3.5. chapter 3), semo: semolina, ext: extraction.
Sample numbers are indicated in the table.

The physiochemical compositions of the extracted semolina used later in the production of pasta are given in Table-5.5. All semolina samples showed specks counts less than the accepted limit (40 specks/10 in²). Samples of Sham-5, Douma-1105, and Douma-18861 had 23 specks/ 10 in² whilst the remaining samples had 17 specks/10 in². These results indicate that the resultant pasta would not be adversely affected by specks for any of the cultivars (Vasiljevic and Banasik 1980).

The relatively high moisture content of the conditioned semolina can account for the reduced ash and protein contents of the material compared to the study on the whole kernels of these cultivar (compare with Table-4.1). The protein content of the semolina still averaged approximately 11 % on dry matter base and the ash content of semolina samples were lower than 0.9 % as required in the premium-grade semolina (Cubadda 1988). Gluten content ranged between 24.41-29.37% and 8.96-10.61% for wet and dry gluten respectively.

Cultivars	Specks No/ 10 in ²	Moisture %	Ash % dmb	Protein % dmb	Wet gluten %	Dry gluten %
Sham-1 (1)	17 ^a	13.80 ^a	0.81 ^{a,b,c}	11.88 ^{a,b}	26.48 ^{a,b}	9.88 ^a
Sham-3 (2)	17 ^a	13.54 ^{a,b}	0.87 ^{a,c}	10.83 ^a	25.00 ^a	8.96 ^a
Sham-5 (3)	23 ^a	13.72 ^{a,b}	0.86 ^{a,c}	12.02 ^{a,b}	27.49 ^b	10.30 ^a
Bohouth-5 (4)	17 ^a	13.56 ^{a,b}	0.78 ^{b,c}	11.72 ^{a,b}	24.41 ^a	9.20 ^a
Bohouth-7 (5)	17 ^a	13.52 ^{a,b}	0.81 ^{a,b,c}	11.91 ^{a,b}	27.32 ^b	9.31 ^a
Douma-1105 (6)	23 ^a	13.39 ^{a,b}	0.77 ^b	11.59 ^{a,b}	26.13 ^{a,b}	8.96 ^a
Douma-18861(7)	23 ^a	13.41 ^b	0.75 ^b	12.61 ^b	29.37 ^c	10.61 ^a
Douma-26827 (8)	17 ^a	13.55 ^b	0.83 ^c	11.02 ^{a,b}	25.69 ^{a,b}	9.14 ^a
Douma-29019 (9)	17 ^a	13.33 ^{a,b}	0.74 ^b	11.75 ^{a,b}	28.14 ^{b,c}	9.68 ^a
SE	1.41	0.08	0.01	0.39	0.35	0.38

Table-5.5. Physical and chemical characteristics of extracted semolina for several cultivars of durum wheat.

Sample numbers are indicated in the table.

It has been well established that semolina granulation, or particle size distribution (PSD), has an important role in pasta making because of its effect on hydration rate (Posner and Hibbs 1997; Yalla and Manthey 2006). Similarly, Grant *et al.*, (1993) demonstrated that as semolina PSD decreased, water absorption increased, and the firmness of the resulting pasta decreased. Table-5.6. illustrates that the amount of material with a PSD greater than 250 μm did not significantly vary between cultivars (60.2 % Sham-1; 57.7 % Douma-29019). All of the cultivars demonstrated a predominant amount of material retained on a No. 60 sieve (between 250-420 μm) and over a quarter of the semolina had a particle size between 149-178 μm , and 10 % was of a size greater than 420 μm . According to the standards, the entire semolina should pass through a No. 20 sieve (840 μm aperture size) but not more than 10 % through a 180- μm sieve. However, in the studied samples approximately 13% of the materials passed the No. 80 sieve (178 μm).

Cultivars	% No. 30 549 µm	% No. 40 420 µm	% No. 60 250 µm	% No. 80 178 µm	% No. 100 149 µm	% No. 100 < 149 µm
Sham-1 (1)	0.6 ^a	11.5 ^a	47.3 ^a	27.2 ^a	4.2 ^a	9.1 ^a
Sham-3 (2)	0.6 ^a	11.3 ^a	48.3 ^a	26.7 ^a	4.3 ^a	8.8 ^a
Sham-5 (3)	0.6 ^a	10.7 ^a	47.9 ^a	27.5 ^a	4.5 ^a	9.0 ^a
Bohouth-5 (4)	0.5 ^a	10.4 ^a	48.7 ^a	27.2 ^a	4.4 ^a	8.6 ^a
Bohouth-7 (5)	0.5 ^a	10.7 ^a	48.4 ^a	27.5 ^a	4.4 ^a	8.2 ^a
Douma-1105 (6)	0.6 ^a	9.8 ^a	48.0 ^a	27.4 ^a	4.6 ^a	9.2 ^a
Douma-18861(7)	0.5 ^a	10.6 ^a	47.1 ^a	27.5 ^a	4.7 ^a	9.0 ^a
Douma-26827 (8)	0.5 ^a	10.7 ^a	47.4 ^a	27.4 ^a	4.7 ^a	9.0 ^a
Douma-29019 (9)	0.6 ^a	10.5 ^a	46.6 ^a	27.5 ^a	4.6 ^a	9.7 ^a
SE	0.10	0.54	0.52	0.46	0.52	0.45 ^a

Table-5.6. Particle Size Distribution of extracted semolina (% passing through a sieve number).

Sample numbers are indicated in the table.

The relationship between the physiochemical composition of the durum kernels and milling potentials and chemical characteristics of the extracted semolina were investigated by correlation and are presented in Table-5.7.

Test weight, kernel weight, kernel size, kernel hardness and kernel vitreousness have been used by millers to assess the suitability of durum wheat for milling into semolina. The rate of semolina extraction was shown to be strongly positively correlated to kernel hardness ($r = 0.78$), and not significantly to the degree of vitreousness ($r = 0.36$), whilst even more weakly positively correlated to 1000-kernel weight and test weight ($r = 0.25$, 0.18 respectively).

Numerous investigations have been undertaken to determine the relationship between test weight and milling potential (Mangels 1960; Shuey 1960; Johnson and Hartsing 1963; Baker *et al.*, 1965; Barmore and Bequette 1965; Finny and Yamazaki 1967; Shuey and Gilles 1972; Watson *et al.*, 1977a; 1977b; Matsuo and Dexter 1980a; Matsuo *et al.*, 1982a; Hook 1984; Dexter *et al.*, 1987). Of these, Dexter *et al.*, (1987) demonstrated a highly significant correlation between test weight, milling characteristics and pasta quality, where a linear decrease of 0.7% in semolina yield was associated with a 1 kg decrease in test weight. However, Hook (1984), when reviewing the relationship between test weight and milling potential, suggested that there was no general agreement among the researchers with regards to the use of test weight as a predicting index for milling potential. The results here support this finding, where the correlation between test weight and milling extraction was not significant ($r = 0.18$). Moreover, previous research supporting the relationship between test weight, 1000-kernel weight, and semolina yield (Matsuo and Dexter 1980a; Marshall *et al.*, 1986; Dexter *et al.*, 1987; Halverson and Zeleny 1988), was conducted on durum samples

with lower test weight, 1000 kernel weight, and kernel size than the wheat used in this study. Cultivars in this study all had relatively high test weight, 1000 kernel weight and kernel size. Thus the variation among these cultivars for these traits was not sufficiently large to support a general relationship and illustrates that at the high quality end of the spectrum this relationship cannot be used to discriminate between samples.

Kernel protein content also had a positive correlation with semolina extraction ($r = 0.49$), which is probably related to the relationship between protein content and vitreousness. Dexter *et al.*, (1989) reported that non-vitreous grains were low in protein.

Semolina protein content gave similar correlation patterns to those previously recorded for kernel proteins (compare with Table-5.3), showing positive correlations to wet and dry gluten content, whilst negative correlations to ash and starch content. Both kernel hardness, and the degree of vitreousness were highly correlated to the amount of protein in the semolina recovered after milling ($r = 0.63$ and 0.68 respectively). This observation is consistent with previous research indicating that vitreous kernels are harder and of higher protein content than starchy kernels (Stenvert and Kingswood 1977, Dexter *et al.*, 1988; 1989, Samson *et al.*, 2005). As such, the results clearly illustrate the importance of protein content on kernel hardness, the degree of kernel vitreousness, and milling potential.

Flour extraction was strongly negatively correlated with the degree of vitreousness, hardness, and wholemeal protein content ($r = -0.42$, -0.74 , and -0.60), which corresponds with previous research that the degree of vitreousness affects semolina yield as starchy kernels impart more flour (rather than semolina) when ground (Menger 1973; Matsuo and Dexter 1980a; Dexter and Matsuo 1981; Sissons *et al.*, 2000).

	semolina extraction	Total extraction	Flour	Semolina moisture	Semolina ash	Semolina protein	Semolina wet gluten	Semolina dry gluten
Vitreousness	0.36	0.03	-0.42	0.01	-0.50*	0.68**	0.61**	0.50*
1000- kernel weight	0.25	-0.34	-0.52*	-0.02	0.01	0.07	-0.24	-0.06
Test weight	0.18	0.77***	0.25	0.02	-0.21	0.08	0.28	0.06
Hardness	0.76***	0.27	-0.74***	-0.02	-0.16	0.63**	0.39	0.32
Ash	0.05	-0.05	-0.10	0.66**	0.87***	-0.56*	-0.74***	-0.43
Protein	0.49	-0.05	-0.60**	-0.23	-0.57*	0.86***	0.70***	0.68**
Wet gluten	0.05	-0.16	-0.15	-0.40	-0.73***	0.71***	0.76***	0.50*
Dry gluten	0.04	-0.22	-0.17	-0.28	-0.70**	0.63**	0.59*	0.45
Starch	0.07	0.70***	0.34	-0.31	-0.22	-0.23	0.00	-0.23
semolina extraction		0.55*	-0.85***	0.24	-0.17	0.67**	0.28	0.47
Total extraction			-0.03	0.19	-0.25	0.26	0.13	0.25
Flour				-0.17	0.05	-0.62**	-0.23	-0.36
Semolina moisture					0.63**	-0.03	-0.29	0.19
Semolina ash						-0.56*	-0.46	-0.22
Semolina protein							0.76***	0.82***
Semolina wet gluten								0.79***

Table-5.7. Correlation between the physiochemical composition of kernels and semolina properties of 9 varieties of durum wheat (n = 27).

*, **, *** significant 5%, 1%, 0.1%

5.5. CONCLUSION:

It is recognised that high extraction rates for durum wheat semolina is the target to the millers (Troccoli *et al.*, 2000). Although researchers have linked factors such as test weight and 1000 kernel weight to semolina yield and hence indirectly to grain hardness (Marshall *et al.*, 1986), the research presented here showed that they are only parts of the answer when defining quality attributes. The results of the correlation analyses confirm the importance of three possible physico-chemical markers with regards to the milling quality attributes of durum wheat, namely the degree of kernel vitreousness, kernel hardness, and kernel protein content. Despite the fact that all the cultivars had high test weight and kernel weight, which theoretically means high semolina yield, kernel hardness and the degree of vitreousness and protein content became more important than small variations in test weight or kernel size. Consequently, a further study was required to demonstrate their effect on end-use quality.

Chapter 6

6. Dough rheology and pasta cooking quality of Syrian durum wheat cultivars:

6.1. INTRODUCTION:

The majority of durum wheat (*Triticum durum*) grown in the world is milled to form semolina. This in turn is used in the manufacture of a multitude of cereal food products, with pasta being the most important in terms of volume and commodity value.

However, durum quality differs according to the effect of genotype, environment and their interaction (Borghi *et al.*, 1982; Sinclair *et al.*, 1993), which in turn affects the cooking quality of resultant pasta. Consequently, extensive research has been conducted in order to determine the semolina characteristics required to make high quality pasta (Dexter and Matsuo, 1980; Dexter *et al.*, 1983, 1987; D'Egidio *et al.*, 1990; Dexter *et al.*, 1994; Kovacs *et al.*, 1995; Ames *et al.*, 1999; Manthey and Schorno, 2002).

It has been found that the majority of semolina characteristics required to make high quality pasta are related to dough development, with the protein quantity and quality of the semolina being closely linked to the elasticity, extensibility and resistance to overcooking of pasta, correspondingly to bread dough in which gluten has been related to the viscoelastic properties (Gupta *et al.*, 1989; Khan *et al.*, 1990; Gupta *et al.*, 1992; Weegels *et al.*, 1996).

In the previous chapter, conclusions about the importance of three physiochemical markers, protein content, kernel hardness, and the degree of vitreousness, on the milling

potential of Syrian durum wheat cultivars were developed. Consequently, the aim to investigate in this chapter was to test this relationship regarding end-use product utilisation.

The resultant semolina of nine selected Syrian durum wheat cultivars, which were grown under the same environmental conditions, was processed into pasta using an 84-strand Teflon-coated spaghetti die with 0.157 cm openings (water temperature was 40 °C, extruder shaft speed 25 rpm, vacuum 18 in. Hg.). Pasta samples were dried at high temperature and high humidity (73 °C and 83% RH) for 12 hours. Dough rheological characteristics and pasta cooking properties were determined (see chapter 3 for full details).

6.2. AIM:

The aim of this part of the study was to comprehensively identify factors influencing end-use product quality of Syrian durum wheat cultivars.

6.3. OBJECTIVES:

1. Determine dough rheological properties.
2. Process the resultant semolina into pasta.
3. Determine the cooking properties of pasta.
4. Investigate the effects of kernel physiochemical composition, semolina characteristics, and dough rheological properties on pasta cooking quality.

6.4. RESULTS AND DISCUSSION:

6.4.1. Dough extension (rheological) properties:

Dough rheological (extension) characteristics were evaluated by farinograph, extensograph, and mixograph.

Farinograph is a broadly used instrument to evaluate the potential mixing characteristics of flour. The recorded parameters were, water absorption, dough development time, and stability (Table-6.3). Water absorption refers to the amount of water required by a dough to reach its optimum consistency, and it is related to the protein and starch contents and other flour components. The selected semolina samples showed variation in water absorption and ranged between 61.4-69.8%. Dough development time, which represents the time required by a dough to reach its optimum consistency, or the time required to form a consistent dough, is an indication of dough strength. Douma-18861 had the highest value (3.5 min), while Douma-29019 showed the lowest values (1.5 min). Dough stability, which refers to resistance of dough to over mixing as well as dough strength, ranged for the semolina samples between 1.8-5.5 min. Guidelines exist defining that weak, medium strong, strong and extra strong semolina values of development time and stability (Table-6.1).

Comparison of the figures of the measured semolina samples with these norms revealed that all the selected semolina samples fitted in the medium strong category.

Flour	Development time (min)	Stability (min)
Weak	1	1
Medium strong	2-4	4-7
Strong	3-5	8-14
Extra strong	4-12	20-23

Table-6.1. Standards of farinograph measurements.

Source: Williams (1997).

The extensograph is another technique used in conjunction with the farinograph to determine the dough rheological properties, particularly dough resistance to stretching and elasticity. Parameters recorded were resistance to extension, which refers to the maximum height of the curve in Brabender Units, extensibility, which indicates the length of the curve in millimetres, and the ratio of the maximum resistance to extension to extensibility, which refers to the elasticity (Table-6.3). It has been reported that the maximum resistance to extension (R_{\max}) of weak, medium strong, strong and extra strong flours should sustain the following values, 120, 350, 450, and 630 BU respectively (Williams 1997). Consequently, nearly all the selected semolina samples fitted in the medium strong category, apart from Sham-3, which fitted the strong flour category.

The mixograph is another rheological instrument used intensely in the USA to evaluate gluten strength. It has extra advantages compared to the previous two techniques, principally it requires less sample size and time, and hence it is used in wheat breeding programmes, where many small samples have to be analysed. Mixogram curves are assessed visually for gluten strength by comparing to standard curves ranked from 1 to 8 (Fig.3.8. in chapter 3), where the higher the number the stronger the gluten. The parameter recorded was the time to peak, which is the time in minutes for the flour to form a consistent dough, and this measurement can be also used to indicate gluten strength (Table-6.3). Guidelines exist defining the time required by different categories of types of flour to form a dough (Table-6.2).

The selected semolina samples showed peak times ranged between 2.80-4.23 min, and hence Sham-1, Sham-5, Bohouth-5, and Douma-29019 could be classified as medium flours, and the remaining samples as strong. However, comparing the mixograms of the semolina samples with the standard scale (1-8) revealed that Sham-3 and Douma-18861

were number 6, which indicates that these two samples showed the best mixing characteristics, whilst Sham-5 showed inferior mixing properties recorded as number 3.

Flour	Peak time min
Very Weak	0.5 - 1.4
Weak	1.5 - 2.4
Medium	2.5 - 3.4
Strong	3.5 - 5.0
Extra Strong	5.0 - 6.0

Table-6.2. Standards of mixograph measurements.

Source: Williams (1997).

Cultivars	Farinograph			Extensograph			Mixograph	
	Water absorption %	Development time min	Stability Min	Extensibility mm	Resistance to extension BU	Ratio R_{max}/E	Peak time min	Classification
Sham-1 (1)	66.0 ^a	1.75 ^a	5.50 ^a	100 ^a	220 ^a	2.20 ^{a,d}	2.95 ^a	4
Sham-3 (2)	63.8 ^b	2.25 ^{a,b}	3.75 ^{b,d}	100 ^a	460 ^b	4.60 ^b	3.80 ^b	6
Sham-5 (3)	66.6 ^a	2.50 ^b	3.00 ^b	125 ^b	260 ^c	2.08 ^a	2.80 ^a	3
Bohouth-5 (4)	68.8 ^c	2.00 ^{a,b}	1.75 ^c	75 ^c	175 ^d	2.33 ^{a,d}	2.83 ^a	4
Bohouth-7 (5)	68.9 ^c	2.50 ^b	4.50 ^d	88 ^d	395 ^e	4.49 ^b	4.07 ^c	5
Douma-1105 (6)	69.8 ^c	2.50 ^b	2.50 ^{b,c}	115 ^b	250 ^c	2.17 ^a	3.70 ^b	5
Douma-18861(7)	65.6 ^a	3.50 ^c	4.00 ^d	115 ^b	120 ^f	1.04 ^c	4.23 ^c	6
Douma-26827 (8)	61.4 ^d	2.00 ^{a,b}	2.50 ^{b,c}	98 ^a	255 ^c	2.60 ^d	3.67 ^b	5
Douma-29019 (9)	63.4 ^b	1.50 ^a	2.50 ^{b,c}	120 ^b	262 ^c	2.18 ^a	3.27 ^d	5
SE	0.27	0.16	0.17	2.38	1.63	0.07	0.05	

Table-6.3. Dough rheological properties of the selected semolina samples.

BU: Brabender Unit. E: extensibility. R_{max} : maximum resistance to extension.
Sample numbers are indicated in the table.

6.4.2. Pasta cooking quality:

It has been demonstrated that cooking properties of pasta are evaluated through its textural and appearance characteristics, such as pasta colour, cooked weight, cooking loss and firmness. Consequently, it has been established that pasta with bright yellow colour, high firmness and elasticity “*al dente*” eating properties, minimum cooking loss, and increased cooked weight, considered as pasta with high quality (Antognelli 1980; D'Egidio *et al.*, 1982; 1993a; 1993b; Dexter *et al.*, 1983; Feillet 1984; Autran *et al.*, 1986; Hosney 1986; Autran and Feillet 1987; Pomeranz 1987, Cole 1991).

Some of the quality characteristics of the cooked pasta obtained from the durum wheat semolina samples are presented in Table-6.4.

Optimum-cooking time, which was defined as the time required for the white core in the centre of the pasta strand to disappear, ranged from 9 min for Sham-3 and Douma-26827 to 10.5 min for Douma-18861. Actual cooked weight showed no significant difference among the cooked pasta samples and ranged between 29.56-30.50 g (approximately three times of the original weight). On the other hand, cooking loss and cooked firmness demonstrated significant variations among pasta made from the different samples. The resultant pasta samples showed firmness figures between 3.60-5.59 gcm⁻¹ and hence they are categorized as poor pasta samples apart from Douma-18861 which gave a fair pasta sample. Cooking loss ranged from 5.9% for Bohouth-5 to 7.33% for Douma-1105.

When the tested pasta samples were overcooked for 6 minutes, increases in cooked weight and cooking loss associated with a decrease in firmness were observed (Table-

6.4). All the tested pasta samples exhibited significant increases in cooked weight when overcooked for 6 min, compared with the cooked weight in optimum time.

The mechanical strength of dried pasta ranged between 94.3-104.3 g, and exhibited significant variation among the samples.

Checks (cracks) in the selected dried pasta samples, which appear as a result of the drying process (Manthey 2000), ranged between 37 for Douma-1105 and 105 for Sham-1. It has demonstrated that the number of cracks in dry pasta can be related to pre-harvest grain sprouting (Donnelly 1980; Maier 1980; Dexter *et al.*, 1990), but this is not relevant to the selected cultivars in this study as all the selected cultivars exhibited high falling number values (Table-4.1).

It has been found that colour scores, as converted using the colour map (Debbouz 1994), of 8 and higher translate to good pasta colour. The tested dried pasta samples showed values 8 and higher, apart from Sham-5 and Bohouth-5 which had values 7.

Cultivars	Optimum cooking time	Actual cooked weight	Residue	Firmness	Optimum time plus six min.				Breaking force of dried pasta	Number of checks in dried pasta	Colour scores of dried pasta
					Cooking time	cooked weight	Residue	Firmness			
	min	g	%	gcm ⁻¹	min	g	%	gcm ⁻¹	g		
Sham-1 (1)	9.50 ^a	30.22 ^a	6.10 ^a	3.80 ^a	15.50 ^a	37.06 ^a	7.93 ^{a,c}	3.10 ^a	102.1 ^a	105 ^a	8.5 ^a
Sham-3 (2)	9.00 ^b	30.11 ^a	6.23 ^{a,b}	3.60 ^a	15.00 ^b	37.29 ^a	7.87 ^a	2.90 ^a	94.3 ^b	55 ^b	8.0 ^b
Sham-5 (3)	9.50 ^a	30.27 ^a	6.07 ^a	4.50 ^b	15.50 ^a	36.50 ^{a,b}	6.77 ^b	3.40 ^{a,b}	99.5 ^{a,c}	77 ^c	7.0 ^c
Bohouth-5 (4)	9.50 ^a	30.50 ^a	5.90 ^a	3.70 ^a	15.50 ^a	35.87 ^{a,b}	7.60 ^a	3.10 ^a	97.4 ^{b,c}	67 ^{b,c}	7.0 ^c
Bohouth-7 (5)	9.50 ^a	29.56 ^a	6.50 ^b	4.40 ^b	15.50 ^a	34.93 ^b	7.90 ^{a,c}	3.70 ^{b,c}	98.6 ^c	53 ^b	8.5 ^a
Douma-1105 (6)	10.00 ^c	30.27 ^a	7.33 ^c	3.80 ^a	16.00 ^c	35.13 ^b	8.33 ^c	3.20 ^a	100.6 ^c	37 ^b	8.0 ^b
Douma-18861(7)	10.50 ^d	29.55 ^a	6.13 ^{a,b}	5.50 ^c	16.50 ^d	34.67 ^b	7.33 ^a	4.10 ^c	101.5 ^{a,c}	53 ^b	9.0 ^d
Douma-26827 (8)	9.00 ^b	29.67 ^a	6.72 ^b	4.20 ^{a,b}	15.00 ^b	35.46 ^{a,b}	7.77 ^a	3.20 ^a	104.3 ^{a,c}	73 ^c	8.5 ^a
Douma-29019 (9)	9.50 ^a	29.67 ^a	6.20 ^a	4.50 ^b	15.50 ^a	35.38 ^{a,b}	7.70 ^a	3.60 ^{a,b}	100.2 ^c	41 ^b	8.5 ^a
SE	0.10	0.34	0.09	0.11	0.10	0.41	0.11	0.09	0.60	3.36	0.00

Table-6.4. Cooking characteristics of pasta produced from a range of Syrian durum wheat cultivar.

Means values in the same column, followed by a different letter are significantly different ($P < 0.05$).
Sample numbers are indicated in the table.

6.4.3. Effect of kernel physical characteristics on dough rheology and pasta cooking quality:

The physical characteristics of the durum kernel have an important role with regard to processing and cooking quality of pasta from durum semolina. The relationship between the kernel physical characteristics and pasta quality were investigated by correlation (Table-6.5).

Whilst many of these correlations were non-significant, the most important features of these correlations showed that pasta firmness had significant relationships with both the degree of vitreousness and hardness ($r = 0.48$ and 0.51 respectively). Moreover, the degree of vitreousness exhibited highly significant correlations with dough stability, optimum cooking time of pasta and pasta colour ($r = 0.74$, 0.57 , and 0.69 respectively). Farinograph water absorption correlated with kernel hardness ($r = 0.56$), which is expected, where the higher the hardness the more the damaged starch, and hence the more the water absorption (Bakhshi and Bains 1987; Boyacioglu and D'Appolonia 1994b). As the hardness and degree of vitreousness of durum wheat kernels are related to the protein composition of the kernels (Stenvert and Kingswood, 1977; Dexter *et al.*, 1989), these observations were to be expected. These findings confirm the importance of the degree of vitreousness and kernel hardness on pasta cooking quality.

Kernel physical properties seem not to display any impact on dough extensograph characteristics, where it has been found that it is more related on gluten strength.

Furthermore, dry pasta cracks and pasta cooking loss showed no correlation with any of the measured kernel physical characteristics.

	Vitreousness	TKW	Test Weight	Hardness	Diameter	Weight	No. 7	No. 9	No. 12
Water absorption	0.19	0.44	-0.20	0.56 [*]	0.24	0.57 [*]	0.27	-0.25	-0.16
Development time	0.30	0.07	-0.50 [*]	0.55 [*]	-0.27	0.06	-0.17	0.17	0.04
Stability	0.74 ^{***}	0.00	-0.03	0.08	0.03	0.04	-0.05	0.17	-0.49 [*]
E	0.00	-0.19	0.10	-0.16	0.26	0.22	0.27	-0.18	-0.52 [*]
R _{max}	-0.29	0.16	-0.03	-0.15	0.42	0.03	0.29	-0.23	-0.47 [*]
R _{max} /E	-0.21	0.19	-0.05	-0.01	0.28	-0.04	0.15	-0.12	-0.27
Peak time	0.34	-0.18	-0.22	0.23	-0.40	-0.17	-0.51 [*]	0.54 [*]	0.08
Optimum cooking time	0.57 [*]	0.13	-0.24	0.42	-0.13	0.42	-0.10	0.13	-0.02
Actual Cooked weight	-0.45	0.53 [*]	-0.40	-0.27	0.40	0.34	0.63 ^{***}	-0.70 ^{***}	-0.03
Residue	-0.14	-0.42	0.08	-0.06	-0.30	-0.20	-0.32	0.35	0.07
Firmness	0.48 [*]	-0.29	0.16	0.51 [*]	-0.27	-0.04	-0.34	0.40	-0.01
Breaking force	0.32	-0.85 ^{***}	0.54 [*]	0.04	-0.70 ^{***}	-0.57 [*]	-0.69 ^{***}	0.73 ^{***}	0.32
checks	0.15	-0.17	0.12	-0.12	-0.16	-0.36	-0.02	0.03	0.03
Colour	0.69 ^{**}	-0.42	0.18	-0.07	-0.45	-0.25	-0.62 ^{**}	0.70 ^{***}	0.01

Table-6.5. Correlations between kernel physical characteristics, dough rheology and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

E: extensibility, R_{max}: resistance to extension, TKW: 1000 kernel weight, No 7: % grains remaining on sieve No 7 (>2.92 mm), No 9: % grains passing No 7 and remaining on No 9 (>2.24 mm), No 12: % grain passing No 9 (< 2.24 mm).

6.4.4. Effect of kernel chemical characteristics on dough rheology and pasta cooking quality:

The relationships between kernel chemical characteristics, dough rheology, and pasta cooking quality were evaluated by correlation (Table-6.6).

It was of interest to notice the correlation between kernel protein content and both pasta firmness ($r = 0.57$) and optimum cooking time ($r = 0.83$). This finding demonstrates the importance of protein on pasta cooking quality. However, kernel protein content did not significantly correlate with water absorption ($r = 0.44$), which was unexpected.

Ash content appeared to adversely affect pasta cooking quality, where ash content significantly negatively correlated with optimum cooking time of pasta, pasta firmness and pasta colour ($r = -0.72$, -0.61 and -0.56 respectively), and positively with dried pasta checks ($r = 0.48$). This supports the negative effect of ash content on pasta colour (Kobrehel *et al.*, 1974; Cubadda 1988; Taha and Sagi 1987; Borrelli *et al.*, 1999) and pigment degradation during pasta processing (Borrelli *et al.*, 1999) previously reported.

Falling number values of the durum wheat wholemeal flour were positively correlated with dough resistance to extension and cooked pasta firmness ($r = 0.47$ and $r = 0.32$, respectively) and negatively to dried pasta cracks ($r = -0.48$). In previous studies on Canadian and American durum wheat investigating the factors affecting pasta cooking quality revealed that low falling number values (associated with high α -amylase activities because of field sprouting) tended to increase the amount of residue in pasta cooking water and reduced the firmness of pasta (Matsuo *et al.*, 1982b; Grant *et al.*, 1993). Moreover, other studies on durum wheat quality also linked kernel sprouting to

increase dried pasta checking (Donnelly 1980; Maier 1980; Dexter *et al.*, 1990).

Nevertheless, all the tested durum wheat grains in this investigation revealed to be sound and free of sprouting because of the high falling number values (more than 400 sec) and hence the correlations reported here do not reflect the findings reported in the literature.

	Moisture	Ash	FN	Protein	Wet gluten	Dry gluten
Water absorption	0.59 [*]	0.01	0.18	0.44	0.27	0.23
Development time	-0.03	-0.21	0.39	0.48 [*]	0.41	0.29
Stability	-0.02	0.02	0.05	0.24	0.34	0.45
E	0.24	-0.56 [*]	-0.25	0.39	0.51 [*]	0.32
R_{max}	0.04	0.49 [*]	0.47 [*]	-0.40	-0.42	-0.44
R_{max}/E	-0.06	0.60 ^{**}	0.57 [*]	-0.45	-0.51 [*]	-0.47 [*]
Peak time	-0.05	-0.29	0.55 [*]	0.08	0.36	0.26
Optimum cooking time	0.26	-0.72 ^{***}	0.01	0.83 ^{***}	0.85 ^{***}	0.78 ^{***}
Actual Cooked weight	0.42	0.46	-0.49 [*]	-0.07	-0.35	-0.20
Residue	0.71 ^{***}	-0.17	-0.09	-0.30	0.21	0.03
Firmness	-0.40	-0.61 ^{**}	0.32	0.57 [*]	0.57 [*]	0.39
Breaking force	0.06	-0.40	-0.47 [*]	-0.11	0.36	0.24
Checks	-0.23	0.48 [*]	-0.48 [*]	-0.24	-0.31	-0.14
Colour	-0.11	-0.56 [*]	0.08	0.12	0.57 [*]	0.57 [*]

Table-6.6. Correlations among kernel chemical characteristics, dough rheology and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

FN: falling number.

6.4.5. Effect of starch content, amylose content, starch thermal and pasting properties on dough rheology and pasta cooking quality:

The correlations between starch quantity and quality with dough rheological properties and pasta cooking quality are presented in Table 6.7.

The influence of starch on pasta cooking quality has not been widely studied, and the results regarding this relationship are still being debated. Nevertheless, it has been proposed that starch determines the optimum cooking time of pasta (Marshall and Wasik 1974; Grzybowski and Donnelly 1977), and Dexter and Matsuo (1979) demonstrated that starch did improve pasta quality. Furthermore, Zeng *et al.*, (1997) suggested that because of the influence of temperature on starch pasting properties, starch could affect end-product quality. On contrary, research conducted by (Sheu *et al.*, 1967; Walsh and Gilles 1971; Grzybowski and Donnelly 1979; Damidaux *et al.*, 1980) found that starch did not affect pasta cooking quality.

As can be seen in Table-6.7., total starch content of wholemeal flour did not correlate with dough water absorption as measured by farinograph nor with optimum cooking time of pasta. Additionally, starch content of the wholemeal flour did not appear to affect significantly the texture of the pasta produced. However, starch did negatively affect dough development time and pasta actual cooked weight ($r = -0.51$ and -0.47 respectively).

On the other hand, amylose content, the linear component of starch, highly positively correlated with dough water absorption ($r = 0.82$). These results are in general agreement with previous research demonstrating that lower amylose is associated with higher peak viscosity, and variations in water absorption (Zeng *et al.*, 1997; Jane *et al.*, 1999; Lee *et al.*, 2001). Furthermore, increased amylose content was associated with a significant increase in pasta optimum cooking time and cooking loss. Similarly, Sharma *et al.*, (2002) when investigating the relationship of starch and protein content in durum wheat pasta, found a positive correlation to the amount of amylose and the cooking loss ($r = 0.62$) and a negative correlation with peak viscosity ($r = -0.69$). However, recent research conducted by Grant *et al.*, (2004) on pasta quality of waxy durum wheat reported that amylose content did not correlate with pasta cooking loss. It is interesting to note that although amylose content affected the peak viscosity of the semolina and also the cooking loss of the pasta, no significant correlation was observed between amylose content and the firmness of the pasta.

Peak viscosity and breakdown, as measured by RVA, were negatively correlated with water absorption, and this is due to the adverse effect of amylose content on peak viscosity and breakdown (Dengate 1984; Crosboie 1991, El-Khayat *et al.*, 2003). It is of interest to notice that all RVA parameters were negatively correlated with cooking loss of pasta. Moreover, starch final viscosity exhibited a highly significant correlation with firmness ($r = 0.73$), and optimum cooking time of pasta ($r = 0.51$). These results indicate the possible use of the RVA as a method to predict the end-use quality of durum wheat.

Starch thermal parameters, onset temperature, peak temperature, conclusion temperature, and enthalpy energy, all showed negative correlations with pasta colour scores ($r = -0.52, -0.72, -0.75$, and -0.48 respectively).

	Starch	Amylose	PV	Tr	BD	FV	T _o	T _p	T _c	ΔH
Water absorption	-0.41	0.82 ^{***}	-0.60 ^{**}	-0.25	-0.71 ^{***}	-0.11	-0.06	0.19	0.16	0.13
Development time	-0.51 [*]	0.33	0.06	0.39	-0.22	0.45	0.16	-0.12	-0.32	0.01
Stability	-0.42	-0.03	0.05	0.04	0.04	0.07	-0.70 ^{***}	-0.70 ^{***}	-0.50 [*]	-0.34
E	-0.18	-0.24	0.08	-0.06	0.17	-0.13	0.25	0.21	0.01	0.06
R _{max}	0.04	-0.11	-0.15	-0.52 [*]	0.18	-0.54 [*]	-0.18	-0.04	0.31	0.38
R _{max} /E	0.10	0.01	-0.17	-0.42	0.07	-0.40	-0.25	-0.15	0.23	0.30
Peak time	-0.05	0.33	-0.12	0.10	-0.27	0.30	-0.19	-0.43	-0.47 [*]	-0.08
Optimum cooking time	-0.41	0.50 [*]	-0.11	0.37	-0.45	0.51 [*]	-0.01	-0.06	-0.40	-0.12
Actual Cooked weight	-0.47 [*]	0.06	-0.18	-0.34	0.00	-0.49 [*]	0.11	0.67 ^{**}	0.65 ^{**}	0.37
Residue	0.03	0.60 ^{**}	-0.83 ^{***}	-0.71 ^{***}	-0.69 ^{**}	-0.51 [*]	-0.02	0.11	0.05	-0.15
Firmness	0.09	-0.07	0.38	0.68 ^{**}	0.05	0.73 ^{***}	0.21	-0.38	-0.58 [*]	-0.27
Breaking force	0.30	0.06	-0.15	0.07	-0.28	0.15	-0.01	-0.36	-0.51 [*]	-0.81 ^{***}
Checks	-0.16	-0.39	0.26	0.10	0.31	-0.07	-0.22	-0.27	-0.11	-0.43
Colour	0.14	0.05	0.02	0.18	-0.12	0.37	-0.52 [*]	-0.72 ^{***}	-0.75 ^{***}	-0.48 [*]

Table-6.7. Correlations among starch quantity and quality, dough rheology and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

PV: peak viscosity, Tr: trough, BD: breakdown, FV: final viscosity, T_o: onset temperature, T_p: peak temperature, T_c: conclusion temperature, ΔH: enthalpy energy.

6.4.6. Effect of semolina physical characteristics on dough rheology and pasta cooking quality:

Semolina extraction rate did not exhibit any correlation with dough rheological properties (Table-6.8). However, only residue of cooked pasta showed a highly negative correlation with extraction rate ($r = -0.63$). Previous research conducted by Dexter and Matsuo (1978b) demonstrated that pasta cooking quality did not show a significant effect with semolina extraction. Moreover, flour percentage in semolina showed an expected positive correlation with cooking loss ($r = 0.48$).

It has been demonstrated that semolina extraction rate and semolina granulation affected farinograph measurements (Irvine *et al.*, 1961, Dexter and Matsuo 1978b). However, no such correlations have been detected in this study.

	Semolina extraction	Total extraction	Flour	No. 30	No. 40	No. 60	No. 80	No. 100	% pass No. 100	Specks
Water absorption	0.45	-0.11	-0.63 ^{**}	-0.07	-0.45	0.59 ^{**}	0.18	-0.25	-0.43	0.34
Development time	0.18	-0.47 [*]	-0.49 [*]	-0.45	-0.23	0.12	0.22	0.37	-0.32	0.72 ^{***}
Stability	0.14	-0.24	-0.33	0.26	0.70 ^{***}	-0.14	-0.14	-0.53 [*]	-0.23	-0.10
E	-0.30	-0.15	0.30	0.43	-0.17	-0.63 ^{**}	0.37	0.45	0.71 ^{***}	0.66 ^{**}
R _{max}	-0.26	-0.38	0.03	0.24	0.33	0.39	-0.51 [*]	-0.42	-0.34	-0.41
R _{max} /E	-0.09	-0.29	-0.12	0.03	0.35	0.56 [*]	-0.53 [*]	-0.51 [*]	-0.57 [*]	-0.56 [*]
Peak time	-0.25	-0.56 [*]	-0.07	-0.33	-0.13	-0.06	0.05	0.38	-0.24	0.14
Optimum cooking time	0.26	-0.17	-0.39	-0.13	-0.46 [*]	-0.24	0.50 [*]	0.39	0.15	0.72 ^{***}
Actual Cooked weight	0.00	-0.09	-0.05	0.37	-0.03	0.52 [*]	-0.43	-0.50 [*]	-0.03	0.10
Residue	-0.63 ^{**}	-0.41	0.48 [*]	0.10	-0.56 [*]	0.04	0.19	0.39	0.10	0.27
Firmness	0.34	0.17	-0.28	-0.44	-0.15	-0.53 [*]	0.66 ^{**}	0.62 ^{**}	0.13	0.48 [*]
Breaking force	-0.16	0.38	0.44	-0.13	-0.15	-0.64 ^{**}	0.65 ^{**}	0.52 [*]	0.39	0.18
checks	0.21	0.33	-0.03	0.11	0.68 ^{**}	-0.02	-0.16	-0.51 [*]	-0.12	-0.24
Colour	-0.27	-0.18	0.19	0.00	0.19	-0.62 ^{**}	0.19	0.27	0.19	-0.12

Table-6.8. Correlations between semolina physical characteristics, dough rheology and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

No 30, No 40, No 60, No 80, and No 100: represent the percent of flour remaining on the top of the following sieves 549, 420, 250, 178, and 149 μm

6.4.7. Effect of semolina chemical characteristics on dough rheology and pasta cooking quality:

It is of interest to notice that increased protein content of the semolina was linked to increase pasta firmness and reduce cooking loss. Work conducted by Grzybowski and Donnelly (1979) also illustrated that pasta cooking loss and firmness were correlated with protein content and gluten strength. This is likely to be associated with the increase observed in optimum-cooking time of pasta made from high protein semolina (Table-6.9).

Both wet and dry gluten content were positively correlated to optimum-cooking time ($r = 0.64$ and 0.57 respectively), with wet gluten content of the pasta being highly correlated to cooked pasta firmness ($r = 0.90$). The relationship between protein (gluten) content and pasta textural and cooking properties is associated with the ability of the protein within the pasta to form a tenacious dough structure during mixing, and a firm visco-elastic matrix on cooking. This can be observed in the positive correlations between both wet and dry gluten contents and extensibility of the doughs produced in the extensograph ($r = 0.65$, and 0.52 respectively), and the negative correlations of protein content and gluten content to dough resistance to extension.

The importance of protein in dough and pasta quality has been studied extensively (Matsuo *et al.*, 1972; Dexter and Matsuo 1977c; Grzybowski and Donnelly 1979; Dexter and Matsuo 1980; Autran and Galterio 1989; D'Egidio *et al.*, 1990; Novaro *et al.*, 1993; Sharma *et al.*, 2002; Edwards *et al.*, 2003). Both protein content and gluten composition have been linked to the viscoelastic nature of pasta (Dexter and Matsuo 1978a, 1980; Kovacs *et al.*, 1995; Edwards *et al.*, 2003). Research by Kovacs *et al.*,

(1995) demonstrated that the mixograph mixing characteristics of durum wheat semolina could be correlated to the viscoelastic nature of cooked pasta, and that these parameters could be correlated to the gluten content (wet and dry) of the semolina rather than the viscoelastic behaviour of the semolina doughs. More recently, genetical analyses have revealed the importance of Glu-A and Glu-B loci on protein content and gluten strength of durum wheats (Martinez *et al.*, 2004). Our results support these observations that the gluten composition of the semolina is of more importance than overall protein content. However, it must be emphasised that the protein level of the semolina samples reported in this investigation was relatively low. As such, one could speculate that when protein content of the semolina is low the importance of gluten strength (composition) becomes much more important. Further analysis is required to determine the basis behind these observations.

	Moisture	Ash	Protein	Wet gluten	Dry gluten
Water absorption	0.03	-0.22	0.42	-0.08	-0.08
Development time	-0.20	-0.06	0.52 [*]	0.47 [*]	0.44
Stability	0.45	0.18	0.27	0.32	0.34
E	-0.20	-0.12	0.28	0.65 ^{**}	0.52 [*]
R_{max}	0.04	0.62 ^{**}	-0.63 ^{**}	-0.31	-0.55 [*]
R_{max}/E	0.08	0.57 [*]	-0.61 ^{**}	-0.44	-0.63 ^{**}
Peak time	-0.57 [*]	-0.15	0.02	0.34	-0.09
Optimum cooking time	-0.37	-0.68 ^{**}	0.83 ^{***}	0.64 ^{**}	0.57 [*]
Actual Cooked weight	0.47 [*]	0.28	-0.18	-0.64 ^{**}	-0.23
Residue	-0.39	-0.10	-0.31	-0.10	-0.52 [*]
Firmness	-0.33	-0.41	0.72 ^{***}	0.90 ^{***}	0.78 ^{***}
Breaking force	0.04	-0.35	0.27	0.37	0.32
checks	0.93 ^{***}	0.42	0.03	-0.20	0.28
Colour	-0.36	-0.39	0.15	0.53 [*]	0.17

Table-6.9. Correlations between semolina chemical characteristics, dough rheology and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

6.4.8. Effect of dough rheological properties on pasta cooking quality:

Assessment of the relationships between dough and pasta-handling characteristics and pasta quality illustrate that the viscoelastic nature of the semolina dough is of great importance. Thus, higher extensibility readings were associated with increased pasta firmness and optimum-cooking time (Table-6.10). The resistance to extension may also be a useful parameter to determine in relation to cooking quality, with negative correlations being observed between dough resistance and optimum-cooking time ($r = -0.64$) and pasta firmness ($r = -0.43$). These correlations are likely to be due to the contribution of gluten to the behaviour of the semolina doughs.

Dough development time exhibited significant correlations with both pasta optimum time and cooked pasta firmness ($r = 0.69$ and 0.63 respectively), which support Matsuo *et al.*, (1982a) suggestion that farinograph results at low water absorption (30%) could impart a useful indication of dough characteristics during extrusion, while measurements obtained at high water absorption (52-65%) could be useful to predict pasta cooking quality. All tested semolina samples showed high water absorption values. However, the lack of significant correlation between water dough absorption and stability and the pasta cooking properties is an unexpected finding, but may be related to the low protein content of the semolina.

	Water absorption	Development time	Stability	E	R _{max}	R _{max} /E	Peak time
Optimum cooking time	0.47	0.69 ^{***}	0.10	0.36	-0.64 ^{**}	-0.65 ^{**}	0.31
Actual Cooked weight	0.44	-0.26	-0.24	-0.18	-0.09	-0.07	-0.71 ^{***}
Residue	0.18	0.10	-0.18	0.18	0.17	0.10	0.43
Firmness	-0.16	0.63 ^{**}	0.13	0.47 [*]	-0.43	-0.48 [*]	0.42
Breaking force	-0.27	0.00	0.06	0.27	-0.59 ^{**}	-0.62 ^{**}	0.02
Checks	-0.17	-0.27	0.45	-0.22	-0.20	-0.13	-0.55 [*]
Colour	-0.38	0.18	0.51 [*]	0.15	-0.03	-0.04	0.70 ^{***}

Table-6.10. Correlations between dough rheological properties and pasta cooking quality of 9 selected durum wheat cultivars (n = 27).

6.5. CONCLUSION:

The correlations, which have been detected in this chapter, revealed the continuous importance of some of the physicochemical characteristics of durum wheat cultivars on pasta processing and end-product quality. Durum wheat protein (gluten) content, kernel hardness and also the degree of vitreousness were important in relation to the optimum-cooking time of the pasta and the firmness of the pasta produced. These relationships are likely to be associated with the binding ability of protein with the other wheat components to form a strong viscoelastic protein matrix during dough formation. Such associations will provide useful traits for future developments in the Syrian durum wheat breeding programmes.

The use of various assessment equipment illustrates that both extensograph and farinograph analysis can be used to evaluate the water absorption behaviour of semolina dough and hence the cooking time and firmness of pasta. Furthermore, results of the peak and final viscosity determination of durum wheat flour indicate that the RVA could be a useful tool in relating the kernel and semolina composition to potential pasta quality of durum wheat cultivars.

Previous research has demonstrated that high-drying temperature have a positive effect on pasta quality, by increasing firmness, and decreasing stickiness and cooking loss (Matsuo *et al.*, 1982a; D'Egidio *et al.*, 1990; Grant *et al.*, 1993; Malcolmson *et al.*, 1993; Novaro *et al.*, 1993; Zweifel 2001; Zweifel *et al.*, 2003). Thus, a relationship was expected to have occurred between the pasta-drying temperature and quality. More thoroughly, a further study needs to be undertaken to investigate this relationship.

Chapter 7

7. The effect of environmental conditions on the physiochemical properties of durum wheat cultivars:

7.1. INTRODUCTION:

There are several reports in the literature which suggest that environmental conditions, inherited genotypic properties, and their interaction exhibit significant influences on the physiochemical properties of wheat kernels which in turn affect the milling potential of wheat grains and end-use product characteristics (Borghi *et al.*, 1982; Sinclair *et al.*, 1993; Mariani *et al.*, 1995; Dexter and Edwards 1998a; 1998b). However, such results are not fully defined and require further verification.

In Syria, durum wheat is grown in areas which often differ significantly in their agricultural environments and there is no evidence in the literature concerning the effects of such environmental variation on the quality of durum wheat. A comprehensive study of environmental interactions was beyond the scope of this investigation but in this section, samples of five different Syrian durum wheat cultivars grown under varying environmental conditions were studied. Two of these cultivars were grown under irrigated conditions whilst two others were grown under rainfed conditions in five different locations, but only two sites were shared between the two sets of samples. The third cultivar (Sham-1) was grown alongside the samples in all eight locations as a control.

The physiochemical characteristics were determined with the intention of presenting an indication of the effect of the different environmental conditions in Syria on these characteristics.

The limitation of this study was mainly related to the availability of the varieties, where it was difficult to obtain the nine durum wheat varieties, studied in the previous chapters, at all the different locations and under different treatments. Consequently, the results achieved from this study do not present a comprehensive understanding of the effect of environment, genotype and their interaction on the Syrian durum wheat quality but are presented here to provide an indication of the level of Genotype \times Environment ($G \times E$) effects.

See Materials and Methods chapter for full details.

7.2. AIMS:

As the most important traits influencing the Syrian durum wheat quality have been identified in the previous chapters of this thesis, the aim of this study was to determine the stability and variability of kernel physiochemical characteristics across the major growing zones in Syria and under different agricultural practices.

7.3. OBJECTIVES:

1. Determine the physical characteristics of the selected cultivars, such as test weight, 1000 kernel weight, and the degree of vitreousness.

2. Determine the chemical properties of the selected cultivars, such as protein content, starch content, amylose content.
3. Determine the pasting properties of starch using the RVA technique.
4. Study the level of variance in the physiochemical properties through the various environmental conditions in Syria as following:
 - a. Determine the effect of the interaction site \times irrigation on the physiochemical properties of the variety Sham-1 at two different sites (Khan-Shehon/ Edleb and Homs/ Homs) and under two treatments (rainfed and irrigation).
 - b. Determine the effect of the interaction cultivar \times site on the physiochemical properties of three cultivars (Sham-1, Sham-3, and Douma-18861) at five different locations (Tal-Sandal/ Edleb, Almalkia/ Al-Hassakah, Khan-Shehon/ Edleb, Yahmol/ Aleppo, and Homs/ Homs) under rainfed conditions.
 - c. Determine the effect of the interaction cultivar \times site on the physiochemical properties of three cultivars (Sham-1, Bohouth-5, and Douma-29019) at five different locations (Amer/ Al-Hassakah, Saalo/ Deir Ezzor, Abou-Rassen/ Al-Raqqqa, Khan-Shehon/ Edleb, and Homs/ Homs) under irrigated conditions.

In determining the relative importance of the main effects and the interactions investigated here, both the significance (F test) and the distribution of variance in the ANOVA (as a %) were used to give an estimate of the importance of the various components.

7.4. RESULTS AND DISCUSSION:

The physical and chemical characteristics of the selected cultivars differed both with site and under two different treatments (irrigation and rainfed) as shown in Fig.7.1. The irrigation treatment significantly influenced the weight and soundness of the grains with positive effects on test weight and 1000 kernel weight of the control cultivar Sham-1 at the two shared locations. However, this was accompanied with a significant reduction in both protein content and the degree of vitreousness, and this finding is supported in the literature (Halverson and Zeleny 1988; Blumenthal *et al.*, 1993; Borghi *et al.*, 1995; Corbellini *et al.*, 1997; 1998). Comparing the measured quality traits with the Canadian grade 1 durum wheat characteristics revealed that all the selected cultivars exhibited lower protein content than the target of 16%. In contrast, the rainfed cultivars showed an elevated degree of vitreousness more than 80%, the minimum requirement of the Canadian grade 1. The effect of environment and genotype interaction was significant on 1000 kernel weight, the degree of vitreousness and amylose content of the irrigated cultivars, while it exhibited a significant effect on only the degree of vitreousness and amylose content of the rainfed cultivars.

It was shown in the previous chapter that test weight had a non-significant effect on semolina yield and pasta quality. However, test weight is still an important quality trait used in kernel grading systems. It has been suggested that test weight is a cultivar and site based characteristic (Stenvert and Moss 1974; Hook 1984). Test weight for the selected samples ranged between 73.20-86.30 kg hl⁻¹ for the irrigated samples but was much narrower between 76.85-82.90 kg hl⁻¹ for the samples grown under rainfed conditions. Although the control cultivar Sham-1 did not reveal a statistically significant difference in test weight between the two studied sites under the two treatments,

irrigation did affect test weight and accounted for 50% of the variation in the ANOVA, and samples grown under irrigated condition showed significant increased in test weight compared with the rainfed samples in each site. However, the interaction (site \times irrigation) had no significant effect on test weight of Sham-1 (Table-7.1). When the other varieties were included in the analysis, the test weights of the cultivars Sham-1, Bohouth-5, and Douma-29019 under five different irrigated locations varied among the cultivars across the different sites, but their interaction (cultivar \times site), did not have a significant effect on test weight. As with the cultivar Sham-1, the effect of the site factor was much greater than the effect of the cultivar factor accounting for 75% of the ANOVA variation compared with 19% for the cultivar factor (Table-7.2), and all the tested samples exhibited elevated test weight in site 5 (Homs) compared with the rest. The cultivars Sham-1, Sham-3, and Douma-18861 grown at the five different rainfed locations followed the same trends, yet the percentage of the variation due to site sources was approximately similar to that of cultivar sources (48 and 40% respectively) as shown in Table-7.3., and site 5 remained the best site.

In contrast, 1000 kernel weight, as an indicator of grain weight and density, showed more variation than did test weight, where, as can be seen in Table-7.1., the cultivar Sham-1 significantly varied in 1000 kernel weight between the two selected sites as well as between the two treatments, although the variation in treatment sources was responsible for approximately twice the ANOVA variation than site sources (66 and 30% respectively). As with test weight, the site \times irrigation interaction had no significant effect on 1000 kernel weight. Mean of 1000 kernel weights of the irrigated samples in the tested sites ranged between 29.04-59.72 g, and exhibited highly significant variations among site differences with site 1 having very low kernel weights. It was of interest to find that the interaction of the cultivar and site exhibited a

significant effect on 1000 kernel weight of the irrigated samples but it was only responsible for 7% of the total ANOVA variation (Table-7.2). With the rainfed samples, it can be seen in Table-7.3. that these samples showed similar results to the irrigated samples apart from the non-significant effect of cultivar \times site interaction with a much narrower range of means between 30.32-51.20 g. Final grain size is frequently affected by drought during grain-filling stage (Halverson and Zeleny 1988; Blumenthal *et al.*, 1993; Borghi *et al.*, 1995; Corbellini *et al.*, 1997; 1998) and was expected to be lower under rainfed conditions, and this was upheld in these results.

The degree of vitreousness is considered a very important quality trait in grading durum wheat both in published Canadian and American systems and this was upheld for Syrian durum wheat cultivars, as shown in the previous chapters. In this investigation, cultivar, site, and their interaction showed a high level of influence on the degree of vitreousness under both irrigated and rainfed conditions with the site differences being slightly more important than cultivar sources, and their interaction being the factor with the lowest importance (42, 51, and 7% of ANOVA variation for cultivar, site and their interaction respectively) in the irrigated sites (Table-7.2) compared with 30, 47, and 23% respectively in the rainfed sites (Table-7.3). In contrast, studying the consequence of irrigation practice on the degree of vitreousness through the cultivar Sham-1 revealed the very high influence of irrigation on this trait, where irrigation accounted for 97% of the total variance comparing with 1% for site and 1% for the interaction site and irrigation (Table-7.1). These findings supported the earlier work demonstrating that the degree of vitreousness is highly influenced by the environmental conditions (Parish and Halse 1968; Hoseney 1986; Pomeranz and Williams 1990). The degree of vitreousness for the cultivars at the different locations ranged between 37-100% in the irrigated areas and between 64-100% in the rainfed areas and overall irrigation reduced vitreousness.

Protein content showed statistically non-significant differences among the three chosen cultivars grown in each irrigated location, where the variations in protein content were primarily due to the differences among the five selected sites with 83% out of the total variation (Table-7.2) and protein content ranged between 10.70-15.30%. In contrast, cultivars grown in the rainfed areas did exhibit a significant variation among each other at each site and among the different sites. Nevertheless, the main variation was due to the site sources (71%) comparing with the cultivars (22%) as shown in Table-7.3. The mean protein contents for the rainfed cultivars ranged between 9.90-15.30%. The interaction of cultivar and site did not show an effect on protein content neither at the irrigated sites nor in the rainfed sites. Furthermore, although protein content of the cultivar Sham-1 did not vary between the two sites under each treatment, irrigation treatment showed a highly significant effect when comparing the figures across each site and accounted for 66% of the total ANOVA variation. However, the interaction of irrigation and site was responsible for 12 % of the total variation in protein content of the cultivar Sham-1 with no significant effect (Table-7.1). Previous research on the effect of environment and genotype on wheat protein content showed that protein content was influenced by the genotype but that environmental factors, such as nitrogen fertilization, water and temperature, could exhibit a large influence (Sosulski *et al.*, 1963; Benzian *et al.*, 1983; Baenziger *et al.*, 1985; Peterson *et al.*, 1986; Stapper and Fischer 1990; Lukow and McVetty 1991; McDonald 1992; Rao *et al.*, 1993; Mariani *et al.*, 1995; Graybosch *et al.*, 1996; Zhu and Khan 2001; Labuschagne *et al.*, 2006; Lerner *et al.*, 2006; Rogers *et al.*, 2006). The lack of variation between the Syrian cultivars in protein content through the irrigated sites could be interpreted due to either the limited number of selected cultivars or to an over-ridingly high influence of genotype on protein content.

Very few studies have been conducted to investigate the effect of environment and genotype on starch quality and quantity of durum wheat. It has however been shown that increased temperature during the grain filling stage caused changes in starch particle size distribution, where an increase in A-starch granules (large granules) was detected (Blumenthal *et al.*, 1994), without any modifications in starch chemical composition. Consequently, water absorption of wheat flour has been found to be affected by these changes in starch distribution and hence dough mixing properties (Pomeranz 1988; Stone and Nicolas 1994). In the current investigation, site, irrigation, cultivar and site \times irrigation interaction, all influenced starch content. Consequently, these findings illustrate that starch content of durum wheat is affected by environment and genotype variations but not by their interaction. Site variation of the irrigated conditions was responsible for 61% of the total ANOVA variation (Table-7.2) compared with 34% in the rainfed conditions (Table-7.3). In contrast, irrigated cultivar variations had no significant effect on starch content, while rainfed cultivar variations did significantly affect starch content with 58% of the total variation. The interaction (cultivar \times site) did not affect starch content in either situation. Investigating the effect of site, irrigation and their interaction on starch content of Sham-1 revealed that all these sources demonstrated significant effects on starch content (41%, 35%, and 22% of ANOVA variation respectively) as seen in Table-7.1. Mean starch contents ranged between 52.29-61.21% for the irrigated cultivars, and between 51.34-64.27% for the rainfed cultivars.

Amylose content, the linear constituent of wheat starch, has been found to be positively controlled by the presence of waxy protein (Yamamori *et al.*, 1992; Nakamura *et al.*, 1993; Yamamori and Quynh 2000), however, environment has been shown to have an influence on amylose content of starch (Sasaki *et al.*, 2002). Here the mean amylose

contents of the selected cultivars were more affected by genotypes than environment, where highly significant variations under the effects of cultivar, site and their interaction occurred. The main effect was due to cultivar variation followed by the effect of the site variation. For instance, amylose content for the three durum wheat cultivars grown in the irrigated areas ranged between 24.80-30.89% and cultivar sources accounted for 63% of the total variation, while 28% of the variation was due to the site sources (Table-7.2). Following approximately the same trend, rainfed cultivars exhibited mean amylose contents between 24.50-27.99% with 66% and 19% of the total variation was due to cultivar and site sources respectively (Table-7.3). On the other hand, the irrigation practice did not display an effect on amylose content of the cultivar Sham-1, while its interaction with site source did highly and significantly vary with 53% variation compared with 45% variation due to the site effect (Table-7.1).

Irrigated

Rainfed

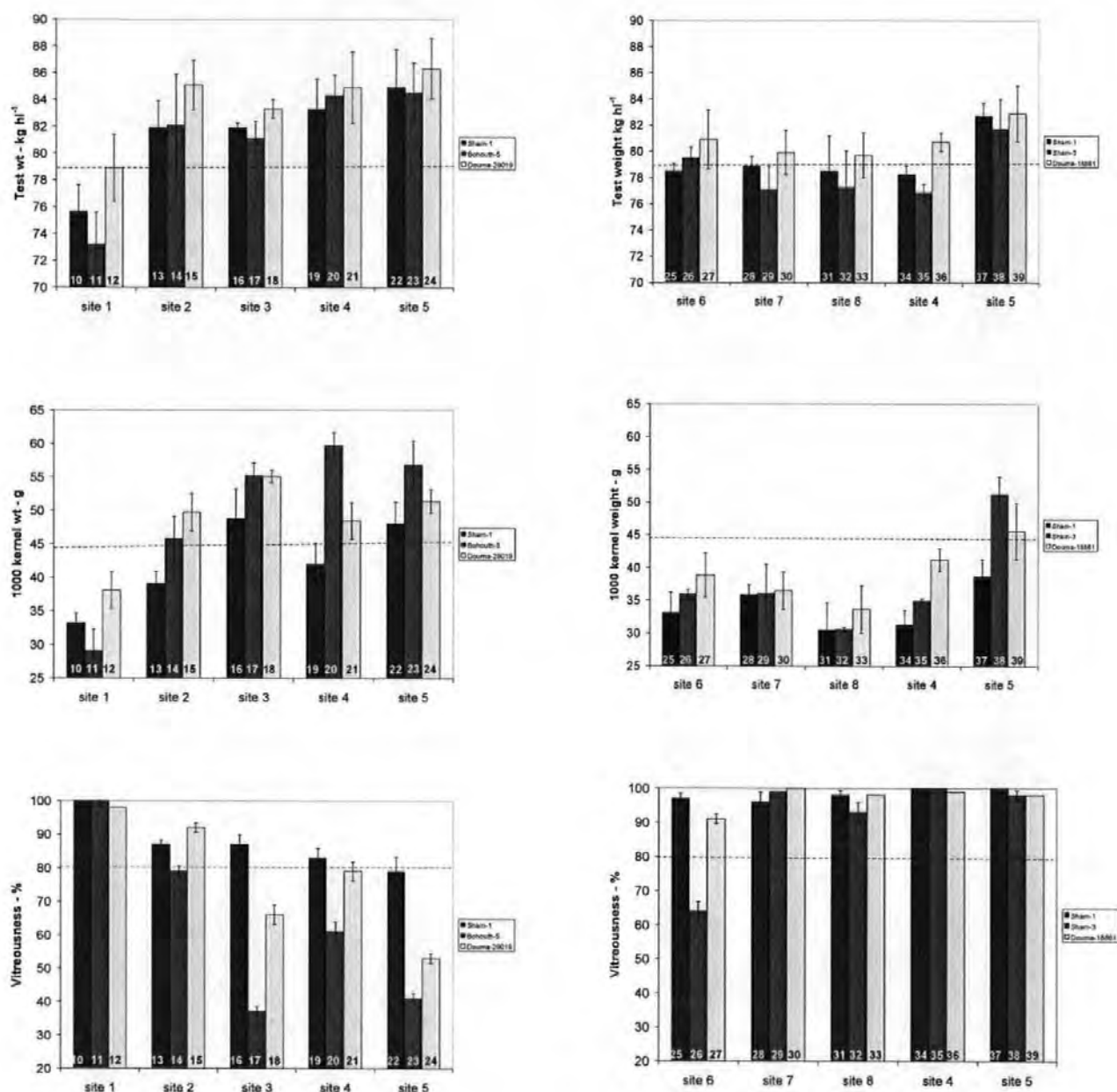
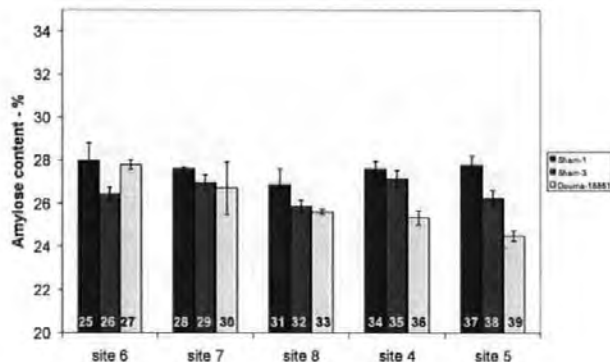
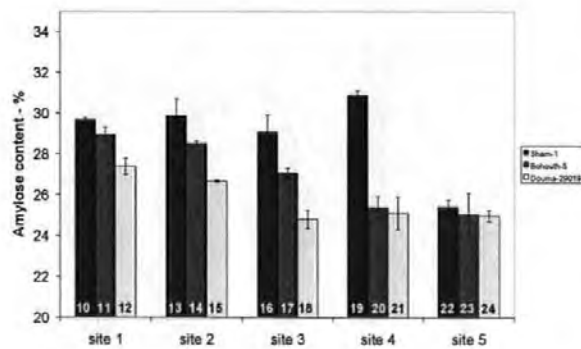
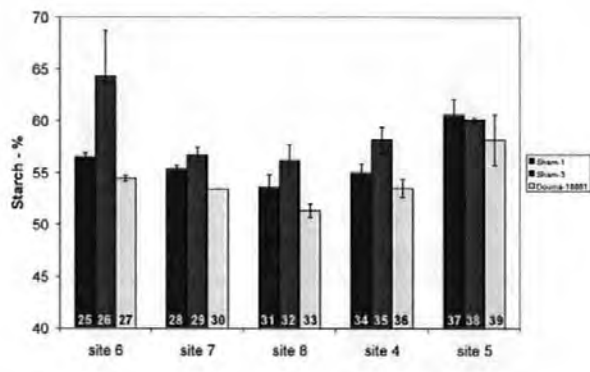
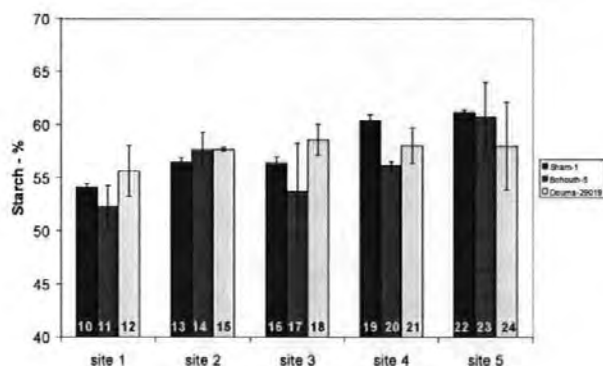
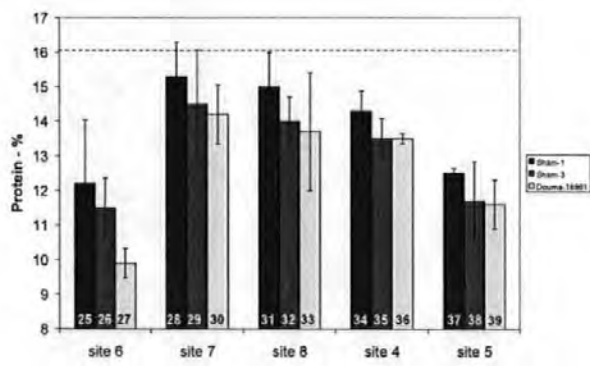
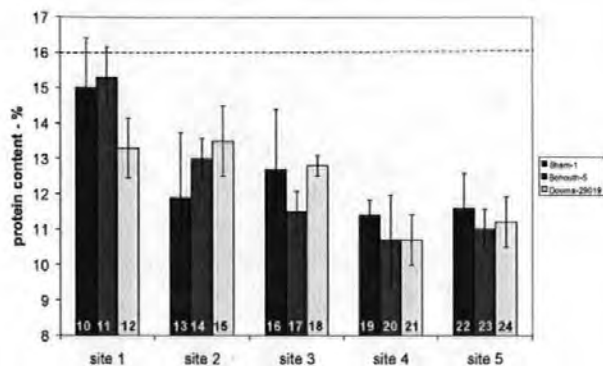


Fig.7.1. Interaction diagrams of physico-chemical characteristics of durum wheat grown under either rainfed or irrigated field condition at 5 sites (error bars are ± 1 SE).

Sample numbers are indicated in the graphs.

Fig.7.1. contd.



It is well accepted that starch content has a limited effect on pasta quality yet starch pasting properties exhibit a remarkable influence on pasta quality (Delcour *et al.*, 2000a; 2000b). Studying the effect of environmental conditions, presented by the effects of different growing sites, irrigation practice, site \times irrigation interaction, cultivars, and the interaction of cultivar and site, on starch pasting properties as measured by the Rapid Visco Analyser (RVA) revealed that the measured parameters, such as peak viscosity, trough, breakdown, and final viscosity, showed highly significant variations with varying sources. The degree of variation however varied according to the measured parameters as well as to the sources. In general, starch of the selected cultivar Sham-1 under irrigated conditions showed elevated pasting properties compared with the rainfed conditions, except for the breakdown viscosity. Variation in the site sources was equally as important as variation in irrigation sources in both peak and final viscosities (49 and 42% compared with 54 and 32% of variation in the ANOVA for peak and final viscosities respectively), the findings were similar for trough (41 and 55% for site and irrigation factors respectively), whilst for breakdown the effects of the sites were negligible (0% for site and 84 % for irrigation) (Table-7.1). Peak viscosity of the irrigated cultivars ranged between 37.33-75.88 RVAU and between 32.96-63.00 RVAU in the rainfed areas (Fig.7.2), and as mentioned earlier, peak viscosity significantly varied with changing cultivar, site and their interaction but this variation was not consistent between the two sets of samples. For example, site sources were the dominant factor effecting starch peak viscosity for the samples which underwent irrigation practices (42% of the total variation comparing with 29% for cultivar factor and 29% for site and cultivar interaction) (Table-7.2). In contrast, cultivar sources in the rainfed areas were responsible for 56% of the total variation with 40% for the site variations and only 4% for their interaction (Table-7.3). It has been demonstrated that starch pasting properties were mainly influenced by genotype (Dengate and Meredith

1984a; 1984b; Yun and Quail 1999). Consequently, the differences in the irrigated lands reported here could be initially interpreted to be due to the irrigation practice, but a further study is required to verify this conclusion. Trough or hot paste viscosity (HPV), which is inversely related to the amount of released starch, followed the same trends as peak viscosity and ranged between 33.71-71.67 RVAU and 28.96-58.29 RVAU for the irrigated and rainfed cultivars respectively. Site, cultivar, and their interaction accounted for the following percentage of variation 56%, 10% and 33% respectively for the irrigated lands (Table-7.2) compared with 40%, 55% and 5% respectively for the rainfed lands (Table-7.3). Breakdown is calculated as the difference between peak viscosity and trough, and it is negatively correlated with trough, where high breakdown, associated with low trough, indicates more damaged starch granules and hence more solubilized starch. Breakdown of the studied cultivars, which ranged between 1.17-14.92 RVAU for the irrigated samples and between 2.50-6.00 RVAU for the rainfed samples, showed the expected inverse results compared with peak viscosity and trough. Variations were mostly affected by cultivar (63%) more than site (15%) in the irrigated lands, and 22% for their interaction (Table-7.2). In contrast, site was more responsible for the variation in the rainfed sites than cultivar (17% and 58% respectively), with 22% for their interaction (Table-7.3). Final viscosity, which occurs due to the reassociation of solubilized starch upon cooling, showed the same trends as peak viscosity and trough. Means ranged between 75.79-155.21 RVAU, and between 76.08-144.21 RVAU for the irrigated and rainfed cultivars respectively. Cultivar, site and their interaction factors were responsible for the following percentage of variation in final viscosity, 24, 50, and 26% respectively in the irrigated areas (Table-7.2), and 48, 48, and 3% respectively in the rainfed areas (Table-7.3).

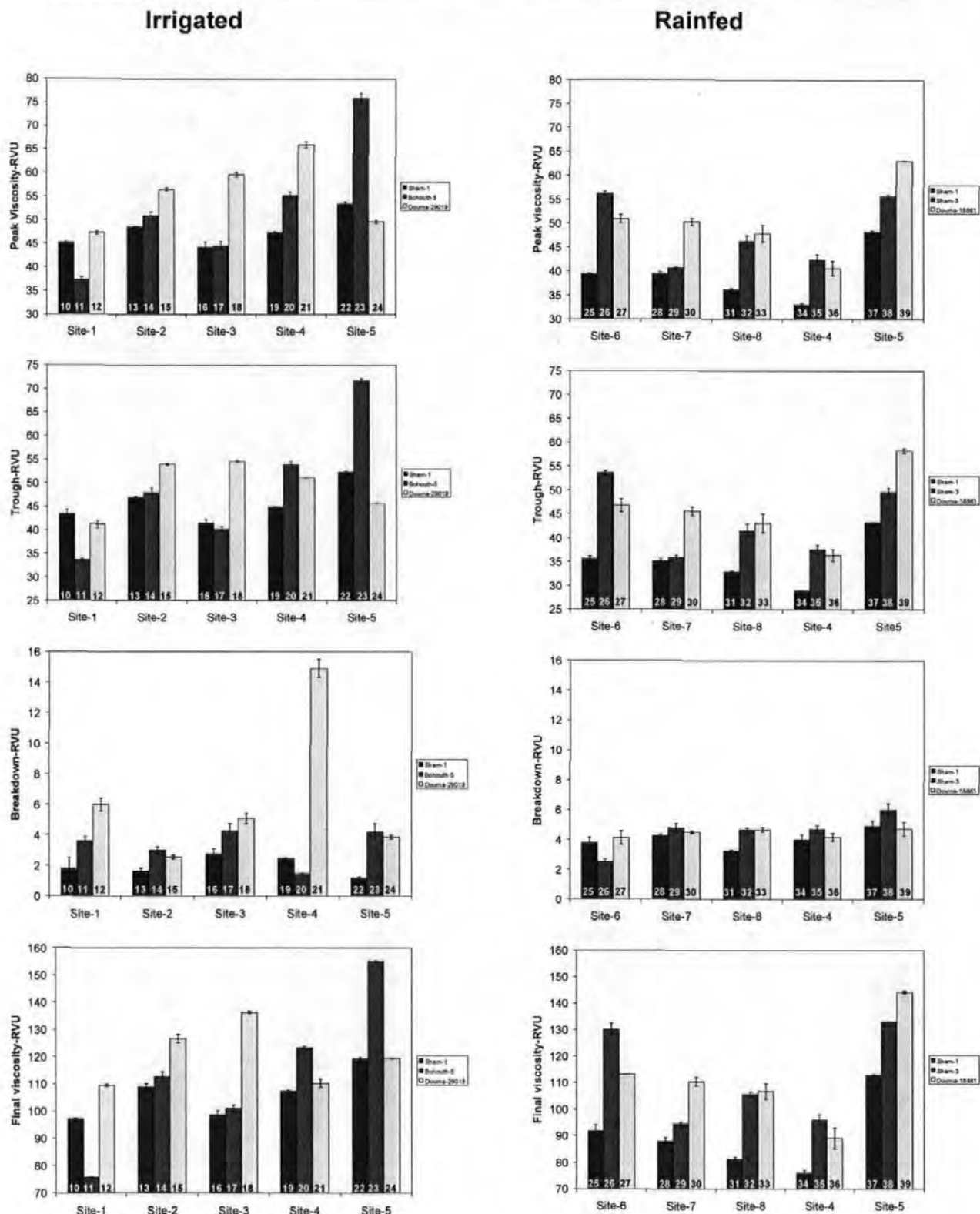


Fig.7.2. Interaction diagrams of starch pasting properties of durum wheat grown under either rainfed or irrigated field condition at 5 sites (error bars are +/- 1 SE).

Sample numbers are indicated in the graphs.

Source	DF	MS	% variance	F	P
TW					
Site	1	18.30	35	5.33	NS
Irrigation	1	26.28	50	7.66	0.050
Site × irrigation	1	4.06	8	1.18	NS
TKW					
Site	1	90.05	30	8.07	0.047
Irrigation	1	199.60	66	17.90	0.013
Site × irrigation	1	0.90	0	0.08	NS
Vitreousness					
Site	1	8.00	1	1.23	NS
Irrigation	1	722.00	97	111.08	0.000
Site × irrigation	1	8.00	1	1.23	NS
Protein					
Site	1	1.28	12	3.41	NS
Irrigation	1	7.22	66	19.25	0.012
Site × irrigation	1	2.00	18	5.33	NS
Starch					
Site	1	20.71	41	24.61	0.008
Irrigation	1	18.09	35	21.50	0.01
Site × irrigation	1	11.40	22	13.55	0.021
Amylose					
Site	1	13.94	45	121.61	0.000
Irrigation	1	0.40	1	3.46	NS
Site × irrigation	1	16.19	53	141.23	0.000
PV					
Site	1	226.63	49	1496.66	0.000
Irrigation	1	194.04	42	1281.46	0.000
Site × irrigation	1	41.68	9	275.24	0.000
Tr					
Site	1	234.69	41	3309.52	0.000
Irrigation	1	312.38	55	4405.08	0.000
Site × irrigation	1	23.91	4	337.16	0.000
BD					
Site	1	0.07	0	1.13	NS
Irrigation	1	13.99	84	219.57	0.000
Site × irrigation	1	2.44	15	38.32	0.003
FV					
Site	1	1182.44	54	2129.27	0.000
Irrigation	1	701.63	32	1263.45	0.000
Site × irrigation	1	315.76	14	568.60	0.000

Table-7.1. Analysis of variance on grain physiochemical characteristics for the cultivar Sham-1 under two sites and two treatments, irrigation and rainfed, and their interaction.

DF: degree of freedom, MS: mean square, F: variance ratio, TW, test weight, TKW: 1000-kernel weight, PV: peak viscosity, Tr: trough, BD: breakdown, FV: final viscosity, P: probability at 5% level, NS: not significant.

Source	DF	MS	% variance	F	P
TW					
Cultivar	2	20.04	19	4.12	0.037
Site	4	79.79	75	16.41	0.000
Cultivar × Site	8	2.08	2	0.43	NS
TKW					
Cultivar	2	152.76	26	20.26	0.000
Site	4	389.97	66	51.73	0.000
Cultivar × Site	8	43.55	7	5.78	0.002
Vitreousness					
Cultivar	2	1408.53	42	293.44	0.000
Site	4	1715.53	51	357.40	0.000
Cultivar × Site	8	242.53	7	50.53	0.000
Protein					
Cultivar	2	0.16	1	0.16	NS
Site	4	12.22	83	11.93	0.000
Cultivar × Site	8	1.27	9	1.24	NS
Starch					
Cultivar	2	8.01	16	1.79	NS
Site	4	29.94	61	6.71	0.003
Cultivar × Site	8	6.41	13	1.44	NS
Amylose					
Cultivar	2	26.03	63	92.95	0.000
Site	4	11.72	28	41.84	0.000
Cultivar × Site	8	3.11	8	11.11	0.000
PV					
Cultivar	2	164.98	29	219.68	0.000
Site	4	239.16	42	318.44	0.000
Cultivar × Site	8	164.01	29	218.37	0.000
Tr					
Cultivar	2	43.11	10	74.89	0.000
Site	4	239.18	56	415.45	0.000
Cultivar × Site	8	142.32	33	247.21	0.000
BD					
Cultivar	2	53.98	63	200.57	0.000
Site	4	12.94	15	48.08	0.000
Cultivar × Site	8	19.17	22	71.21	0.000
FV					
Cultivar	2	500.72	24	249.44	0.000
Site	4	1044.56	50	520.36	0.000
Cultivar × Site	8	536.96	26	267.50	0.000

Table-7.2. Analysis of variance on grain physiochemical characteristics for the cultivar Sham-1, Bohouth-5, and Douma-29019 under five different sites and irrigated conditions, and their interaction.

Source	DF	MS	% variance	F	P
TW					
Cultivar	2	14.06	40	4.99	0.022
Site	4	16.85	48	5.98	0.004
Cultivar × Site	8	1.11	3	0.39	NS
TKW					
Cultivar	2	75.31	30	9.19	0.002
Site	4	149.51	59	18.24	0.000
Cultivar × Site	8	19.16	8	2.34	NS
Vitreousness					
Cultivar	2	161.20	30	75.56	0.000
Site	4	252.47	47	118.34	0.000
Cultivar × Site	8	121.37	23	56.89	0.000
Protein					
Cultivar	2	4.20	22	4.14	0.037
Site	4	13.71	71	13.51	0.000
Cultivar × Site	8	0.27	1	0.26	NS
Starch					
Cultivar	2	60.61	58	25.45	0.000
Site	4	35.76	34	15.02	0.000
Cultivar × Site	8	6.15	6	2.58	NS
Amylose					
Cultivar	2	6.49	66	25.52	0.000
Site	4	1.89	19	7.42	0.002
Cultivar × Site	8	1.15	12	4.54	0.006
PV					
Cultivar	2	353.01	56	248.89	0.000
Site	4	252.61	40	178.10	0.000
Cultivar × Site	8	25.27	4	17.82	0.000
Tr					
Cultivar	2	325.10	55	195.48	0.000
Site	4	236.38	40	142.13	0.000
Cultivar × Site	8	31.77	5	19.11	0.000
BD					
Cultivar	2	0.67	17	4.02	0.040
Site	4	2.34	58	13.95	0.000
Cultivar × Site	8	0.88	22	5.26	0.003
FV					
Cultivar	2	1653.83	48	259.74	0.000
Site	4	1645.78	48	258.48	0.000
Cultivar × Site	8	116.52	3	18.30	0.000

Table-7.3. Analysis of variance on grain physiochemical characteristics for the cultivar Sham-1, Sham-3, and Douma-18861 under five different sites and rainfed conditions, and their interaction.

7.5. CONCLUSION:

This study aimed at investigating the effects of different environmental factors in Syria and their interaction with locally adapted genotypes on the quality of Syrian durum wheat and their resultant flour.

Although there were only a limited number of cultivars studied, considerable variations occurred. It was shown that the interaction of environmental conditions (site \times irrigation) had little or no significant effect on the most important quality traits, such as test weight, 1000 kernel weight, the degree of vitreousness, and protein content, of the selected durum wheat cultivar Sham-1. These traits were revealed to be more influenced by the irrigation factor than the site factor, whilst site variations were more significant in affecting starch chemical composition.

Despite the limitations of the data and analysis under both irrigated and rainfed conditions the importance of the interaction of cultivar \times site on the degree of vitreousness, amylose content and starch pasting properties was illustrated. Moreover, kernel quality traits, such as test weight, 1000 kernel weight, the degree of vitreousness and protein content, showed a higher significant influence of the selected locations, in both irrigated and rainfed lands, than either the cultivar or site \times cultivar interaction factors, which verifies the importance of location in durum wheat farming in Syria.

Starch quantity, chemical composition, and pasting properties were mainly influenced by the cultivar factor, taking into account the rainfed treatment as a standard practice, which supported previous findings. However, the different results exhibited by starch pasting properties in the irrigated lands, where the site factor was higher in effect than

the cultivar factor, could be initially interpreted as being due to the impact of the use of irrigation, but a further study is required to verify this assumption.

It has been reported that 70% of cereal production in Syria is under irrigated conditions due to the limited amounts of rainfall in the winter season (Oweis *et al.*, 1999).

Research elsewhere has illustrated that both protein content and the degree of vitreousness of durum wheat are highly influenced by environment particularly nitrogen fertilization and irrigation and with respect to irrigation this is upheld here.

Consequently, the agricultural practices of fertilization and irrigation should be taken into account when aiming for a quality crop (Bulman and Smith 1993; Webster and Jackson 1993; Ryan *et al.*, 1997).

This study was directed at studying some grain quality traits of the most commonly grown durum wheat cultivars in Syria. Accordingly, it is necessary to expand this work in order to include additional cultivars in additional locations to verify the findings reported here. Furthermore, a more detailed study is required to define the genetic basis of environmental sensitivity among the cultivars. With this information it would be possible to recommend varieties for specific locations or for specific farming practices. The work presented here also indicates that particular sites can be identified that consistently produce high quality crop samples. If this were to be maintained over time then crops from such sites could be kept separate and sold into the more exacting world market.

Chapter 8

8. General discussion:

Syria was ranked fourth in durum wheat production in the crop year 2002/ 2003, and remains in this position currently (Lennox 2003; Anon. 2005b) and plays an important role in the Syrian economy. The majority of this wheat however was used in the domestic market for the manufacture of Arabic bread, bulgur and pasta and only 21% of the production found its way to the external markets and these were mainly to near neighbours in the Middle East. The possibility of expanding the export of durum wheat to the local and world markets has been recently raised as an economic development issue for Syria with the potential to improve an important revenue stream (Anon 2005c).

As with any other products, exported durum wheat will have to meet the standard requirements of the world market but to date, the quality characteristics of Syrian durum wheat cultivars have not been systematically studied and defined. As a consequence of this situation, three critical objectives were defined and investigated in this study (Fig.8.1). These objectives were concerned firstly with the measurement of the overall quality of the dominant durum wheat cultivars in Syria in relation to the physiochemical composition of grain and milling potential and their influence on pasta cooking properties and the interrelationships among these variables. Secondly, once these quality parameters were determined, a comparison between the Syrian, Canadian and American durum wheat quality was necessary in order to map the Syrian durum wheat characteristics onto the world market requirements to define suitability and shortfalls. Thirdly, information was required on the variability of the quality traits identified across the major growing zones in Syria under different agricultural practices in order to determine the stability of the measured traits.

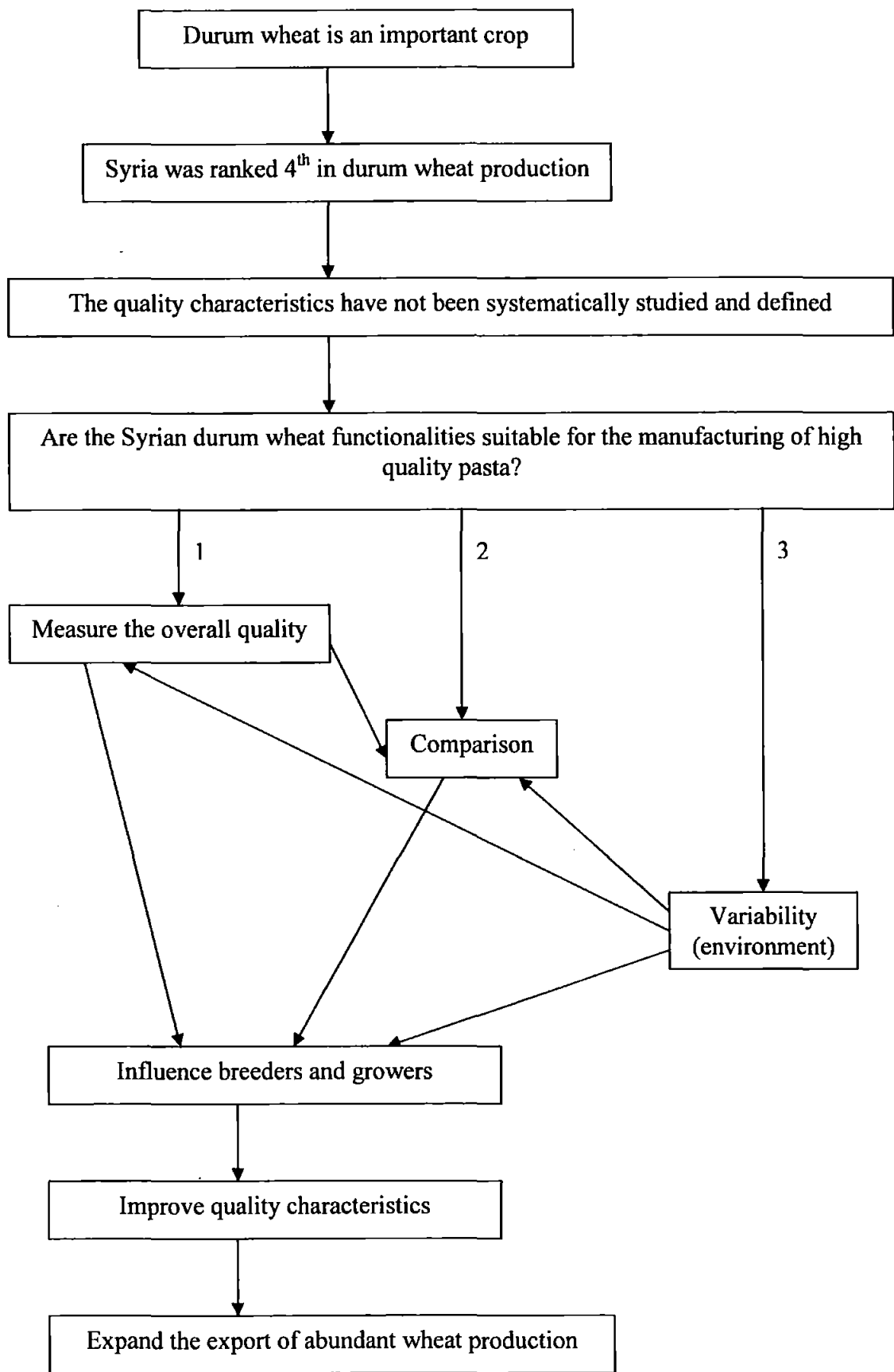


Fig.8.1. Reasons, aim and objectives of the study.

8.1. PHYSIOCHEMICAL CHARACTERISTICS:

The marketplace for all cereal products sold for human consumption involves a series of interlocking enterprises, for example:

Breeders & Seed Merchants -> Growers -> Grain Merchants -> Millers -> Pasta Processor -> Retailer -> Consumer

and at each enterprise interface quality parameters need to be defined, measured and assured in order to guarantee end-use quality. Many of the most important quality requirements of durum wheat, just like with bread wheat, are initially defined by the cultivars bred for the purpose but can be influenced by the agricultural environment in which they are grown. Furthermore, processors of grain and food manufacturers can influence the end-product to a certain degree by food technologies, for example, for bread wheat in the UK a shortfall in suitable gluten can be compensated for to a certain extent by the Chorleywood process and in pasta, a shortfall in gluten strength can be somewhat compensated for by high temperatures in processing (Zweifel *et al.*, 2003). Few food technology processes however are available for pasta, dictating an increased reliance on the final physicochemical characteristics of the grain ex-farm. Whilst this has been determined elsewhere in the world for durum wheats of local origin, this has never been determined before for durum wheat of Syrian origin. Consequently, examining the physiochemical composition of durum wheat grains is a very important primary practice in the assessment of overall durum wheat quality which is performed once the crop is harvested to determine its subsequent milling potential and end-use products quality. Common practice comprises a group of analyses have to be carried out, such as test weight, 1000 kernel weight, the degree of vitreousness, kernel hardness, falling number and protein content. In the investigation reported here the Syrian durum wheat cultivars exhibited high values for test weight, 1000 kernel weight

and falling number which reflects the soundness of grains and theoretically predicts high semolina extraction rate. Moreover, the Syrian cultivars exceeded both the Canadian and American grade No. 1 cultivars in these measured traits. In contrast however, the degree of vitreousness and protein content, which are considered crucial in determining durum wheat quality (Dexter *et al.*, 1994; Sissons *et al.*, 2000; 2005), fell below the required levels of the Canadian and the US standards. This suggests that such grain would produce pasta with inferior cooking properties and would downgrade the Syrian cultivars and restrict them from competing in the world durum wheat markets. A direct comparison of USA or Canadian grade 1 samples with Syrian grade 1 samples on end-product quality was not undertaken in this investigation and so it is not definitive that Syrian samples cannot make good world class pasta. In fact the domestic market is satisfied with the quality of the end-product with few reports of inferior quality product. It is acknowledged however, that even if Syrian quality was demonstrated to be satisfactory for the production of quality pasta, Syria would have little influence on changing the world market requirements in the short or medium term and therefore will be forced to pursue improved grain quality in order to break into these markets.

The importance of both protein content and the degree of vitreousness on milling potential and pasta cooking properties has been well documented (Dexter *et al.*, 1994; Sissons *et al.*, 2000) and consequently, it was very important to investigate whether these traits have the same fundamental roles on the Syrian durum wheat quality. Even though protein content is affected to a large extent by the environmental factors such as nitrogen fertilization, irrigation and temperature (Mariani *et al.*, 1995; Zhu and Khan 2001), increasing potential protein quantity is under genetic control (Cox *et al.*, 1985). In contrast, environmental factors during grain development would determine whether grains appear vitreous or starchy (Parish and Halse 1968; Hosene 1986; Pomeranz and

Williams 1990). The role that the degree of vitreousness imparts on the quality of the Syrian durum wheat kernels was therefore a key part of the current investigation (Fig.8.2). This study was performed by creating three simulated samples with different degrees of vitreousness for each of the selected cultivars; whole sample, the actual measured degree of vitreousness, a 100% vitreous sample which corresponded to the highest degree of vitreousness that could have been achieved and a 0% vitreous sample (starchy sample) composed of only completely starchy kernels representing the worst degree of vitreousness that could be attained. All samples were analysed for kernel hardness, protein content, and wet and dry gluten content. All vitreous fractions of each cultivar demonstrated the same trend regarding the measured traits, hardness, protein content, wet and dry gluten and amylose content, where higher values were recorded for the vitreous kernels comparing with the whole samples and starchy samples. These findings supported previous research (Stenvert and Kingswood 1977; Dexter *et al.*, 1988; Dexter *et al.*, 1989; El-Khayat *et al.*, 2003) and emphasised the important role of the degree of vitreousness in durum wheat quality.

Despite starch being the dominant component of wheat flour (Dick 1981), very limited research has been conducted to investigate the effect of starch quality and quantity on flour end-use properties whereas protein has received much more attention (Lin and Czuchajowski 1997). Subsequently, the effect of the degree of vitreousness on the quality characteristics was extended to incorporate starch content, amylose content, and starch thermal and pasting properties. This analysis was conducted in order to establish a preliminary study for understanding the consequence of starch properties on durum end-use product quality.

Results from this study indicated significant negative correlations between amylose content and both peak viscosity and breakdown for the three simulated samples of each

durum cultivar and corresponded with previous research (Dengate 1984; Crosboie 1991; Ming *et al.*, 1997; Sasaki *et al.*, 1998). Consequently, swelling and disruption of wheat starch granules was linked to the effect of amylose content, while retrogradation of starch was not an attribute of amylose content. This finding emphasised the importance of amylose content when evaluating the potential use of durum wheat cultivars. However, contrary to the findings of Fredriksson *et al.*, (1998), amylose content did not exhibit any effect on the thermal properties of starch. This could be interpreted to be due to the contribution of other flour components, such as protein and lipid, on the swelling and gelatinisation behaviour of starches as suggested by Tester and Morrison (1990a).

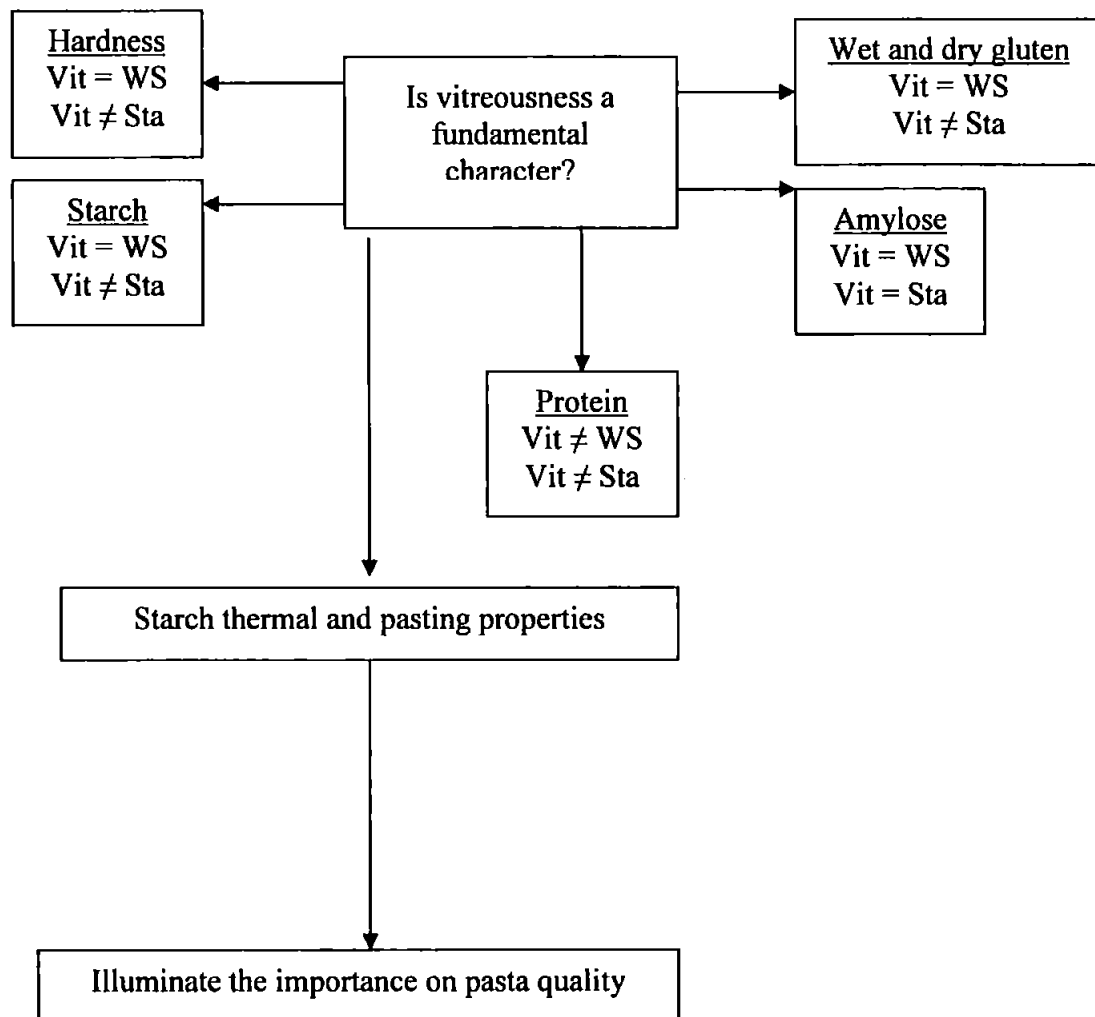


Fig.8.2. A summary of the findings of the importance of the degree of vitreousness on grain quality.

WS: whole sample, Vit: vitreous sample, Sta: starchy sample, =: not significant, ≠: significant.

Once the physical and chemical traits had been measured for the selected cultivars, it was important to determine the interrelationships among them to assist in identifying the linked traits which will help predict links to milling performance and pasta cooking properties.

The most substantial findings of this study were revealed to be the positive correlations between the degree of vitreousness, kernel hardness and total protein content. These supported published research which illustrated that vitreous kernels are harder and of higher protein content than starchy kernels (Stenvert and Kingswood 1977; Dexter *et al.*, 1988; Dexter *et al.*, 1989; Samson *et al.*, 2005), and hence substantiate the fundamental influential effects on the overall quality of the selected Syrian durum wheat grains. Because of the overriding importance of these traits revealed by this investigation the same samples were taken forward to investigate their effects on milling performance.

8.2. MILLING PERFORMANCE:

In durum wheat milling industry, the required objective is to acquire semolina with a high extraction rate (Troccoli *et al.*, 2000). The kernel physical characteristics, test weight, 1000 kernel weight, kernel hardness, and the degree of vitreousness, along with total protein content have been widely used to predict the milling potential of durum wheat, but again not systematically with Syrian cultivars.

Although a huge body of research has been conducted to investigate the effect of both test weight and 1000 kernel weight on semolina yield (Mangels 1960; Shuey 1960; Johnson and Hartsing 1963; Barker *et al.*, 1965; Barmore and Bequette 1965; Finny and Yamazaki 1967; Shuey and Gilles 1972; Watson *et al.*, 1977a; 1977b; Matsuo and

Dexter 1980a; Matsuo *et al.*, 1982a; Hook 1984; Dexter *et al.*, 1987), results remain contradictory. The findings of the current investigation revealed that test weight and 1000 kernel weight exhibited no effect on semolina yield of the selected cultivars which was in agreement with Hook (1984) but in contradiction to Matsuo and Dexter (1980a) Marshall *et al.*, (1986), Dexter *et al.*, (1987) and Halverson and Zeleny (1988). The lack of significant correlations could be related to the lack of variation among the cultivars for these traits since the samples did not have a wide range and were all considered to be “good” quality samples. This can frequently happen with correlation analysis, where an overall trend for a large set of variable samples does not hold true when used to compare a set of samples clustered at one end of the scale (the “good” end as in this example).

The kernel hardness, the degree of vitreousness, and total protein content did however demonstrate positive significant correlations with both semolina yield and semolina protein content (Fig.8.3). These findings further substantiated the importance of these traits. Hence protein content, kernel hardness and the degree of vitreousness are more valuable indicators of quality than test weight and kernel weight in relation to milling potential of Syrian durum wheat cultivars.

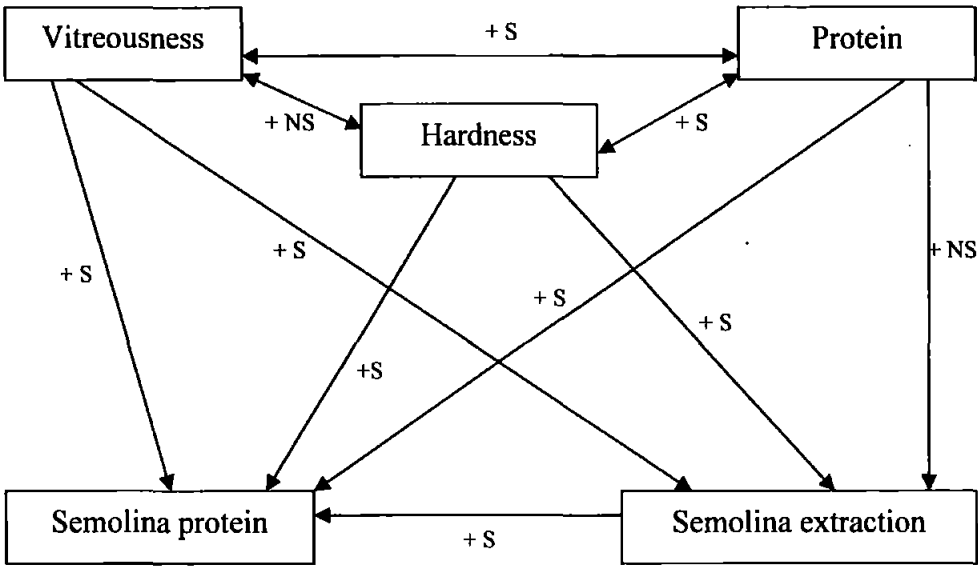


Fig.8.3. Summary of the relationships (correlation) between the physiochemical composition and milling potential.

S = significant, NS = non-significant.

8.3. PASTA COOKING PROPERTIES:

The cooking properties of pasta are definably the determinable factors of the quality of a durum wheat cultivar, and has been the focus of an extensive body of published research (e.g. see Dexter and Matsuo, 1980; Dexter *et al.*, 1983, 1987; D'Egidio *et al.*, 1990; Dexter *et al.*, 1994; Kovacs *et al.*, 1995; Ames *et al.*, 1999; Manthey and Schorno, 2002). It was very important therefore to investigate the cooking properties of the selected cultivars and determine the factors that were most responsible for variations in these properties.

Throughout this investigation, the continuous importance of the degree of vitreousness, kernel hardness and protein content is emphasised and these were investigated in relation to optimum cooking time and firmness of pasta. Regarding the influence of total protein content and gluten composition on pasta quality, this relationship has been widely investigated (Matsuo *et al.*, 1972; Dexter and Matsuo 1977a; Grzybowski and Donnelly 1979; Dexter and Matsuo 1980; Autran and Galterio 1989; D'Egidio *et al.*, 1990; Novaro *et al.*, 1993; Sharma *et al.*, 2002; Edwards *et al.*, 2003; Sissons *et al.*, 2005), and is still debated within the literature. The study here revealed that the gluten composition of the semolina is of more importance than overall protein content, which supported previous finding by Martinez *et al.*, (2004). However, this could be related to the reduction in protein content and hence the effect of gluten content would be more effective and a further study is required to verify this assumption.

Studying the effect of the different quality factors on pasta cooking properties also revealed the importance of the RVA technique. It is well known that RVA is used mainly to measure starch pasting properties but in this study, significant positive correlations were detected between final viscosity of durum starch and both optimum

cooking time and firmness of pasta. These findings therefore propose a new technique to predict pasta cooking quality which could be a substantial help in breeding programmes as it requires only a small amount of sample as well as being a quick test. Furthermore, the use of various equipments to evaluate dough rheological characteristics showed that extensograph and farinograph instruments were of great importance in relation to the cooking properties of pasta. Higher extensibility readings were associated with increased pasta firmness and optimum cooking time whilst the resistance to extension negatively correlated with optimum cooking time and pasta firmness. These correlations are likely to be due to the contribution of gluten to the behaviour of the semolina doughs. Moreover, dough development time as measured by the farinograph exhibited significant correlations with both pasta optimum time and cooked pasta firmness. This supports the findings of Matsuo *et al.*, (1982) that farinograph measurements at high water absorption could be utilized in predicting pasta cooking quality.

8.4. ENVIRONMENT, GENOTYPE AND THEIR INTERACTION:

Having determined the kernel physiochemical composition, milling potential, pasta cooking properties and the interrelationship among the variable traits for the selected samples of a range of Syrian cultivars, it was essential to complete this investigation by studying the effect of the environmental conditions in Syria on the quality of durum wheat samples. The literature reports a significant influence imparted by these factors on the overall quality of the crop (Borghi *et al.*, 1982; Sinclair *et al.*, 1993; Mariani *et al.*, 1995; Dexter and Edwards 1998a; 1998b). Although Syria is considered a small country compared with the top durum wheat producer countries, durum wheat is grown in areas which often differ significantly in their agricultural environments and there is

no evidence in the literature concerning the effects of such environmental variation on quality of durum wheat. As a consequence, the physiochemical characteristics of selected durum wheat cultivars under different locations and agricultural practices were determined with the intention of presenting an indication of the effect of the different environmental conditions in Syria on these characteristics and the level of Genotype \times Environment (G \times E) effects. This was not a comprehensive study but is used in an indicative manner.

The study revealed a high influence of the environmental conditions, location and irrigation, on the degree of vitreousness which is supported in the literature (Parish and Halse 1968; Hoseney 1986; Pomeranz and Williams 1990). Moreover, as was previously mentioned, the degree of vitreousness is a fundamental character and influences the final quality of any durum wheat sample. This finding presents a key clue to investigations aimed at overcoming the reduction in the degree of final quality.

The importance of the agricultural locations in durum wheat farming in Syria has been verified in this investigation by the highly significant effect of the sites on the quality traits of test weight, 1000 kernel weight, the degree of vitreousness and protein content and the site effects were much greater than the cultivars or their interactions. On the other hand, starch quantity, chemical composition, and pasting properties were mainly influenced by the cultivar factor, which is supported in the literature (Dengate and Meredith 1984a; 1984b; Yun and Quail 1999).

Since vitreousness is the key quality factor, it is clear that correct site selection is a clear way to move towards improved samples and if grain collections could be organised and stored separately then export quality may be achieved more reliably in the short term. There is a risk however to the domestic market of removing the best quality grain to export.

8.5. CONCLUSION:

- There has been significant recent progress in durum wheat production in Syria. Moreover, cultivars demonstrate good test weights, 1000-kernel weights and falling numbers which testify to the soundness of Syrian production. However, the relatively low levels of the degree of vitreousness and protein content would restrict Syrian wheat compatibility to the world durum wheat market. Consequently, improvements in kernel quality are needed to enable the majority of the cultivars to reach the highest grade standards in relation to the degree of kernel vitreousness and protein content.
- Investigation of the relationships among kernel physiochemical composition, milling characteristics and pasta cooking properties illuminated the importance of three physico-chemical markers, namely the degree of kernel vitreousness, kernel hardness, and kernel protein content, which provide useful traits indicators for future developments in the Syrian durum wheat breeding programmes.
- Finally, the importance of agronomic practice including site selection should not be ignored and may have a bigger combined effect on quality than any other factor.
- It is clear therefore that genetic (breeding) and growing (agronomic) improvements to the Syrian durum wheat crop are still required in the medium term in order to sustain and improve the domestic and potential export markets of the crop

8.6. FURTHER STUDIES:

- Extensive research has been dedicated to understanding the functional properties of gluten protein on pasta quality while the importance of starch in pasta-making and other durum wheat products still needs further investigation.
- A further study is needed regarding the effect of protein quality, gluten properties and amino acids composition on pasta cooking properties of Syrian durum wheat cultivars.
- It has been demonstrated that applying high-drying temperature during pasta drying process imparts a positive effect on the pasta quality, by increasing the firmness, and decreasing the stickiness and cooking loss which in turn would overcome the problem related to the gluten strength reduction and a thorough further study needs to be undertaken to investigate this relationship on the Syrian durum wheat cultivars.
- The limitations of the study regarding the effect of environment, genotype and their interaction on the Syrian durum wheat cultivars were mainly related to the availability of the samples and hence a further study is required to verify the findings reported here through including more variables, such as cultivars, fertilization, and irrigation.

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Evaluation of Vitreous and Starchy Syrian Durum (*Triticum Durum*) Wheat Grains: The Effect of Amylose Content on Starch Characteristics and Flour Pasting Properties

The physicochemical composition of durum wheat cultivars was studied in order to investigate the influence of vitreousness on the chemical composition of starch and its thermal and pasting properties. Six durum wheat lines were chosen and grown in northern Syria. Grains of each cultivar were visually sorted according to the degree of vitreousness into fully vitreous and fully starchy fractions. Amylose/amylopectin ratio and total starch was determined using Megazyme methods, while thermal and pasting properties were determined using DSC and RVA. Starchy kernels were higher in total starch than vitreous kernels but showed a decreased amylose content. Negative linear relations were found between amylose content, and both peak viscosity and break-down. Trends in variation of gelatinisation characteristics were observed between vitreous and starchy kernels from the same cultivar, with higher total enthalpy being associated with starchy grains compared with vitreous grains of the same line.

Keywords: Durum wheat; Gelatinisation; Pasting

1 Introduction

Durum wheat (*Triticum durum*) is regarded as an ancestral relation to modern day bread wheat (*Triticum aestivum*) and is characterised by possessing kernels showing a high degree of vitreousness, relatively high endosperm hardness and being amber in colour. The kernels' tendency to hardness and vitreousness enables their milling into semolina, which may then be used for pasta, couscous and burghul production. Both the degree of vitreousness and hardness of durum wheat samples have implications on international grading of the kernel and hence commercial value of the commodity [1, 2].

Vitreousness is related to compaction of the kernel and air spaces between starch granules [3]. Previous research has shown that vitreous kernels are harder and of higher protein content than non-vitreous (starchy) kernels [4], and that a tight adherence between the protein matrix and starch granules exist in such areas. Vitreous kernels have also been shown to exhibit improved cooking quality, better product colour, coarser granulation, higher protein content, increased hardness, and as such sell for a premium [5–7].

Starch is the primary component of wheat. Its characteristics contribute to the utilisation of flour and semolina [8].

Most of the functional attributes of starch can be related to the temperature interaction of starch with water in the processes known as gelatinisation, pasting, gelation and retrogradation [9]. The amylose and amylopectin ratio has been shown to affect these physicochemical properties of starch [10]. Amylose content of starch appears to be under genetic control and varies over a limited range (16–28%) within durum wheat [11–13].

Reduction in amylose content of *Triticum aestivum* starch has been found to contribute to an increase in starch pasting viscosity [14]. Additionally, both the branch chain distribution of amylopectin and the granular structure of starch may affect starch functionality. In particular a relationship exists between long-branch chains of amylopectin and increased gelatinisation temperature. Leloup et al. [11] studied the influence of different proportions of amylose on the characteristics of starch gels. Amylopectin-rich gels were found to be well degraded (chemically and enzymatically), but had poor mechanical properties and solubility behaviour, while amylose-rich gels were only slightly degraded, exhibiting good mechanical and thermal resistance. Zeng et al. [14] supported this observation by demonstrating that variation in pasting properties among wheat cultivars could largely be explained by variation in amylose content. Further studies by Franco et al. [15] illustrated that the branch chain length of amylopectin affected the thermal and pasting properties of soft wheat starch (starch gelatinisation temperature, paste peak viscosity and shear thinning).

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The technique of Differential Scanning Calorimetry (DSC) has been extensively used to investigate the phase transitions of starch/water systems over a wide range of temperatures and estimation of transition enthalpies. Early research by *Tester and Morrison* [16] focussed on the behaviour and rheological properties of partially or fully swollen cereal starch granules. They concluded that the degree of swelling was related to the amylopectin content of starch, while amylose and lipids could inhibit swelling. Research conducted by *Fredriksson et al.* [10] showed similar characteristics by indicating that amylose content was negatively correlated to the onset and peak minimum temperature of gelatinisation. *Lee et al.* [17] studied the thermal properties of isolated wheat starches with various amylose contents using DSC. They found that decreased amylose content (from 30 to 24%) increased starch gelatinisation enthalpy (from 10.5 to 15.3 J/g). Additionally, higher retrogradation enthalpy values were observed in breads containing waxy wheat starch (4.56 J/g at 18% amylose and 5.43 J/g at 12% amylose) compared with bread containing regular wheat starch (3.82 J/g at 24% amylose).

There appears to be a paucity of information in published research specifically on Syrian durum wheat starches. The present study is part of a joint project aiming towards a comprehensive understanding of Syrian durum wheat structure, properties and applications. In this paper, we aim to utilise the background research on *Triticum aestivum* starch composition to determine some of the functional base of variations in kernel composition. This includes amylose content, starch pasting and thermal properties of whole samples, vitreous and starchy grains of six different durum wheat cultivars.

2 Materials and Methods

2.1 Materials

Six Syrian spring durum wheat cultivars, Sham-1, Sham-3, Sham-5, Bohouth-5, Bohouth-7, and Douma-1105 were selected. The first five cultivars are lines currently used on farms, while Douma 1105 is in the process of accreditation. The samples were obtained from the Ministry of Agriculture Research Station at Raqqa, Northeast Syria. Cultivars were grown at the same location and under the same agroecological conditions in the crop year 2002.

2.2 Methods

2.2.1 Physical and chemical analysis

The degree of vitreousness was ranked visually and hand sorted. Vitreous kernels were defined as whole sound kernels that exhibited the natural amber colour of durum wheat with no starchy white flecks. Starchy samples were

defined as kernels with 100% starchy endosperm and no vitreous flecking. The vitreous kernels from 50 g of wheat were hand sorted, weighed and reported as a percentage of total wheat kernels.

Vitreous, starchy and whole-wheat samples were ground to wholemeal using a laboratory mill (Micro Hammer mill C680, Glen Creston, Stanmoor, UK), and the flour sieved through standard sieves 500 µm and 250 µm, to obtain a particle size of >250 µm for subsequent determinations.

Thousand-kernel weight was determined according to *Williams et al.* [18]. Test weight was determined using the AACC method 55-10 [19], results were reported in kilograms per hectolitre. Moisture content was determined by the approved AACC method 44-15 [19]. Protein analysis was conducted by the Dumas method (Leco model FB-428) and expressed using the conversion factor ($N \times 5.7$). The Hagberg Falling Number was determined using the approved AACC method 56-81B [19].

2.2.2 Grain starch properties

Total starch content was determined using the Megazyme starch assay kit (Megazyme Int., Wicklow, Ireland), approved method 76-13 [19]. The apparent amylose content was determined using the Megazyme amylose/amylopectin ratio assay kit.

2.2.3 Pasting properties of wheat starches

Flour pasting properties were evaluated using a Rapid Visco Analyser (RVA-4) and data analysed using Thermocline software (Newport Scientific Pty Ltd. Warriewood, NSW, Australia). A total weight of 28 g per canister was maintained with the amount of wholemeal flour added based on 3 g dry matter basis as of *Grant et al.* [20]. Total run time was 13 min with using the parameters of the approved method 76-21 [19]. Peak viscosity (PV), holding strength or hot paste viscosity (HPV), breakdown (PV-HPV), final paste viscosity (FV), and setback (FV-HPV), were recorded.

2.2.4 Thermal properties

Gelatinisation properties of wheat starches were determined using a Differential Scanning Calorimeter (DSC), Mettler TA Instrument DSC 12 E (Mettler Toledo Instruments, Leicester, UK). Wholemeal wheat samples (3 mg, dry matter basis) were weighed into aluminium pans, mixed with distilled water (10 µL) and sealed. The weighed samples were kept at room temperature for 1 h to equilibrate, and scanned at a rate of 10 °C/min over a temperature range of 30–100 °C. An empty pan was used as reference. Each DSC endotherm of gelatinisation was

characterised by the onset temperature (T_o), the temperature at peak minimum (T_p), the conclusion temperature (T_c) and melting enthalpy (ΔH_{gel}).

2.2.5 Statistical analysis

Results from all of the tests were calculated as means \pm SD. Analysis of variance (ANOVA), followed by Tukey test, were performed using Minitab 1332 software (Minitab Inc. USA). Results were reported on significance level 5% ($p < 0.05$). Tests were run in at least triplicate for all experiments apart from DSC determination, where the results are from duplicate analysis.

3 Results and Discussions

3.1 Characteristics of durum wheat cultivars

Determinations of thousand kernel weight, test weight, vitreousness, moisture, protein content, and Hagberg Falling Number, were made on whole sample durum wheat cultivars, with regard to their contribution to milling and final product quality. Tab. 1 illustrates that all tested cultivars had higher values for test and thousand kernel weight than previously reported for Syrian durum wheat varieties [21, 22], and were within the high range of durum wheat grown elsewhere [1, 8, 23, 24]. Sham-3 and Bohouth-5 had the highest thousand kernel weight (55.0 g) whilst the lowest was Bohouth-7 (49.0 g).

Vitreousness is an important international quality-grading factor for countries marketing durum wheat. For example, the Australian grading system has three grades: ADR1 > 90%, ADR2 80–89% and ADR3 < 79% [24]. Applying this parameter to Syrian durum cultivars, only Sham-1 (93 %) fell within the ADR1 range. Previous results for a range of Syrian durum wheat cultivars [25] showed difference in vitreousness/starchiness for the same and different cultivars between locations. Starchy grains render the appearance of the grains chalky, which is less desirable and often adversely affects the end use of the durum wheat [23]. Results from Tab. 1 indicate that variation in vitreousness is also cultivar based and has a genetical background supporting the research of *Shehadeh et al.* [25].

Tab. 1 also shows low α -amylase activity (relatively high falling number) and low moisture content for all tested cultivars, compared to previously recorded durum wheats [8]. Low moisture is important for prolonging the storage period and increasing the milling yield, both are important factors for wheats grown in semi-arid areas. Protein content between the cultivars showed little variation and ranged between 12.93–12.01%.

3.2 Total starch and amylose contents

Tab. 2 shows both total starch and amylose content for whole sample (WS), vitreous (V) and starchy (S) grains of cultivars under investigation. Mean total starch values obtained for whole samples ranged from 64.3 to 66.1%,

Tab. 1. Characteristics of whole sample durum wheat cultivars.

Cultivars	1000 grain weight [g]	Test weight [kg/hL]	Vitreousness [%]	Moisture [%]	Hagberg Falling Number [s]	Protein [%]
Sham-1	50.00	84.90	93.00	8.46	433	12.73
Sham-3	55.00	83.10	45.00	8.20	528	12.01
Sham-5	50.00	84.90	45.00	8.30	502	12.93
Bohouth-5	55.00	84.10	50.00	8.17	505	12.56
Bohouth-7	49.00	85.50	85.00	8.30	597	12.71
Douma-1105	50.00	84.15	57.00	9.09	472	12.76

Tab. 2. Starch characteristics of wholemeal durum wheat cultivars.

Cultivars	Total starch [% Dw]			Amylose content [%]		
	WS	Vit	Sta	WS	Vit	Sta
Sham-1	64.3 \pm 1.1	63.8 \pm 0.9	72.5 \pm 1.3	28.3 \pm 0.0	28.0 \pm 1.9	26.9 \pm 1.0
Sham-3	64.3 \pm 0.5	65.0 \pm 0.1	71.9 \pm 0.1	27.6 \pm 0.3	27.0 \pm 1.3	25.1 \pm 0.5
Sham-5	65.0 \pm 0.3	66.2 \pm 0.1	71.8 \pm 0.8	27.8 \pm 0.8	27.9 \pm 1.1	26.1 \pm 0.2
Bohouth-5	65.5 \pm 0.6	66.2 \pm 0.3	71.9 \pm 0.6	29.0 \pm 0.9	29.1 \pm 1.8	27.6 \pm 1.8
Bohouth-7	66.1 \pm 0.8	66.1 \pm 0.1	73.1 \pm 1.3	29.8 \pm 1.1	29.7 \pm 0.4	28.3 \pm 1.0
Douma-1105	64.4 \pm 1.1	64.1 \pm 0.1	71.1 \pm 0.9	30.4 \pm 0.0	32.1 \pm 0.8	31.3 \pm 0.0

Dw: Dry weight, WS: Whole sample, Vit: Vitreous, Sta: starchy.

whilst starchy kernel meal showed higher total starch (73.1–71.1%), compared to vitreous kernel meal (66.2–63.8%). Analysis of between-cultivar starch contents showed significant variation in total starch ($p<0.05$) between vitreous Sham-1 versus Sham-5, Bohouth-5 and Bohouth-7, and also between Sham-5 versus Douma-1105, and Bohouth-5 compared to Douma-1105 and Bohouth-7 versus Douma-1105. No significant differences in total starch were found between whole sample and starchy wheat grains for any cultivars. Analysis of starch content of vitreous and starchy grains from the same cultivar showed significant variation ($p<0.05$), with a lower starch content evident in vitreous grains.

The main variation in composition of starches has previously been attributed to the relative proportions of amylose and amylopectin in the starch granules [26]. Results from within-cultivar analysis indicate that there was a general trend (although not significant) of flour samples from starchy grains containing less amylose than vitreous flours. The mean amylose values for the starchy grains were in the range of 25.1–31.3%, for vitreous grains from 27.0 to 32.1%.

Between-cultivar analysis showed significant variation in whole flour amylose content ($p<0.05$) between Sham-3 compared to Douma-1105, together with variation for starchy grains, between Sham-1, Sham-3 and Sham-5 compared to Douma-1105. The high amylose contents of these Syrian durum wheat cultivars fall within the range reported by *Midcalf and Gilles* [27]. It is this high amylose content (sometimes up to 30%) which gives optimum product quality for pasta and noodles. In particular, the resulting gelatinised gel structure is reported to be less susceptible to enzymatic degradation, rendering these slowly hydrolysed foods of potential medical interest for diabetic control and reduction of serum lipid levels [11].

3.3 Pasting properties

Pasting properties of starch for whole sample, vitreous and starchy grains were studied using RVA, with the aim of identifying the pasting characteristics of tested cultivars. RVA parameters were Peak viscosity (PV), Trough (Tr), Breakdown (BD) and Final viscosity (FV). Whole-meal flour was used throughout this study. Research conducted by *Bhattacharya et al.* [28] demonstrated a high correlation between the properties of purified starch and the corresponding wholemeal, provided α -amylase was inactivated. There was no need to conduct enzyme inactivation in this study as all samples showed low levels of amylase activity derived from the falling number values (Tab. 1).

Tab. 3. Pasting properties of the whole meal durum wheat cultivars.

Cultivars	Peak viscosity [RVU]			Trough [RVU]			Breakdown [RVU]			Final viscosity [RVU]		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
Sham-1	170±6.2	166±6.1	183±8.1	129±5.4	129±4.4	123±4.9	41±3.6	37±1.7	60±3.2	262±6.8	260±6.5	249±9.1
Sham-3	189±5.7	183±0.2	203±3.2	128±3.1	125±0.0	132±2.1	60±2.5	58±0.2	71±1.1	256±5.2	254±0.4	259±3.9
Sham-5	182±0.8	173±3.0	220±0.9	132±0.6	123±2.4	153±0.5	50±0.1	51±0.6	67±1.5	257±0.9	245±2.4	284±0.6
Bohouth-5	178±2.5	156±0.3	198±1.3	141±2.2	125±0.1	147±1.6	37±0.3	31±0.2	51±0.4	280±4.1	259±0.6	289±1.4
Bohouth-7	151±6.7	143±1.1	196±2.4	129±4.5	125±1.2	151±1.0	23±2.2	18±0.1	45±1.4	271±6.3	271±1.1	296±2.7
Douma-1105	125±3.4	115±3.9	155±0.9	113±1.7	108±3.5	126±0.8	12±1.7	7±0.4	28±0.1	245±3.6	241±6.4	263±1.5

WS: whole sample, Vit: Vitreous, Sta: starchy.

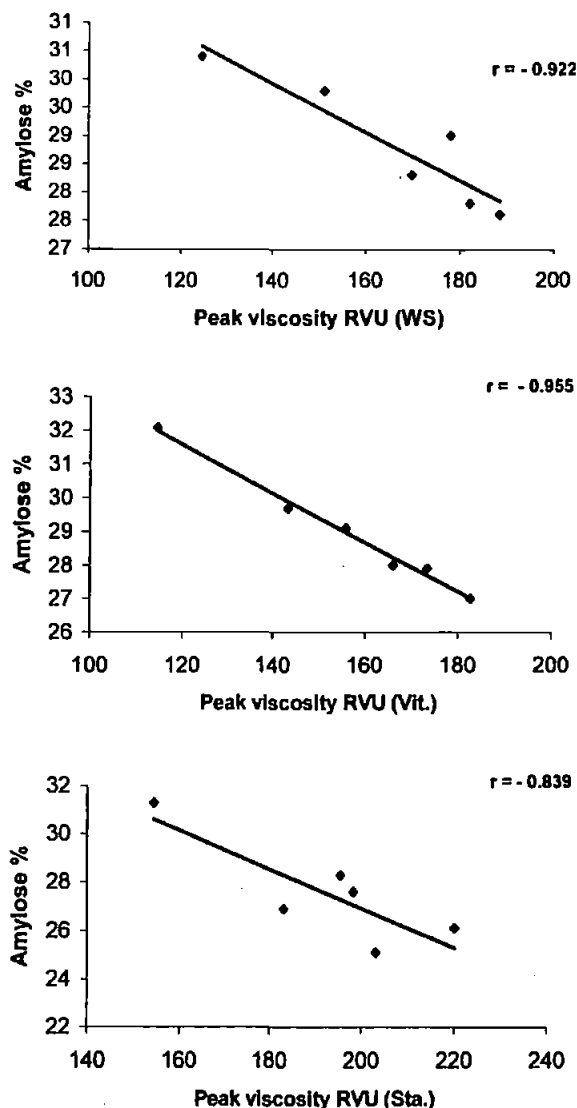


Fig. 1. Correlation of amylose content vs. peak viscosity among Syrian cultivars (Ws:- whole sample; Vit:- Vitreous sampe; Sta:- Starchy sample).

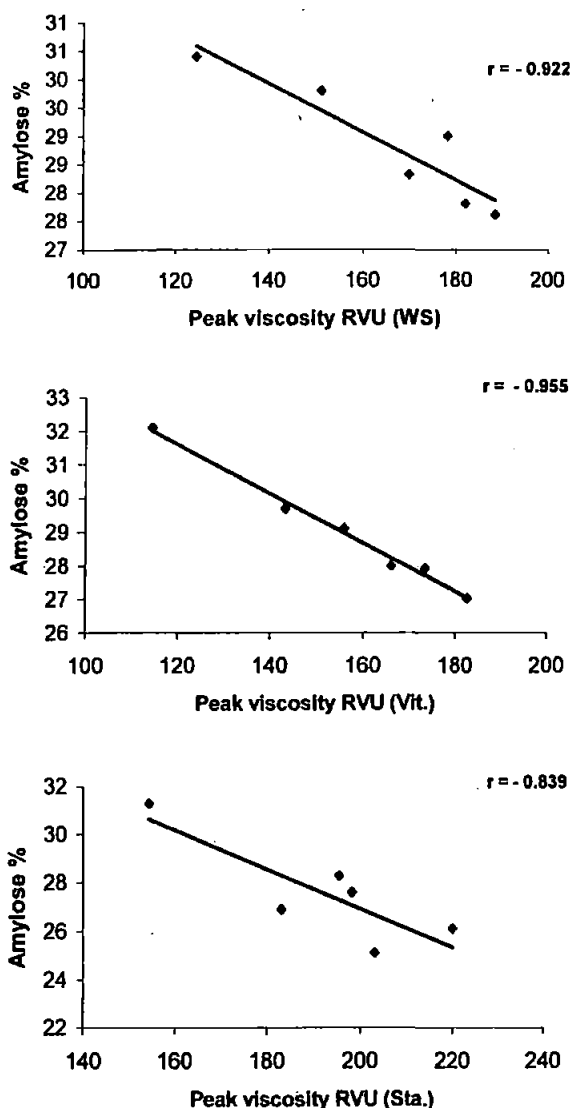


Fig. 2. Correlation of amylose content vs. breakdown among Syrian cultivars (Ws:- whole sample; Vit:- Vitreous sampe; Sta:- Starchy sample).

Tab. 3 illustrates variation of RVA parameters. Previously Loney et al. [29, 30] found that genetic factors (i.e. difference among cultivars) were a significant source of variation for peak paste viscosity of prime starch. Results from our analysis demonstrate a significant difference in between-cultivar variation with regards to the pasting characteristics of Douma-1105 and Bohouth-7. Within-cultivar variation in RVA parameters were also detected (comparing vitreous and starchy grains of the same cultivar). Starchy grains tended to have higher values when compared to vitreous grains (except the breakdown and peak viscosity of Sham-1). Vitreous and starchy grains of Douma-1105 and Bohouth-7 showed lower peak viscosity, trough and breakdown values when compared to other

tested cultivars. According to Bhattacharya et al. [28] diversity in starch physical properties (amylose content) could be useful in breeding for improved quality of specific products such as various type of Asian noodles. Results from our study indicate a negative correlation between amylose content and both peak viscosity (Fig. 1) and breakdown (Fig. 2). Fig. 1 illustrates the trends for peak viscosity in whole samples (WS), vitreous sample (V) and starchy sample (S) with respective correlation coefficients of $r = -0.922$, -0.955 , -0.839 ($p < 0.05$). Fig. 2 shows the trends for breakdown in similar samples (respective $r = -0.983$, -0.947 , -0.988 ; $p < 0.05$). No significant correlation was found between amylose content and final viscosity and trough. This may indicate that differ-

ences in amylose content have a greater affect on the swelling and disruption of the granule, rather than the subsequent realignment of the starch components during retrogradation.

Fabriani and Lintas [31] reported that durum wheat starches start to gelatinise at a slightly lower temperature than starches of other wheats. This property appears to be related to the presence of amylose, lowering the crystallinity of starch [32]. Therefore vitreous grains which had amylose content ranging from 27.0 to 32.1%, potentially required less energy to start swelling than the starchy grains (25.1–31.3% amylose). This may also account for the variations in pasting properties observed between the samples. Research conducted by Ming et al. [33] and Sasaki et al. [34] indicated that as the amylose content decreases, swelling increases, reducing the amount of free water and resulting in a higher pasting viscosity. The negative correlations obtained in the current study support these observations.

Significant variations ($p < 0.05$) in pasting properties were found between some of the Syrian durum wheat cultivars studied in this paper (Tab. 5), indicating differences in starch composition and properties among the Syrian varieties. Within-cultivar variations (Tab. 3) showed trends with starchy grains of a cultivar appearing to have elevated peak viscosity, trough viscosity, breakdown and final viscosity when compared to the vitreous grains of the same cultivar. However, these trends may be more related to high total starch composition in the starchy grains rather than any variation in amylose content.

3.4 Thermal properties

Tab. 4 reports the DSC parameters T_o , T_p , T_c , and ΔH , that correspond to the onset, peak, conclusion temperatures and enthalpy of gelatinisation [35, 36]. Overall T_o varied between 58.2–60.0 °C, 57.4–59.2 °C, and 58.2–60.0 °C for the whole sample, vitreous and starchy grains, respectively. Examining variations between cultivars, significant variations for whole sample and vitreous grains were found between Sham-1 compared with Sham-5 and Bohouth-5 in the onset temperature. A larger number of between-cultivar variations were observed in the starchy grain samples (Tab. 5). Peak gelatinisation temperature (T_p) of whole grain samples ranged between 63.2–64.2 °C and exhibited variation between cultivars, while the peak temperatures of vitreous and starchy grains ranged between 63.3–64.2 °C and 63.4–64.4 °C, respectively, and did not demonstrate significant variations. In general, the cultivars exhibited no significant difference in their conclusion temperature with T_c values of 69.7–71.1 °C, 69.8–70.4 °C and 69.9–71.1 °C for the whole sample, vitreous and starchy grains, respectively.

Tab. 4. Thermal properties of the durum wheat cultivars.

Cultivars	Onset temperature (T_o) [°C]			Peak temperature (T_p) [°C]			Conclusion temperature (T_c) [°C]			Gelatinisation enthalpy (ΔH) [J/g]		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
Sham-1	58.2±0.1	56.9±0.0	58.2±0.1	63.2±0.1	63.0±0.3	63.6±0.1	69.7±0.7	69.9±0.2	69.9±0.5	3.6±0.0	4.0±0.3	4.7±0.0
Sham-3	58.7±0.2	59.2±0.4	58.7±0.2	63.9±0.0	63.9±0.1	63.8±0.4	71.0±0.1	69.9±0.1	70.7±0.1	4.7±0.2	3.6±0.1	4.4±0.1
Sham-5	59.8±0.2	59.5±0.3	59.8±0.2	64.1±0.0	64.2±0.2	64.4±0.1	71.1±0.1	70.1±0.0	71.1±0.3	4.2±0.3	3.9±0.2	4.8±0.1
Bohouth-5	60.0±0.1	59.4±0.0	60.0±0.1	64.1±0.0	64.4±0.4	64.4±0.4	70.9±1.1	70.4±0.4	70.4±0.1	4.3±0.4	4.1±0.0	4.4±0.1
Bohouth-7	58.3±0.3	58.4±0.8	58.3±0.3	63.0±0.1	63.3±0.3	63.4±0.1	69.7±0.6	70.3±0.8	70.1±0.2	3.9±0.1	3.4±0.2	4.6±0.0
Douma-1105	59.0±0.3	58.6±0.5	59.0±0.3	64.2±0.4	63.5±0.4	63.8±0.1	70.8±0.0	70.3±0.3	70.2±0.1	4.1±0.2	3.3±0.2	3.8±0.2

WS: whole sample, Vit: Vitreous, Sta: starchy.

Significant differences in ΔH were observed between the varieties, Sham-1 compared with Bohouth-5, Douma-1105 compared with Sham-3 and Sham-5 (mean range of starchy grain ΔH being 3.8–4.8 J/g). Conversely, vitreous grains had ΔH between 3.3–4.1 J/g and exhibited no significant differences between any of the studied cultivars. Similarly, little significant difference was observed between whole samples of cultivars, with only Sham-3 significantly differently compared with Sham-1 and Bohouth-7 (ΔH of the whole sample grains between 3.6–4.7 J/g).

Vitreous grains exhibited a trend to lower total energy of enthalpy when compared to starchy grains of the same cultivar (Tab. 4). This may be due to the higher amylose content in vitreous grains depressing the enthalpy energy, or just a result of higher starch content in the starchy grains. Although previous research by *Fredriksson et al.* [10] indicated a negative correlation between amylose content and gelatinisation onset and peak temperature of the tested starches, no such correlation could be found either between or within the Syrian durum wheat cultivars investigated in this report, indicating that many factors can contribute to swelling and gelatinisation behaviour of starches [16].

4 Conclusion

Variation in apparent amylose content exists on a genetical basis between whole grain samples of Syrian durum wheat cultivars. Within-cultivar variation between vitreous and starchy grains of the same cultivars illustrate that grain samples classified as starchy have an increased total starch content but a generally lower amylose content when compared to grain classified as vitreous. This difference in starch characteristics may explain the increased visco-gelatinisation properties (peak viscosity, breakdown and final viscosity) in starchy grains compared to vitreous grains coupled to a similar trend to elevated onset temperatures (T_o) and total enthalpy (ΔH). The clearly negative correlation observed between amylose content and peak viscosity and breakdown illustrates the importance of amylose content when evaluating the potential use of durum wheat cultivars. The lack of clear correlation between amylose content and final viscosity or the gelatinisation properties (T_o , T_p and T_c) of the cultivars examined may indicate that grain protein and lipid quantity and quality, may be as important in regulating these properties as starch quality. Further work is being undertaken to evaluate these relationships.

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Tab. 5. Statistical comparison of between-cultivar variations.

Comparison	T_o			T_p			T_c			ΔH			PV			BD			Tr			FV			AC			TS		
	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta	WS	Vit	Sta
S1-S3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S1-S5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S1-B5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S1-B7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S1-D11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S3-S5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S3-B5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S3-B7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S3-D11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S5-B5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S5-B7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
S5-D11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B5-B7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B5-D11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B7-D11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

S1, S3, S5 For Sham 1,3 and 5 respectively, B5, B7: Bohouth 5 and 7 respectively, D: Douma 1105, PV: Peak viscosity, BD: Breakdown, Tr: Trough, FV: Final viscosity, AC: Amylose content, TS: Total Starch, —: Significant, !: Insignificant.

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Original article

Durum wheat quality I: some physical and chemical characteristics of Syrian durum wheat genotypesGhassan H. El-Khayat,^{1,2} Jihad Samaan,¹ Frank A. Manthey,³ Mick P. Fuller¹ & Charles S. Brennan^{1,4*}¹ School of Biological Sciences, University of Plymouth, Plymouth, PL4 8AA, UK² Food Science Department, Faculty of Agriculture, University of Damascus, Damascus, Syria³ Department of Plant Sciences, North Dakota State University, Fargo, ND, USA⁴ Institute of Food Nutrition and Health, Massey University, Private Bag 1222, Palmerston North, New Zealand

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Summary Some physical and chemical characteristics of nine Syrian durum wheat genotypes were determined in order to investigate the relationships among individual kernel components and kernel quality. All genotypes were grown on fully irrigated plots in Syria. Test weight, 1000-kernel weight, kernel size distribution, hardness and semolina extraction rates were determined along with the chemical characteristics of the kernel (ash, moisture, protein, wet gluten, starch content and falling number). All tested genotypes had high test weight (83.1–85.9 kg hl⁻¹) and 1000-kernel weight (42.5–55.5 g) indicating high milling yield potential. Additionally, all the wheat genotypes demonstrated high falling numbers (433–597 s). Correlation coefficients among the quality properties showed that moisture content did not demonstrate any strong correlations with the studied quality parameters. Protein content exhibited a positive correlation with vitreousness ($r = 0.78$), and a negative correlation with ash content ($r = -0.57$). Test weight exhibited a negative correlation with 1000-kernel weight ($r = -0.66$), and a positive correlation was observed between test weight and starch content of the kernel ($r = 0.78$). The results illustrate the commonality between Syrian durum wheat genotypes and US and Canadian durum wheat genotypes reported by researchers previously.

Keywords Durum wheat, gluten, protein content, starch, vitreousness.

Introduction

Durum wheat is an important cereal crop for Syria and countries around the Mediterranean. Pasta is regarded as the major end-product for which the majority of the crop is grown; hence, the selection and use of cultivars possessing optimal processing characteristics is imperative for both the grower and food processor. The physico-chemical quality of the durum wheat kernel is the major determinant of the suitability of the crop for its end-use, and inevitably is responsible for the quality of pasta (Mariani *et al.*, 1995). Factors which have been shown to affect durum wheat quality include genotype (Troccoli *et al.*, 2000), environment (Kovacs *et al.*, 1997; Sharma *et al.*, 2002) and the interaction between genotype and environment.

The relationship between some of the physical characteristics (such as density, test weight, kernel size and kernel weight) and the chemical properties (such as

moisture, starch and protein content) have been studied extensively in *Triticum aestivum* (Igrejas *et al.*, 2002a,b; Khatkar *et al.*, 2002; Chung *et al.*, 2003; Kim *et al.*, 2003).

Early research by Tkachuk & Kuzina (1979), studying hard red spring wheat, illustrated that an increase in grain moisture content caused a decrease in test weight and density, but an increase in kernel weight. Additionally, they demonstrated a negative correlation between test weight and protein content, possibly because of the association between shrunken grains and low test weight.

Another important factor that determines end-use quality characteristics of cereal is hardness. The hardness of a grain is important with regards to the milling process, where it has a significant impact on the fracture characteristics of kernels during milling (Symes, 1961). This has a subsequent effect on factors such as, the conditioning of wheat before milling, the particle size of flour, quantity of damaged starch, water absorption, milling extraction rate (Hoseney, 1987; Pomeranz & Williams, 1990; Delwiche, 1993), as well as the

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rheological properties of the flour produced (Pomeranz *et al.*, 1984). Much of the research investigating the genetic basis of kernel hardness has been conducted on *T. aestivum*. Such work has illustrated the role of the starch granule proteins, sometimes named friabilins (Greenwell & Schofield, 1986; Brennan *et al.*, 1993) and other times puroindolines (Baldwin, 2001; Igrejas *et al.*, 2001). The scarcity of these puroindolines in durum wheats is often regarded as one of the factors which explain the high hardness of durum wheat kernels.

In durum wheat, the degree of vitreousness of the kernel is often used, in conjunction with kernel hardness, to predict the quality of the cereal crop. The degree of kernel translucency, and hence the apparent degree of vitreousness, is related to the degree of compactness of the kernel (Yamazaki & Donelson, 1983). The degree of vitreousness of kernels has been linked to the hardness of the kernel, and the amount of protein and starch within the kernel (Stenvert & Kingswood, 1977). Starchy kernels have been shown to have a discontinuous endosperm with many air spaces and appear white in colour (Dexter *et al.*, 1989). These air spaces, and the more porous nature of the kernel, appear to be related to softer texture of the starchy kernels. Many studies have shown that the environmental factors, such as, temperature and light intensity during grain development, determine whether the kernels will appear vitreous or starchy (Parish & Halse, 1968; Hosney, 1987). Pomeranz & Williams (1990) observed that nitrogen fertilisation affects kernel protein content; and hence, the hardness and appearance of kernels. So the degree of vitreousness is highly influenced by both genetic and environmental factors.

Research by Matsuo & Dexter (1980) illustrated that the degree of vitreousness has an important impact on the milling quality of durum wheat, because of its effect on semolina yield, granulation and protein content. Thus, when durum wheat is grown in low protein environments, a decrease in kernel protein content, an increase in starchiness (decrease of kernel vitreousness), and a decrease in semolina yield were observed. The reduction in semolina yield is possibly related to how quickly the starchy kernels were reduced to fine flour particles (Matsuo & Dexter, 1980; Dexter & Matsuo, 1981; Sissons *et al.*, 2000).

Ash content is also regarded as a quality characteristic for durum wheat kernels as it has an influence on pasta colour. The faint colour of semolina is caused by high ash content, and may be due to high extraction rates (Cubadda, 1988). The resulting pasta tends to have a brown colour (Taha & Sagi, 1987; Borrelli *et al.*, 1999). Premium-grade semolina generally has ash content lower than 0.9% (Cubadda, 1988).

Protein content is one of the most important quality characteristic of durum wheat kernels in relation to

determining pasta quality (Dexter & Matsuo, 1977, 1980; Autran & Galterio, 1989). As alluded to previously, protein content is highly influenced by environment much more than genotype (Mariani *et al.*, 1995), where protein content increases with increasing temperature and reduced rainfall.

Dexter & Matsuo (1977) investigated the influence of protein on some of durum wheat quality aspects for two Canadian durum wheat cultivars that differed in their protein contents, but were grown under the same environmental conditions. They found that the increase in protein content was associated with an increase in pigment content and improvement in cooking quality of resulted pasta. Although total protein content is a major factor in final pasta quality, research has also investigated the importance of the gluten components in determining the rheological and cooking quality of pasta (Damidaux *et al.*, 1980; Du Cros *et al.*, 1982; Carrillo *et al.*, 1990).

Limited information is available concerning the quality of Syrian durum wheat. The aim of this study was to investigate some of the physico-chemical properties of durum wheat genotypes derived from a genetic pool in Syria, in the context of the Canadian and US durum wheat grading systems. To this end, nine Syrian durum wheat genotypes were grown at the same location under the same agricultural practices in order to determine the relationships among the physical and chemical characteristics of the kernels.

Materials and methods

Nine spring durum wheat genotypes (Sham-1, Sham-3, Sham-5, Bohouth-5, Bohouth-7, Douma-1105, Douma-18861, Douma-26827 and Douma-29019) were selected for analysis. The first five genotypes are commercially available, whereas the Douma genotypes are experimental lines in the process of accreditation. The samples were obtained from Ministry of Agriculture Research Station at Raqqa (Northeast) of Syria, which is one of the main durum wheat provinces in Syria. All genotypes were grown at the same location and under the same agroecological conditions in the crop year 2002. The crops were from an irrigated agricultural practice and were not exposed to drought conditions. The land was previously laid down to vegetable crop production and the initial soil fertility was nitrogen 18.4 ppm, phosphorous 12 ppm and potassium 220 ppm. Total rainfall for the 2001–2002 season was 184 mm with 13 recorded days where the field temperatures reached below 0 °C, and no days recorded where the temperature was above 30 °C. The field plots received 4500 L ha⁻¹ of water during the growing season with the total amount of nitrogen and phosphorous used during fertilising of 138 and 69 kg ha⁻¹ respectively.

Physical analyses

The degree of vitreousness was determined by hand sorting kernels. Vitreous kernels (those completely free of starchy or speckled appearance) were separated from a 15 g kernel sample, and weighed. Vitreousness was calculated as a percentage of vitreous kernels (w/w) in the sample. Test weight was determined using the Approved AACC method 55-10 (AACC, 2000); results were reported in kilograms/hectolitre. 1000-Kernel weight was determined using an electronic seed counter, where the number of kernels in a 10 g clean wheat sample was determined. Results were adjusted to reflect the weight of 1000 kernels.

Kernel size distribution was determined according to the procedure described by Shuey (1960), which used a kernel sizer consisting of two sieves, Tyler No. 7 with 2.92 mm openings and Tyler No. 9 with 2.24 mm openings. A 100 g of clean wheat was placed on the top sieve Tyler No. 7 and was shaken for 3 min. Kernels remaining on the top sieve were classified as large kernels, while kernels passing through the top sieve and remaining on the second one were classified as medium kernels. Kernels passing through the second sieve were classified as small. Each fraction weight was reported as percentage of large, medium or small kernels.

A Single-Kernel Characterisation System was determined using SKCS 4100 (Perten Instruments, Huddinge, Sweden), using a 300-kernel sample (conditioned to 11% moisture). The SKCS had previously been calibrated using hard wheat samples. Means and standard deviation for weight, diameter, hardness index and moisture were recorded.

Chemical analyses

A whole wheat sample of each genotype was ground to wholemeal using a laboratory mill (Micro Hammer mill C680; Glen, Creston, Stanmoor, UK) and the flour sieved through standard sieves 500 and 250 μ m to obtain semolina-like flour particle size of 250 μ m for subsequent determinations. All chemical analysis were conducted on this milled semolina-like wholemeal flour.

Moisture content of the wholemeal flour sample was determined by the Approved AACC method 44-15 (AACC, 2000). Protein analysis was conducted by the Dumas method (Leco model FB-428) and expressed using the conversion factor ($N \times 5.7$). Wet gluten was performed according to the Approved AACC methods 38-12 (AACC, 2000) using a glutomatic (Perten Instruments, Springfield, IL, USA). Falling number was determined using the Approved AACC method 56-81B (AACC, 2000). Ash content was determined using the Approved AACC method 08-01 (AACC, 2000) and expressed on a 14% moisture content. Total starch was conducted using the Megazyme starch assay kit (Megazyme International,

Wicklow, Ireland), which corresponds to Approved AACC method 76-13 (AACC, 2000).

Semolina yield

Semolina production was achieved by cleaning the kernels using a Carter-Day dockage tester (Simon-Carter Company, Minneapolis, MN, USA) that was configured with a number 25 riddle, and two number 2 sieves. Kernels were then scoured using a cyclone grain cleaner (Foster Manufacturers, Chicago, IL, USA) and tempered to 17.5% moisture. Tempered kernels were milled into semolina using a Bühler experimental mill fitted with two Miag laboratory scale purifiers (Bühler-Miag, Minneapolis, MN, USA). Semolina extraction was expressed on a total product basis.

Statistical analyses

All measurements are means of at least three determinations. Correlation coefficients were run between the different variables using Microsoft Excel. Analysis of variance (ANOVA), followed by Tukey Student's test (significance level $P < 0.05$), were performed using Minitab 1332 software package (Minitab Inc., State College, PA, USA).

Results and discussion

Physical properties

The physical properties of durum kernels, which relate to milling performance and overall assessment of durum wheat quality, are presented in Table 1. As the agronomic conditions of the trial plots were as uniform as possible with regards to field plot experiments, the variation in traits is likely to be a result of the genotypic variation within the genotypes examined.

The test weight values of the samples in this study were high and showed no significant difference between the genotypes, although values ranged from 83.1 kg hl^{-1} for Sham-3 to 85.9 kg hl^{-1} for Douma-29019. All of the genotypes exhibited 1000-kernel weights suitable for high quality kernels. 1000-Kernel weight did vary with genotype from 42.5 g for Douma-26827 to 55.5 g for Sham-3 (Table 1). Kernel weight for Syrian durum wheat genotypes were similar to those reported for US irrigated durum which had an average 1000-kernel weight of 47.3 in 2002 and 52.5 g in 2003 (Anon., 2003).

Kernel Size Index (Table 1) as measured by the procedure of Shuey (1960) showed that the durum wheat kernels tested were relatively large (Size greater than 2.92 mm; Size No. 7 sieve) with genotypes having over 85% of the kernels tested being greater than 2.92 mm. The percentage of the medium kernels ranged from 4.3% for Sham-3 and Sham-5 to 12% for

Table 1 Physical characteristics of grain from Syrian durum wheat genotypes^{a,b}

Genotype	TWT (kg ha ⁻¹)	KWT (g)	Kernel Size Index			Kernel mean diameter* (mm)	Vitreousness (%)	Hard Index	Hard Class	Semolina yield (%)
			L%	M%	S%					
Sham-1	84.9 ^a	50.3 ^a	91.0 ^a	7.7 ^{a,b}	1.3 ^a	3.1 ^a	71.3 ^a	89.1 ^a	H	64.2 ^{a,b}
Sham-3	83.1 ^a	55.5 ^a	94.0 ^a	4.3 ^c	1.3 ^a	3.2 ^a	52.7 ^b	86.7 ^a	H	62.9 ^b
Sham-5	84.9 ^a	50.4 ^a	94.6 ^a	4.3 ^c	1.0 ^a	3.2 ^a	60.4 ^c	95.7 ^b	EH	65.0 ^a
Bohouth-5	84.1 ^a	55.1 ^a	91.6 ^a	5.7 ^{a,c}	2.6 ^a	3.1 ^a	63.1 ^c	94.3 ^{a,b}	EH	65.5 ^a
Bohouth-7	85.5 ^a	49.6 ^a	89.0 ^a	9.7 ^b	1.3 ^a	3.1 ^a	85.7 ^d	100.9 ^b	EH	65.5 ^a
Douma-1105	84.2 ^a	50.7 ^a	91.3 ^a	7.0 ^a	1.6 ^a	3.1 ^a	63.3 ^c	91.5 ^{a,b}	EH	62.7 ^b
Douma-18861	83.7 ^a	50.8 ^a	88.3 ^a	9.6 ^b	2.0 ^a	3.0 ^a	93.6 ^a	96.1 ^b	EH	64.7 ^a
Douma-26827	85.5 ^a	42.5 ^b	85.3 ^a	12.0 ^d	2.7 ^a	2.9 ^a	50.4 ^b	90.6 ^{a,b}	EH	62.9 ^b
Douma-29019	85.9 ^a	50.4 ^a	92.0 ^a	6.7 ^a	1.3 ^a	3.2 ^a	69.4 ^a	89.3 ^a	H	64.0 ^c

Mean values in the same column followed by a different letter are significantly different ($P < 0.05$). TWT, test weight; KWT, 1000-kernel weight; L, large kernel size; M, medium kernel size; S, small kernel size; Vitreousness, vitreous kernel content; Hard Index, Kernel hardness index from SKSC; Hard Class, Hardness Classification from SKSC (H, hard; EH, extra hard).

^aDetermined from Single-Kernel Characterisation System.

Douma-26827. Small kernels ranged between 1.0% and 2.7% amongst the genotypes. The mean kernel diameter, as determined by SKCS, ranged from 2.9 to 3.2 mm. 1000-Kernel weight had a positive correlation with kernel diameter ($r = 0.69$) and Kernel Size Index (KSI) large kernel content ($r = 0.74$) (Table 2). The high percentage of the large kernels supports the observations of high 1000-kernel weight and test weight values, indicating that the kernels from the majority of the genotypes were plump, unbroken and sound, and would be suitable for high milling yields.

Significant variations in the degree of vitreousness and hardness were observed among genotypes (Table 1). Vitreousness ranged from 50.4% for Douma-26827 to 93.6% for Douma-18861. Previous studies have also indicated a high degree of variation in vitreousness within and between cultivars of on Syrian durum wheats (Shehadeh *et al.*, 1999; El-Khayat *et al.*, 2003). Hardness index varied from 86.7 for Sham-3 to 100.9 for Bohouth-7. Sham-5, Bohouth-5, Bohouth-7, Douma-1105, Douma-18861 and Douma-26827 were classified as extremely hard. Sham-5, Bohouth-7 and Douma-18861 had a higher hardness index than did Sham-1, Sham-2 and Douma-29019.

Kernel hardness was correlated with falling number ($r = 0.65$) and the degree of vitreousness ($r = 0.63$) (Table 2). This observation is similar to that of Stenvert & Kingswood (1977) who found that vitreous kernels were harder than starchy kernels. It is interesting to note that the correlation between protein content of the kernel and hardness was very poor in our experiments ($r = 0.37$). This is despite the fact that protein content was significantly correlated with kernel vitreousness in our genotypes.

Semolina yield varied with Syrian genotype (Table 1). Semolina yield ranged from 62.7% for Douma-1105 to 65.5% for both Bohouth-5 and Bohouth-7. Test weight,

kernel weight, kernel size, kernel hardness and kernel vitreousness have been used by millers to assess the suitability of durum wheat for milling into semolina. Semolina extraction was correlated with hardness ($r = 0.75$) and vitreousness ($r = 0.57$) (Table 2). Test weight, 1000-kernel weight, and kernel size did not correlate with semolina yield. Other researchers have reported that these traits did correlate with milling yield (Matsuo & Dexter, 1980; Marshall *et al.*, 1986; Dexter *et al.*, 1987; Halverson & Zeleny, 1988). Most research has been conducted on durum wheat with lower test weight, 1000-kernel weight and kernel size than the wheat used in this study. Genotypes in this study all had relatively high test weight, 1000-kernel weight and kernel size. Thus the variation among these genotypes for these traits was not sufficiently large to establish a relationship.

It is of interest to compare the quality of the Syrian durum wheats in terms of both the Canadian and US grading systems, especially in relation to market export potential.

The Canadian Grain Commission (CGC) specification of durum wheat grades classifies durum wheat into three grades according to the degree of vitreousness; grade No. 1, grade No. 2 and grade No. 3, where the minimum of vitreous kernels required are 80%, 60% and 40% respectively (CGC, 2001). The US grading system operates a subclassification system for durum wheat. Thus, under the US grading system durum wheat with over 75% vitreous kernel content is classified as Hard Amber Durum; wheat with less than 75 but greater than 60% vitreous kernel content is classified as Amber Durum; and with wheat with less than 60% vitreous kernel content is classified as Durum. The US system also operates a numerical grading system based on test weight and content of damaged kernels, foreign material, shrunken and broken kernels, and wheat of

Table 2. Correlation coefficients between physical and chemical properties of durum wheat grains

Correlations	Ash	Falling No.	Protein	Starch	KSI Large	KSI Medium	KSI Small	1000-k. wt.	Test wt.	Vitreousness	SKCS Hardness	SKCS Diameter	Wet glu.	Dry glu.	Semo. Extra.
Moisture	-0.16	-0.36*	0.10	-0.39*	0.24	-0.19	-0.31	0.07	-0.07	-0.09	-0.11	0.20	-0.24	-0.30	-0.35*
Ash		0.08	-0.57*	-0.22	0.28	-0.29	-0.21	0.01	-0.21	-0.58*	-0.16	0.16	-0.53*	-0.23	-0.19
Falling No.			0.14	0.20	-0.07	0.10	-0.11	0.16	0.00	0.40*	0.65**	0.10	0.07	-0.10	0.43*
Protein				-0.42*	0.32	-0.25	-0.40*	0.45*	-0.19	0.78***	0.37*	0.36*	0.81***	0.73***	0.49*
Starch					-0.45*	0.44*	0.35*	0.54*	0.78***	-0.15	0.07	-0.25	-0.12	-0.26	0.08
KSI Large						-0.98***	0.66**	0.74***	-0.32	-0.25	-0.23	0.94***	0.08	0.47*	0.10
KSI Medium							0.50*	0.42*	0.42*	0.33	0.27	-0.88***	-0.01	-0.44*	-0.08
KSI Small								-0.79***	-0.08	-0.16	0.01	-0.77***	-0.32	-0.35*	-0.06
1000-k. wt.								-0.28	-0.66**	0.08	-0.09	0.69**	0.11	0.34*	0.26
Test wt.										0.05	0.20	-0.11	0.00	-0.13	0.20
Vitreousness											0.63**	-0.10	0.67**	0.33*	0.57*
Hardness												-0.16	0.11	0.01	0.75***
Diameter													0.17	0.42*	0.17
Wet gluten														0.82***	0.24
Dry gluten															0.35*

*, **, *** correlation significantly different at the 0.05, 0.01 and 0.001 level of probability, respectively.

contrasting classes. The grades for this system are 1 (minimum of 78.2 kg hl⁻¹); 2 (minimum of 75.6 kg hl⁻¹); 3 (minimum of 73.0 kg hl⁻¹); 4 (minimum of 70.4 kg hl⁻¹); 5 (minimum of 66.5 kg hl⁻¹), so that two categories of grading based on vitreousness and test weight exist (Anon., 2003). These test weights would satisfy requirements for No. 1 grade for both the Canadian and US grading systems (CGC, 2001; Anon., 2003).

Hence, only two of the wheat genotypes studied would satisfy the Canadian grade No. 1 or the US Hard Amber Durum subclassification requirement (Douma-18861 and Bohouth-7), while Sham-3 and Douma-26827 would be classified as Canadian grade No. 3, and Sham-1, Sham-5, Bohouth-5, Douma-1105 and Douma-29019 being graded by the US subclassification of Durum as Amber Durum. All the durum wheat samples studied would also reach grade 1 standards according to the US grading system based on test weight.

Chemical properties

Chemical properties of the durum wheat genotypes are presented in Table 3. Moisture content ranged between 8.1 and 9.1. The low moisture contents reflect the desert environment in which the wheat was grown. Moisture content did not correlate strongly to any of the parameters evaluated, which probably reflects the narrow range in moisture content (Tables 2 and 3).

All of the tested genotypes showed falling number values above 400 s, indicating sound grain with low α-amylase activities (Matsuo *et al.*, 1982a) (Table 3). Research conducted by Donnelly (1980) on durum wheat kernels indicated that falling number values less than 400 s were an indication of some degree of sprouting and may be related to poor quality attributes. A degree of variability was observed between our samples with Sham-1, Douma-1105 and Douma-26827 having falling number values below 500 s while the remaining genotypes had falling number values above 500 s.

Some significant differences were observed in the ash content of the genotypes, with the studied genotypes ranging between 1.45% and 1.74% (on dry basis) (Table 3). Douma-29019 showing the lowest ash content of all genotypes and being significantly different to all genotypes excepting Douma-18861 and Douma-1105. This is likely to be due to the genetic similarity of the Douma samples compared with the Sham and Bohouth genotypes. The ash values for whole grain are at levels typically observed (Cubadda, 1988).

Protein content exhibited significant variations among the studied genotypes and ranged between 10.7% and 14.1% (on dry base) (Table 3), and generally showed lower values than durum wheat grown elsewhere (Autran & Galterio, 1989; Carrillo *et al.*, 1990; Ames

Table 3 Chemical characteristics of grain from Syrian durum wheat genotypes

Genotypes	Moisture %	Falling No. Sec	Ash (db)%	Protein (db)%	Starch (db)%
Sham-1	8.5 ^a	433 ^a	1.65 ^{a,b}	12.7 ^{a,b}	64.4 ^a
Sham-3	8.2 ^a	528 ^b	1.74 ^a	12.1 ^a	64.3 ^a
Sham-5	8.3 ^a	502 ^b	1.70 ^a	12.9 ^{a,b}	65.0 ^{a,b}
Bohouth-5	8.2 ^a	505 ^b	1.71 ^a	12.6 ^{a,b}	66.2 ^b
Bohouth-7	8.3 ^a	597 ^c	1.65 ^{a,b}	12.7 ^{a,b}	66.8 ^b
Douma-1105	9.1 ^a	472 ^d	1.55 ^{a,b,c}	12.8 ^{a,b}	64.4 ^a
Douma-18861	8.1 ^a	524 ^b	1.47 ^{b,c}	14.1 ^c	64.4 ^a
Douma-26827	8.1 ^a	485 ^d	1.70 ^a	10.7 ^d	68.2 ^c
Douma-29019	8.2 ^a	501 ^b	1.45 ^c	13.1 ^b	68.3 ^c

^a means values in the same column, followed by a different letter are significantly different ($p < 0.05$).

et al., 1999). The low protein contents of the genotypes examined may be an indication of the low nitrogen contents of the gypsiferous soils in which the crops were grown. Dry gluten contents of the kernels also varied between genotypes (results are not shown). Starch content of the samples ranged from 64.3% for Sham-3 to 68.3% for Douma-26827, and showed significant variations between genotypes (Table 3). A negative correlation between starch and protein ($r = -0.42$) was observed (Table 2). This observation was to be expected as starch and protein levels (based as a % of kernel weight) are intrinsically linked.

Protein content and test weight were not correlated (Table 2). Previous correlations by Tkachuk & Kuzina (1979) and Matsuo & Dexter (1980) have illustrated that low test weight is an indication of shrunken kernels and higher protein content. Durum kernels evaluated in this study were generally plump, with > 85% of the kernels classified as large (Table 1).

Positive correlations existed between protein content and the degree of vitreousness ($r = 0.78$) and kernel weight ($r = 0.75$) (Table 2). These results emphasise the role that protein has on kernel weight and the degree of vitreousness. Our previous research, on similar durum wheat genotypes, also demonstrated a correlation between protein content and vitreousness (El-Khayat *et al.*, 2003). Protein content also had a positive correlation with semolina extraction ($r = 0.49$), which is probably related to the relationship between protein content and vitreousness. Dexter *et al.* (1989) reported that nonvitreous regions were low in protein.

Starch content of the kernel was negatively correlated with 1000-kernel weight ($r = -0.54$), and was positively correlated with test weight ($r = 0.78$) (Table 2). It is of interest to note that starch content did not correlate with vitreousness in this particular study. However in our previous paper (El-Khayat *et al.*, 2003) a clear relationship existed between high starch content and a decrease in kernel vitreousness.

The end-product utilisation of the durum wheat crop focuses on the semolina market, hence there exists the need to investigate the quality attributes needed to supply this market. It is recognised that high extraction rates for durum wheat semolina (rather than the smaller particle sized flour) is of importance to the miller (Troccoli *et al.*, 2000), and that semolina yield is related to kernel hardness. Although researchers have linked factors such as test weight and 1000-kernel weight to semolina yield and hence indirectly to grain hardness (Marshall *et al.*, 1986), our research showed that they are only parts of the answer when defining quality attributes. In this research all the genotypes had high test weight and kernel weight (Table 1). In this situation, kernel hardness and the degree of vitreousness and the falling number (measure of soundness and enzymic level of the kernel) became more important than small variations in test weight or kernel size. Both the degree of vitreousness and 1000-kernel weight are considered as primary factors in wheat grading (Dexter *et al.*, 1987). Their effects on wheat milling have been widely investigated (Shuey, 1960; Matsuo & Dexter, 1980; Matsuo *et al.*, 1982b; Hook, 1984; Marshall *et al.*, 1986; Dexter *et al.*, 1987; Halverson & Zeleny, 1988; Troccoli *et al.*, 2000). Previous work has indicated that milling performance of the kernel was related to the size of the kernel, degree of vitreousness and overall hardness of the endosperm; hence, kernels with high protein content are generally assumed to yield more semolina than either starchy or piebald kernels (McDermott & Pace, 1960; Matsuo, 1988; Troccoli & Di Fonzo, 1999).

Conclusions

The Syrian durum wheat genotypes varied in kernel vitreousness, kernel hardness, kernel weight, kernel size, semolina extraction, falling number, protein content and starch content. All the Syrian durum wheat genotypes that were evaluated had hard to extremely hard, large, sound kernels which resulted in high test weights and kernel weights. However, all the genotypes tested had low protein content. Experimental line, Douma-18861, had greater vitreousness (93.6%) and protein content (14.1%) than any of the other genotypes (50.4–85.7% and 10.7–13.1%, respectively).

The quality attributes of durum wheat cultivars have often been defined in relation to bread wheat (*T. aestivum*) samples, and the results of these experiments with Syrian durum wheat samples support these associations. Comparisons between the Canadian and US durum wheat grading systems illustrate that improvements in kernel quality are needed to enable the majority of the genotypes examined to reach the highest grade standards in relation to the degree of kernel vitreousness,

whereas all samples were considered to be 1 grade in relation to test weight evaluations.

The results of our correlation analyses confirm the importance of three possible physico-chemical markers with regards to the milling quality attributes of durum wheat, namely the degree of kernel vitreousness, kernel hardness and kernel protein content. In our subsequent study, we aim to examine these parameters in relation to pasta quality and hence link the physico-chemical properties of the kernel to the end-product utilisation of the crop.

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Original article

Durum wheat quality: II. The relationship of kernel physicochemical composition to semolina quality and end product utilisationJihad Samaan,¹ Ghassan H. El-Khayat,^{1,2} Frank A. Manthey,³ Mick P. Fuller¹ & Charles S. Brennan^{1,4*}¹ Applied Food Research Group, University of Plymouth, Newton Abbot, Devon, TQ12 6NQ, UK² Food Science Department, Faculty of Agriculture, University of Damascus, Damascus, Syria³ Department of Plant Sciences, North Dakota State University, Fargo, ND 58105-5728, USA⁴ Institute of Food Nutrition and Health, Massey University, Private Bag 11222 Palmerston North, New Zealand

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Summary Kernel quality characteristics, semolina milling potential, dough rheology and pasta making properties of kernels from nine fully irrigated Syrian durum wheat genotypes were observed. Protein content of the kernels exerted a significant affect on the physical characteristics hardness and the degree of kernel vitreousness, both of which were highly correlated with superior end-use product. Gluten composition of semolina appeared as significant as overall protein content in determining the optimum end-use product cooking quality (cooking time and pasta texture). The final viscosity of durum flour exhibited positive correlations with semolina recovery, protein content, gluten content, vitreousness, the optimum-cooking time of pasta and pasta firmness. This indicates the relevance of using the rapid visco analyser technique in evaluating the durum wheat and pasta qualities. Dough rheology measurements confirmed that farinograph and extensograph are useful indicators of the cooking properties of pasta. The research also illustrates that although variability between Syrian durum wheat genotypes were observed, their milling and processing parameters were similar to those previously reported for Canadian and American durum wheats, indicating the potential to use these lines in mainstream pasta production.

Keywords Gluten, pasta, rapid visco analyser, semolina, vitreous.

Introduction

The majority of durum wheat (*Triticum turgidum* var. *durum*) grown in the Mediterranean countries is milled to form durum wheat semolina. This in turn is used in the manufacture of a multitude of cereal food products, with pasta being the most important in terms of commodity value. The milling requirements of durum wheat are significantly different to those of hard and soft bread wheats (*Triticum aestivum*). The objective of durum wheat milling is to remove the bran and germ from the endosperm and to coarsely grind the endosperm. In general, the particle size of semolina in the USA is such that the entire product passes through a no. 20 sieve (840 µm aperture size), with no more than 3% passing through a no. 100 sieve (149 µm aperture size). In contrast, the particle size of bread wheat flour is normally within the range of 75–150 µm.

Durum wheat kernels tend to be harder than bread wheat kernels (Miller *et al.*, 1982). This is assumed to be

due to the absence of the starch granule puroindoline protein on the surface of the starch granules (Greenwell & Schofield, 1986). Therefore, in order to crack the durum wheat kernel and produce both semolina and durum wheat flour, a high force needs to be applied during milling (Mousa *et al.*, 1983). Durum wheat can be tempered prior to milling in order increase the friability of the endosperm and to reduce the energy required for milling. This tempering is typically used to increase the grain moisture to 17–17.5% moisture in stages over 16–24-h period.

The milling quality of durum wheat is often assessed by the potential extraction rate of the kernels (extraction rate representing the proportion of wheat that is milled into semolina). A high semolina extraction rate reduces the amount of the smaller-sized durum wheat flour and optimises the kernel utilisation for pasta production (Troccoli *et al.*, 2000).

Extensive research has been conducted in order to determine the semolina characteristics required to make high quality pasta (Dexter & Matsuo, 1980; Dexter *et al.*, 1983, 1987; D'Egidio *et al.*, 1990; Dexter *et al.*, 1994; Kovacs *et al.*, 1995; Ames *et al.*, 1999; Manthey &

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Schorino, 2002). The majority of these characteristics are related to dough development, with the protein content and quality of the semolina being closely linked to the elasticity, extensibility and resistance to overcooking of pasta, in a similar way to which gluten has been related to bread dough viscoelastic properties (MacRitchie, 1984; Shewry & Miflin, 1985; Payne, 1987; Wrigley & Bietz, 1988; Gupta *et al.*, 1989; Khan *et al.*, 1990; Gupta *et al.*, 1992; Weegels *et al.*, 1996). Additionally, ash content has been linked to semolina colour where it is used to assess the cleanliness of semolina (Pomeranz, 1987), and hence the appearance of the finished pasta (Troccoli *et al.*, 2000).

Cubadda (1988) investigated the relationship of several semolina characteristics to pasta quality. Assessments were based firstly on the factors that affect dough development and some of the quality aspects of the end-use product, and secondly on factors affecting the cooking quality of pasta. The work illustrated that the particle size distribution of semolina affected dough development by regulating hydration during the mixing stage. Improper hydration is detrimental to dough development so that dough strength tends to decline with increased hydration, partly because of the lack of gluten network formation (Cubadda, 1989).

Dexter & Matsuo (1977) investigated the influence of protein on some of durum wheat quality aspects for two Canadian durum wheat cultivars and found that an increase in protein content was associated with an increase in pigment content and improvement in cooking quality of resulting pasta together with improved tolerance to overcooking. Further work by the same authors investigated thirty lines of durum wheat differing in spaghetti cooking quality (Dexter & Matsuo, 1980). They found that gluten strength had a strong influence on farinograph properties, which, in turn, could be related to improve the pasta cooking quality.

The aim of this work was to extend these previous research findings by studying the aspects of the milling and processing potential of nine Syrian durum wheat genotypes grown under the same environmental conditions, and determining the specific correlations between the physicochemical characteristics of durum wheat kernels, semolina characteristics and pasta quality.

Materials and methods

Nine Syrian spring durum wheat genotypes, SHAM-1, SHAM-3, SHAM-5, BOHOUTH-5, BOHOUTH-7, DOUMA-1105, DOUMA-18861, DOUMA-26827 and DOUMA-29019 were selected. These are from lines recommended for irrigated lands. The first five genotypes are currently in use as on farm cultivars, while the DOUMA genotypes are still in a process of accreditation. The samples were obtained from the Ministry of Agriculture Research Station at Raqqa (Northeast) of

Syria, which is one of Syria's main durum wheat-growing provinces. All genotypes were grown at the same location and under the same agroecological conditions in the crop year 2002 as described in our previous paper (El-Khayat *et al.*, 2006).

Grain was cleaned using a Carter-Day dockage tester (Simon-Carter Company, Minneapolis, MN, USA) that was configured with a number 25 riddle, and two number 2 sieves. Grain was scoured using a cyclone grain cleaner (Foster Manufacturers, Wichita, KS, USA) and tempered to 17.5% moisture. Tempered grain was milled into semolina using a Bühler experimental mill fitted with two Miag laboratory scale purifiers (Bühler-Miag, Minneapolis, MN, USA). Semolina extraction was expressed on a total product basis.

Physicochemical analysis of wheat kernels

Kernel starch content and semolina moisture, protein, gluten content, falling number, and ash were analysed for: kernel vitreousness, hardness, test weight, 1000 kernel weight, moisture, protein, gluten and falling number (as reported in our previous paper, El-Khayat *et al.*, 2006). Amylose content of starch extracted from whole kernels was determined using the Megazyme amylose and amylopectin assay kit (Megazyme International, Wicklow, Ireland). The pasting characteristics of ground durum wheat kernels were investigated using the RVA (rapid visco analyser; Newport Scientific, Warriewood, Australia), adopting the methodology of El-Khayat *et al.* (2003).

Semolina particle size distribution was conducted using the US standard sieves no. 30 (549 µm), no. 40 (420 µm), no. 60 (250 µm), no. 80 (178 µm) and no. 100 (149 µm), which were connected to a Rotap sieve shaker. A 100 g of semolina was shaken for 5 min, and the separated fractions on the top of each sieve were weighed and expressed as a per cent of the whole sample.

Pasta dough characteristics

Extensograph analysis was determined according to the approved AACC method 54-10 (American Association of Cereal Chemists, 2000), measurements recorded were extensibility, resistance to extension, energy and proportional number. Farinograph analysis of semolina samples was determined according to the approved AACC method 54-21 (American Association of Cereal Chemists, 2000) to evaluate the water absorption of the samples.

Pasta production

Spaghetti samples were processed according to the procedure described by Walsh *et al.* (1971) and in the

approved AACC method 66-41 (American Association of Cereal Chemists, 2000). Semolina (1 kg) was mixed with water to reach 32% absorption. The hydrated semolina was mixed at high speed in a Hobart mixer (Hobart Corporation, Troy, OH, USA) for 4 min, placed in a mixing chamber under vacuum, and extruded as spaghetti through an 84-strand Teflon-coated die using a DeMaCo semi-commercial laboratory extruder (DeFrancisci Machine Corp., Melbourne, FL, USA). The extruder was operated under the following conditions: extrusion temperature of 45 °C, mixing chamber vacuum with 46 cm of Hg, and auger extrusion speed of 25 r.p.m.

Extruded spaghetti samples were dried at high temperature 73 °C for 12 h at a relative humidity of 83%.

Pasta quality analysis

Pasta cooked weight was determined according to the approved AACC method 66-50 (American Association of Cereal Chemists, 2000), with some modifications described by Dick *et al.* (1974), where 10 g of dry pasta, broken into approximately 5-cm length, and boiled in 300 mL of distilled water. Each pasta sample was cooked to its optimal cooking time (defined as the time required for the white core in the centre of the pasta strand to disappear). Optimum-cooking time was assessed by removing a strand from the cooking water every 30 s and cut between two plexiglass plates. Subsequently, the cooked pasta was rinsed with distilled water 25 °C and drained for 2 min, weighed, and the final weight reported in gram.

Cooking loss was conducted by the AACC approved method 66-50, where the cooking water and rinse water were dried in an air oven at 110 °C, and the residue was weighed and reported as a percentage of the total dry sample weight (Dick *et al.*, 1974).

Pasta firmness was determined as of Tudorica *et al.* (2002) using a Stable Microsystems TAXTII machine (Stable Microsystems, Reading, UK) according to the

approved AACC method 66-50 (American Association of Cereal Chemists, 2000). The mechanical strength of dried pasta was determined by placing ten strands from each sample (10-cm long) on the heavy duty stage of the Texture Analyser, and the samples cut with a craft knife.

Statistics

All measured characteristics were conducted in triplicate and expressed as means, apart from farinograph analysis which was performed in duplicate. Correlation coefficients were run between the different variables using the MICROSOFT EXCEL. Analysis of variance (ANOVA) was performed using MINITAB 1332 software package (Minitab Inc., State College, PA, USA).

Results and discussion

Table 1 details the extraction rates and particle size analysis of the semolina from the nine Syrian durum wheat lines. Extraction rates for semolina varied between genotypes from 62.7% (Douma 1105) to 65.5% (Bohouth 5 and 7). Douma 1105, 26827 and Sham 3 all yielded significantly lower extraction rates than the Bohouth samples. However, the extraction rates observed are within the expected ranges for hard durum wheat material (60–68%).

Although the semolina extraction rate is important from a commercial basis, research conducted by Dexter & Matsuo (1978a) has indicated that the extraction rate of semolina may not exhibit a significant effect on spaghetti cooking quality. Conversely, semolina particle size distribution has an important role in pasta making because of its effect on the hydration rate (Posner & Hibbs, 1997). Grant *et al.* (1993) demonstrated that as semolina PSI decreased, water absorption increased, and the firmness of the resulting spaghetti decreased. Table 1 illustrates that the amount of material with a particle size > 250 µm did not significantly vary between

Table 1 Semolina extraction rate and particle size distribution of durum semolina

Cultivars	Semolina extraction %	% No. 30**	% No. 40**	% No. 60**	% No. 80**	% No. 100**	% Pass no. 100**
Sham-1	64.2 ^{a,b}	0.63	11.50	47.30	27.20	4.20	9.10
Sham-3	62.9 ^b	0.60	11.30	48.30	26.70	4.30	8.80
Sham-5	65.0 ^a	0.56	10.70	47.90	27.50	4.50	9.00
Bohouth-5	65.5 ^a	0.52	10.40	48.70	27.20	4.40	8.60
Bohouth-7	65.5 ^a	0.50	10.70	48.40	27.50	4.40	8.20
Douma-1105	62.7 ^b	0.60	9.80	48.00	27.40	4.60	9.20
Douma-18861	64.7 ^a	0.50	10.60	47.10	27.50	4.70	9.00
Douma-26827	62.9 ^b	0.50	10.70	47.40	27.40	4.70	9.00
Douma-29019	64.0 ^c	0.60	10.50	46.60	27.50	4.60	9.70

^aMeans values in the same column, followed by a different letter are significantly different ($P < 0.05$).

**No significant difference observed between cultivars in particle size distribution.

lines (60.2% Sham -1; 57.7% Douma 29019). All of the lines demonstrated a predominant amount of material retained on no. 60 sieve (between 250 and 420 µm), which is the preferential level for pasta semolina.

Table 2 details some of the physical characteristics of tested durum wheat genotypes and the chemical compositions of the subsequent semolina used in the production of pasta. These results are reported as example of the data used in the calculation of correlations reported in Table 3.

Our previous paper has discussed some of the variations observed between lines in their kernel characteristics (El-Khayat *et al.*, 2006). Semolina moisture ranged between 13.33% and 13.80%, whereas ash content ranged from 0.64% to 0.75%. Between lines, variations were not significant. These values are similar to those reported for semolina from durum wheat grown in Canada and the US. The protein content of the

semolinas (on a 14% moisture level) was relatively low with the semolina of Douma 18861 exhibiting the higher protein levels than the rest of the samples, and the semolinas of Sham 3 and Douma 26827 exhibiting the lowest protein contents. A similar pattern was observed for both wet and dry gluten.

Table 3 illustrates correlations between the physico-chemical properties of the durum wheat kernels and the milling potentials. The rate of semolina extraction showed a positive correlation to semolina protein content ($r = 0.67$). A positive correlation was also observed between semolina extraction and kernel hardness ($r = 0.76$), and degree of vitreousness ($r = 0.57$). Generally, protein content of a semolina is regarded as being linked to the level of semolina extraction as protein content increases from the centre of the endosperm outward towards the aleurone and bran layer. Thus, as milling extraction increases, more endosperm

Table 2 Some physiochemical characteristics of durum wheat kernels, and subsequent semolina, used for pasta production

Cultivars	Kernel characteristics				Semolina characteristics							
	Hardness Av.	Vitreousness %	1000 kernel weight (g)	Test weight in kg hl ⁻¹	Amylose %	Starch % on dry base	Moisture %	Ash % on 14% moist.	Protein % on 14% moist.	Wet gluten (g)	Dry gluten (g)	Falling no. second
Sham-1	89.1 ^a	71.33 ^a	50.31 ^a	84.90 ^a	28.3 ^a	64.43 ^a	13.80 ^a	0.69 ^a	10.22 ^a	26.48 ^a	9.88 ^a	433 ^a
Sham-3	86.7 ^a	52.70 ^b	55.54 ^a	83.10 ^a	27.6 ^a	64.29 ^a	13.54 ^a	0.75 ^a	9.31 ^b	25.00 ^{a,b}	8.96 ^b	528 ^b
Sham-5	95.7 ^b	60.43 ^c	50.35 ^a	84.90 ^a	27.8 ^a	65.01 ^a	13.72 ^a	0.74 ^a	10.34 ^a	27.49 ^{a,c}	10.30 ^a	502 ^b
Bohouth-5	94.3 ^{a,b}	63.07 ^c	55.12 ^a	84.10 ^a	29.0 ^a	66.24 ^b	13.56 ^a	0.67 ^a	10.08 ^{a,b}	24.41 ^b	9.20 ^b	505 ^b
Bohouth-7	100.9 ^b	85.73 ^d	49.62 ^a	85.50 ^a	29.8 ^a	66.82 ^b	13.52 ^a	0.69 ^a	10.24 ^a	27.32 ^{a,c}	9.31 ^b	597 ^c
Douma-1105	91.5 ^{a,b}	63.33 ^c	50.71 ^a	84.15 ^a	30.4 ^a	64.39 ^a	13.39 ^a	0.66 ^a	9.97 ^{a,b}	26.13 ^a	8.96 ^b	472 ^d
Douma-18861	98.1 ^b	93.63 ^e	50.81 ^a	83.70 ^a	28.7 ^a	64.42 ^a	13.41 ^a	0.65 ^a	10.85	29.37 ^d	10.61 ^a	524 ^b
Douma-26827	90.6 ^{a,b}	50.43 ^b	42.53 ^b	85.50 ^a	28.0 ^a	68.24 ^c	13.55 ^a	0.71 ^a	9.48 ^b	25.69 ^b	9.14 ^a	485 ^d
Douma-29019	89.3 ^a	69.40 ^a	50.41 ^a	85.90 ^a	27.8 ^a	68.28 ^c	13.33 ^a	0.64 ^a	10.10 ^a	28.14 ^{c,d}	9.68 ^{a,b}	501 ^b

^aMeans values in the same column followed by a different letter are significantly different ($P < 0.05$).

Table 3 Correlations between the physicochemical properties of the durum wheat kernels and the milling potentials

	Semolina extraction	Falling no.	Protein	Wet gluten	Dry gluten	Starch	Hardness	Vitreousness	1000 kernel weight	Test weight	Moisture	Ash
Amylose	0.12	0.20	0.26	-0.03	-0.29	-0.17	0.50**	0.39	0.04	-0.06	-0.30	-0.41*
Semolina extraction		0.43*	0.67***	0.28	0.47*	0.07	0.76***	0.57**	0.25	0.18	0.24	-0.17
Falling no.			0.10	0.21	-0.07	0.20	0.65**	0.40*	0.16	0.00	-0.33	0.08
Protein				0.78***	0.82***	-0.23	0.63**	0.84***	0.07	0.08	-0.03	-0.56**
Wet gluten					0.79***	0.00	0.39	0.74***	-0.24	0.28	-0.29	-0.46*
Dry gluten						-0.23	0.32	0.58**	-0.06	0.06	0.19	-0.22
Starch							0.07	-0.15	-0.54**	0.78***	-0.31	-0.22
Hardness								0.63**	-0.09	0.20	-0.02	-0.16
Vitreousness									0.08	0.05	-0.23	-0.58
1000 kernel weight										-0.66***	-0.02	0.01
Test weight											0.02	-0.21
Moisture												0.63**

*, **, ***Correlation significantly different at the 0.05, 0.01 and 0.001 level of probability, respectively.

near the bran and aleurone layers is removed, resulting in increased semolina protein content. The semolina yields for most of the lines investigated were on the lower side of acceptability, this would indicate a removal of starchy endosperm region around the bran layer, and explain the low semolina protein levels within our samples. The semolina protein content of the lines followed similar correlation patterns to that previously recorded in our previous paper concentrating on their kernel proteins (El-Khayat *et al.*, 2006), which showed positive correlations to wet and dry gluten content, whilst negative correlations to ash and starch content. Table 3 illustrates that both kernel hardnesses, and also the degree of vitreousness within kernels, are correlated to the amount of protein in the semolina recovered after milling ($r = 0.63$ and 0.84 , respectively). This observation is consistent with previous research indicating that vitreous kernels are harder, and of higher protein content, than starchy kernels (Stenvert & Kingswood, 1977; Dexter *et al.*, 1989; El-Khayat *et al.*, 2003). As such, the results clearly illustrate the importance of protein content on kernel hardness, the degree of kernel vitreousness and milling potential.

Table 4 illustrates some of the quality characteristics of the cooked pasta obtained from the durum wheat samples. Optimum-cooking time ranged from 9 min for Sham-3 and Douma-26827 to 10.5 min for Douma-18861. Actual cooked weight showed no significant difference among the cooked pasta samples and ranged between 29.56 and 30.50 g. On the other hand, cooking loss residue and cooked firmness demonstrated significant variations among spaghetti made from the different lines. Cooking loss ranged from 5.9% for Bohouth-5 to 7.33% for Douma-1105.

When the tested pasta samples were overcooked 6 min, increases in cooked weight and cooking loss

associated with a decrease in firmness were observed (Table 4). As would be expected, all the tested pasta samples exhibited significant increases in cooked weight when overcooked by 6 min, compared with the cooked weight in optimum time.

The physicochemical composition of the kernel has an important role with regard to processing and cooking quality of pasta from durum semolina. Table 5 illustrates the correlations between some of these physicochemical properties and processing qualities.

Numerous investigations have been detected to find the relationship between test weight and milling potential (Mangels, 1960; Shuey, 1960; Johnson & Hartsing, 1963; Barmore & Bequette, 1965; Shuey & Gilles, 1972; Watson *et al.*, 1977a,b; Matsuo & Dexter, 1980; Matsuo *et al.*, 1982; Hook, 1984; Dexter *et al.*, 1987). Of these, Dexter *et al.* (1987) demonstrated a highly significant correlation among test weight, milling characteristics and pasta quality, where a linear decrease of 0.7% in semolina yield was associated with a 1-kg decrease in test weight. However, Hook (1984), when reviewing the relationship between test weight and milling potential, suggested that there was no general agreement among the researchers with regard to the use of test weight as a predicting index for milling potential. This supports our finding, where the correlation between test weight and milling extraction was poor ($r = 0.18$).

Amylose content of the durum wheat semolina showed positive correlations to farinograph water absorbance, optimum-cooking time and cooking loss of the pasta, whilst being negatively correlated to peak viscosity (Table 5). These results are in general agreement with previous research demonstrating that lower amylose is associated with higher peak viscosity, and variations in water absorption (Zeng *et al.*, 1997; Jane *et al.*, 1999). Similarly, Sharma *et al.* (2002), when

Table 4 Cooking characteristics of pasta produced from a range of Syrian durum wheat cultivar

Cultivars	Optimum-cooking time in minute	Actual cooked wt. (g)	Residue (g)	Firmness (g cm ⁻¹)	Optimum time plus six min.			Breaking force of dried pasta (g)	Number of checks of dried pasta	Colour score of dried pasta
					Cooked weight (g)	Residue (g)	Firmness (g cm ⁻¹)			
Sham-1	9.50 ^a	30.22 ^a	6.10 ^a	3.80 ^a	37.06 ^a	7.93 ^a	3.10 ^a	102.1 ^a	105 ^a	8.5 ^a
Sham-3	9.00 ^b	30.11 ^a	6.23 ^{a,b}	3.60 ^a	37.29 ^a	7.87 ^a	2.90 ^a	94.3 ^b	55 ^b	8.0 ^b
Sham-5	9.50 ^a	30.27 ^a	6.07 ^a	4.50 ^b	36.50 ^a	6.77 ^a	3.40 ^{a,b}	99.5 ^{a,c}	77 ^c	7.0 ^c
Bohouth-5	9.50 ^a	30.50 ^a	5.90 ^a	3.70 ^a	35.87 ^a	7.60 ^a	3.10 ^a	97.4 ^{b,c}	67 ^{b,c}	7.0 ^c
Bohouth-7	9.50 ^a	29.56 ^a	6.50 ^b	4.40 ^b	34.93 ^a	7.90 ^a	3.70 ^{b,c}	98.6 ^c	53 ^b	8.5 ^a
Douma-1105	10.00 ^c	30.27 ^a	7.33 ^c	3.80 ^a	35.13 ^a	8.33 ^a	3.20 ^a	100.6 ^c	37 ^b	8.0 ^b
Douma-18861	10.50 ^c	29.55 ^a	6.13 ^{a,b}	5.50 ^c	34.67 ^a	7.33 ^a	4.10 ^c	101.5 ^{a,c}	53 ^b	9.0 ^d
Douma-26827	9.00 ^b	29.67 ^a	6.72 ^b	4.20 ^{a,b}	35.46 ^a	7.77 ^a	3.20 ^a	104.3 ^{a,c}	73 ^c	8.5 ^a
Douma-29019	9.50 ^a	29.67 ^a	6.20 ^a	4.50 ^b	35.38 ^a	7.70 ^a	3.60 ^{a,b}	100.2 ^c	41 ^b	8.5 ^a

^aMeans values in the same column, followed by a different letter are significantly different ($P < 0.05$).

Table 5 Correlations between dough rheology and pasta quality

	Extensibility	Resistance	Water absorption	Optimum-cooking time	Residue	Pasta firmness	Spaghetti hardness	Peak viscosity	Final viscosity
Amylose	-0.24	-0.11	0.82***	0.50*	0.60**	-0.07	0.06	-0.82***	-0.07
Semolina extraction	-0.30	-0.26	0.45*	0.26	-0.63**	0.34	-0.16	0.24	0.53*
Falling no.	-0.25	0.47*	0.18	0.01	-0.09	0.32	-0.47*	0.07	0.31
Protein	0.28	-0.63**	0.42*	0.83***	-0.31	0.72***	0.27	0.12	0.62**
Wet gluten	0.85**	-0.31	-0.08	0.64**	-0.10	0.90***	0.37	0.21	0.51*
Dry gluten	0.52*	-0.55*	-0.08	0.57**	-0.52*	0.78***	0.32	0.52*	0.57**
Starch	-0.18	0.04	-0.41*	-0.41*	0.03	0.09	0.30	0.05	0.13
Hardness	-0.16	-0.15	0.56*	0.42*	-0.06	0.51*	0.04	-0.16	0.40*
Vitreousness	0.06	-0.32	0.36	0.75***	-0.18	0.69***	0.14	0.04	0.68**
1000 kernal weight	-0.19	0.16	0.44*	0.13	-0.42*	-0.29	-0.85***	0.18	0.04
Test weight	0.10	-0.03	-0.20	-0.24	0.08	0.16	0.54*	-0.18	-0.07
Moisture	-0.20	0.04	0.03	-0.37	-0.39	-0.33	0.04	0.13	-0.28
Ash	-0.12	0.62**	-0.22	-0.68**	-0.10	-0.41*	-0.35	0.14	-0.52*
Extensibility		-0.14	-0.23	0.36	0.18	0.47*	0.27	0.08	-0.13
Resistance			-0.11	-0.64**	0.17	-0.43*	-0.59*	-0.15	-0.54*
Water absorption				0.47*	0.18	-0.16	-0.27	-0.60**	-0.11
Optimum cooking					0.09	0.63**	0.24	-0.11	0.51*
Residue						-0.18	0.30	-0.83***	-0.51*
Pasta firmness							0.38	0.38	0.73***
Spaghetti hardness								-0.15	0.15
Peak viscosity									0.58*

*, **, ***Correlation significantly different at the 0.05, 0.01 and 0.001 level of probability, respectively.

investigating the relationship of starch and protein content in durum wheat pasta, found a positive correlation to the amount of amylose and the cooking loss ($r = 0.62$) and a negative correlation with peak viscosity ($r = -0.69$). It is interesting to note that although amylose content affected the peak viscosity of the semolina and also the cooking loss of the pasta, no significant correlation was observed between amylose content and the firmness of the pasta. Additionally, starch content of the semolina did not appear to affect the texture of the pasta produced significantly.

Falling number values of the durum wheat semolina were positively correlated to dough resistance and cooked spaghetti firmness ($r = 0.47$ and $r = 0.32$, respectively). Matsuo *et al.* (1982) and Grant *et al.* (1993) indicated that low falling number values (associated with high α -amylase activities because of field sprouting) tended to increase the amount of residue in spaghetti cooking water, and reduced the firmness of spaghetti. This causal relationship may help explain the correlations observed within the Syrian genotypes examined.

Increased protein content of the semolina was linked to increased pasta firmness and a reduction in cooking loss. Work conducted by Grzybowski & Donnelly (1979) also illustrated that spaghetti cooking loss and firmness were correlated with protein content and gluten strength. This is likely to be associated with the increase observed in optimum-cooking time of pasta

made from high protein semolina (Table 5). Both wet and dry gluten content were positively correlated to optimum-cooking time ($r = 0.64$ and 0.57 respectively), with wet gluten content of the pasta being highly correlated to cooked spaghetti firmness ($r = 0.90$). The relationship between protein (gluten) content and pasta textural and cooking properties is associated with the ability of the protein within the pasta to form a tenacious dough structure during mixing, and a firm visco-elastic matrix on cooking. This can be observed in the positive correlations between both wet and dry gluten contents and extensibility of the doughs produced in the extensograph, and the negative correlations of protein content and gluten content to dough resistance to extension.

The importance of protein in dough and pasta quality has been studied extensively (Matsuo *et al.*, 1972; Dexter & Matsuo, 1977; Grzybowski & Donnelly, 1979; Dexter & Matsuo, 1980; Autran & Galterio, 1989; D'Egidio *et al.*, 1990; Novaro *et al.*, 1993; Sharma *et al.*, 2002; Edwards *et al.*, 2003). Both protein content and gluten composition have been linked to the visco-elastic nature of pasta (Dexter & Matsuo, 1978b, 1980; Kovacs *et al.*, 1995; Edwards *et al.*, 2003). Research by Kovacs *et al.* (1995) demonstrated that the mixograph mixing characteristics of durum wheat semolina could be correlated to the viscoelastic nature of cooked pasta, and that these parameters could be correlated to the gluten content (wet and dry) of the semolina rather than

the viscoelastic behaviour of the semolina doughs. More recently, genetical analyses have revealed the importance of *Glu-A* and *Glu-B* loci on protein content and gluten strength of durum wheats (Martinez *et al.*, 2004). Our results support these observations that the gluten composition of the semolina is of more importance than overall protein content. However, it must be emphasised that the protein level of the semolina samples reported in this paper was relatively low. As such, one could speculate that when protein content of the semolina is low the importance of gluten strength (composition) becomes much more important. Further analysis is required to determine the basis behind these observations.

Of the other physicochemical characteristics studied, kernel hardness was observed to be positively correlated to dough water absorbance ($r = 0.56$), pasta optimum-cooking time ($r = 0.42$), and pasta firmness ($r = 0.51$). Similarly, the degree of vitreousness was correlated to optimum-cooking time ($r = 0.75$) and pasta firmness ($r = 0.69$). As the hardness and degree of vitreousness of durum wheat kernels are related to the protein composition of the kernels (Stenvert & Kingswood, 1977; Dexter *et al.*, 1989), these observations were to be expected.

Assessment of the relationships between dough and pasta-handling characteristics and pasta quality illustrate that the viscoelastic nature of the semolina dough is of great importance. Thus, higher extensibility readings were associated with increased pasta firmness and optimum-cooking time (Table 5). The resistance to extensibility may also be a useful parameter to determine in relation to cooking quality, with negative correlations being observed between dough resistance and optimum-cooking time ($r = -0.64$) and pasta firmness ($r = -0.43$). These correlations are likely to be due to the contribution of gluten to the behaviour of the semolina doughs.

The mechanical strength of the dried spaghetti (force in Table 5) was not correlated to the textural analysis of cooked pasta. Dried pasta strength was poorly correlated to optimum-cooking time ($r = 0.24$) and pasta firmness ($r = 0.38$), whilst being negatively correlated to dough resistance ($r = -0.59$), 1000 kernel weight ($r = -0.85$) and falling number ($r = -0.47$). The lack of significant correlation between the mechanical strength of the dried pasta and the subsequent cooking properties is an unexpected finding, but may be related to either the low protein content of the semolina or the drying conditions of the pasta samples. Previous research has demonstrated that high-drying temperature have a positive effect on the spaghetti quality, by increasing the firmness, and decreasing the stickiness and cooking loss (Matsuo *et al.*, 1982; D'Egidio *et al.*, 1990; Grant *et al.*, 1993; Malcolmson *et al.*, 1993; Novaro *et al.*, 1993). Thus, a relationship was expected to have occurred between the pasta-drying temperature and quality.

Results from Table 5 also indicate the possible use of the RVA as a method to analyse the durum wheat kernel quality. The final viscosity of pastes from durum wheat flours showed positive correlations for amount of semolina recovered ($r = 0.53$), the amount of protein in the semolina ($r = 0.62$), the amount of semolina gluten (wet, $r = 0.51$; dry, $r = 0.57$), the degree of kernel vitreousness ($r = 0.68$), optimum-cooking time of pasta ($r = 0.51$) and pasta firmness ($r = 0.73$). The RVA measures the pasting interactions between starch and protein in a high moisture environment and as such would be expected to be correlated to the hydration properties of the semolina, and stability of the resulting product.

Conclusion

The results of this paper indicate that some physicochemical characteristics of durum wheat genotypes were more clearly related to durum wheat milling potential, pasta processing and end-product quality than others. Protein content, kernel hardness and the degree of vitreousness were all positively correlated to semolina recovery after milling.

Additionally, durum wheat protein (gluten) content, kernel hardness and also the degree of vitreousness were important in relation to the optimum-cooking time of the pasta and the firmness of the pasta produced. These relationships are likely to be associated with the tenacity of protein binding and the formation of a strong viscoelastic protein matrix during dough formation. Such associations will provide useful traits for future developments in the Syrian durum wheat breeding programme.

The use of various assessment equipment illustrates that both extensograph and farinograph analysis can be used to evaluate the water absorption behaviour of semolina dough and hence the cooking time and firmness of pasta. However, results of the peak and final viscosity determination of durum wheat flour indicate that the RVA could be a useful tool in relating the kernel and semolina composition to potential pasta quality of durum wheat cultivars.

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EVALUATION OF VITREOUS AND STARCHY SYRIAN DURUM WHEAT (*TRITICUM DURUM*) WHEAT GRAINS: THE EFFECT OF AMYLOSE CONTENT ON STARCH CHARACTERISTICS AND FLOUR PASTING PROPERTIES.

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INTRODUCTION

Durum wheat (*Triticum durum*) is favoured for use in pasta production mainly due to the fact that its kernels show a high degree of vitreousness, and exhibit a hard endosperm. The degree of vitreousness and hardness of durum wheat are involved in the international grading of the kernel and hence commercial value of the commodity (Dexter *et al.*, 1988). Vitreous kernels tend to be harder and of higher protein content than non-vitreous (starchy) kernels (Stenvert and Kingswood, 1977). Additionally, research has indicated that vitreous kernels may exhibit improved cooking quality, better colour, coarser granulation and higher protein content (Matsuo and Dexter, 1980).

Starch is the primary component of wheat. Most of the functional attributes of starch can be related to the temperature interaction of starch with water in the processes known as gelatinisation, pasting, gelation and retrogradation (Dengate, 1984). The physicochemical properties of starch are associated with its amylose and amylopectin ratio (Fredriksson *et al.*, 1998). This in turn has been shown to be under genetic control and varies over a limited range (16-28%) within durum wheat (Leloup *et al.*, 1991). Research by Tester and Morrison (1990) indicated that the degree of wheat (*Triticum aestivum*) starch swelling was related to the amylopectin content, while amylose and lipids could inhibit swelling.

In this paper, we investigate the relationship between amylose content, starch pasting and thermal properties of whole sample, vitreous and starchy grain of durum wheat cultivars.

MATERIALS AND METHODS

Six Syrian durum wheat cultivars, SHAM-1, SHAM-3, SHAM-5, BOHOUTH-5, BOHOUTH-7, and DOUMA-1105 were obtained from Ministry of Agriculture Research Station at Raqqa, Northeast Syria (crop year 2002). All varieties were hand sorted for the degree of vitreousness and 1,000 kernel weight. Test weight, moisture content, and Hagberg falling number were determined for the varieties using the AACC methods 55-10, 44-15, and 56-81B (AACC, 2000). Protein content was conducted by the DUMAS method. The separated fractions (vitreous, starchy and whole-wheat samples) were ground using a laboratory mill, and sieved through standard sieves to obtain flour of 250 µm. Total starch of each of the fractions was determined using AACC method 76-13 (AACC, 2000), as was apparent amylose content (Megazyme amylose / amylopectin assay kit).

Flour pasting properties were evaluated using a Rapid Visco Analyser (RVA-4) and data were analysed using Thermocline software (Newport Scientific Pty Ltd, Warriewood, NSW Australia), with using the parameters of the approved method 76-21 (AACC, 2000). Peak viscosity (PV), holding strength or hot paste viscosity (HPV), breakdown (PV-HPV), final paste viscosity (FV), and setback (FV-HPV), were recorded.

Differential Scanning Calorimeter (DSC) was used to evaluate gelatinisation characteristics using a Mettler TA Instrument DSC 12 E (Mettler Toledo Instruments, Leicester, UK).

the viscoelastic behaviour of the semolina doughs. More recently, genetical analyses have revealed the importance of *Glu-A* and *Glu-B* loci on protein content and gluten strength of durum wheats (Martinez *et al.*, 2004). Our results support these observations that the gluten composition of the semolina is of more importance than overall protein content. However, it must be emphasised that the protein level of the semolina samples reported in this paper was relatively low. As such, one could speculate that when protein content of the semolina is low the importance of gluten strength (composition) becomes much more important. Further analysis is required to determine the basis behind these observations.

Of the other physicochemical characteristics studied, kernel hardness was observed to be positively correlated to dough water absorbance ($r = 0.56$), pasta optimum-cooking time ($r = 0.42$), and pasta firmness ($r = 0.51$). Similarly, the degree of vitreousness was correlated to optimum-cooking time ($r = 0.75$) and pasta firmness ($r = 0.69$). As the hardness and degree of vitreousness of durum wheat kernels are related to the protein composition of the kernels (Stenvert & Kingswood, 1977; Dexter *et al.*, 1989), these observations were to be expected.

Assessment of the relationships between dough and pasta-handling characteristics and pasta quality illustrate that the viscoelastic nature of the semolina dough is of great importance. Thus, higher extensibility readings were associated with increased pasta firmness and optimum-cooking time (Table 5). The resistance to extensibility may also be a useful parameter to determine in relation to cooking quality, with negative correlations being observed between dough resistance and optimum-cooking time ($r = -0.64$) and pasta firmness ($r = -0.43$). These correlations are likely to be due to the contribution of gluten to the behaviour of the semolina doughs.

The mechanical strength of the dried spaghetti (force in Table 5) was not correlated to the textural analysis of cooked pasta. Dried pasta strength was poorly correlated to optimum-cooking time ($r = 0.24$) and pasta firmness ($r = 0.38$), whilst being negatively correlated to dough resistance ($r = -0.59$), 1000 kernel weight ($r = -0.85$) and falling number ($r = -0.47$). The lack of significant correlation between the mechanical strength of the dried pasta and the subsequent cooking properties is an unexpected finding, but may be related to either the low protein content of the semolina or the drying conditions of the pasta samples. Previous research has demonstrated that high-drying temperature have a positive effect on the spaghetti quality, by increasing the firmness, and decreasing the stickiness and cooking loss (Matsuo *et al.*, 1982; D'Egidio *et al.*, 1990; Grant *et al.*, 1993; Malcolmson *et al.*, 1993; Novaro *et al.*, 1993). Thus, a relationship was expected to have occurred between the pasta-drying temperature and quality.

Results from Table 5 also indicate the possible use of the RVA as a method to analyse the durum wheat kernel quality. The final viscosity of pastes from durum wheat flours showed positive correlations for amount of semolina recovered ($r = 0.53$), the amount of protein in the semolina ($r = 0.62$), the amount of semolina gluten (wet, $r = 0.51$; dry, $r = 0.57$), the degree of kernel vitreousness ($r = 0.68$), optimum-cooking time of pasta ($r = 0.51$) and pasta firmness ($r = 0.73$). The RVA measures the pasting interactions between starch and protein in a high moisture environment and as such would be expected to be correlated to the hydration properties of the semolina, and stability of the resulting product.

Conclusion

The results of this paper indicate that some physicochemical characteristics of durum wheat genotypes were more clearly related to durum wheat milling potential, pasta processing and end-product quality than others. Protein content, kernel hardness and the degree of vitreousness were all positively correlated to semolina recovery after milling.

Additionally, durum wheat protein (gluten) content, kernel hardness and also the degree of vitreousness were important in relation to the optimum-cooking time of the pasta and the firmness of the pasta produced. These relationships are likely to be associated with the tenacity of protein binding and the formation of a strong viscoelastic protein matrix during dough formation. Such associations will provide useful traits for future developments in the Syrian durum wheat breeding programme.

The use of various assessment equipment illustrates that both extensograph and farinograph analysis can be used to evaluate the water absorption behaviour of semolina dough and hence the cooking time and firmness of pasta. However, results of the peak and final viscosity determination of durum wheat flour indicate that the RVA could be a useful tool in relating the kernel and semolina composition to potential pasta quality of durum wheat cultivars.

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Results from all of the tests were calculated as means \pm SD. Analysis of variance (ANOVA), followed by Tukey test, were performed using Minitab 1332 software (Minitab Inc. USA). Results were reported on significant level 5% ($p < 0.05$).

RESULTS AND DISCUSSION

Starch characteristics of durum wheat cultivars

Figure 1 illustrates the differences observed in total starch between flours made from whole sample, vitreous and starchy fractions. Flours made from starchy kernels exhibited a much higher total starch content compared to the fractions from either the vitreous or whole sample from each durum wheat variety. Bohouth-7 and Sham-1 exhibit the highest total starch content in the starchy kernel fractions.

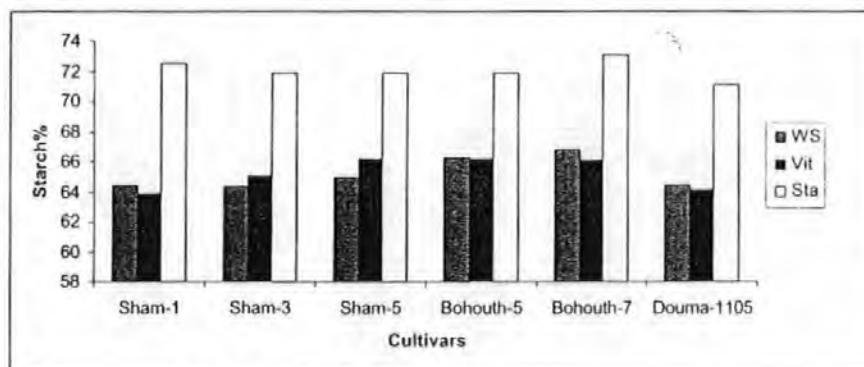


Figure 1. Total starch content on dry basis.

Determination of apparent amylose content showed a different characteristic with the starchy fractions of each variety having a significantly reduced amylose content compared to the vitreous fraction of the same variety (Figure 2).

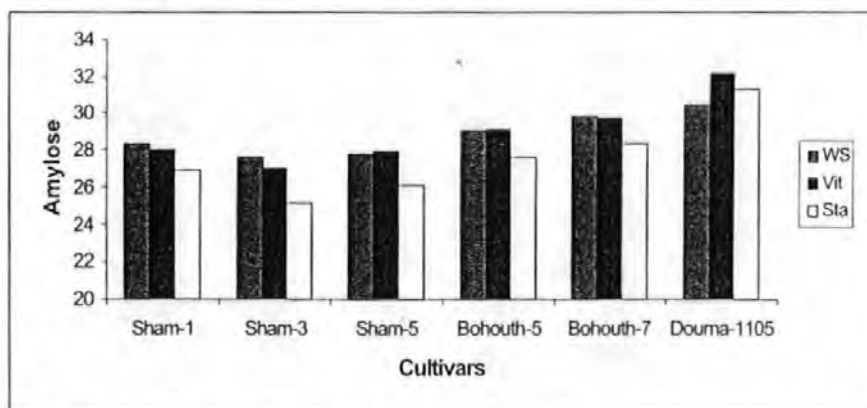


Figure 2. Amylose content of tested cultivars.

Pasting properties of flours

The pasting properties of the flours showed variability in relation to the degree of vitreousness of the varieties (Figure 3). Generally peak viscosity of the sample was seen to be higher in the

flour fractions from starchy kernels of the same variety compared to those of the vitreous kernels.

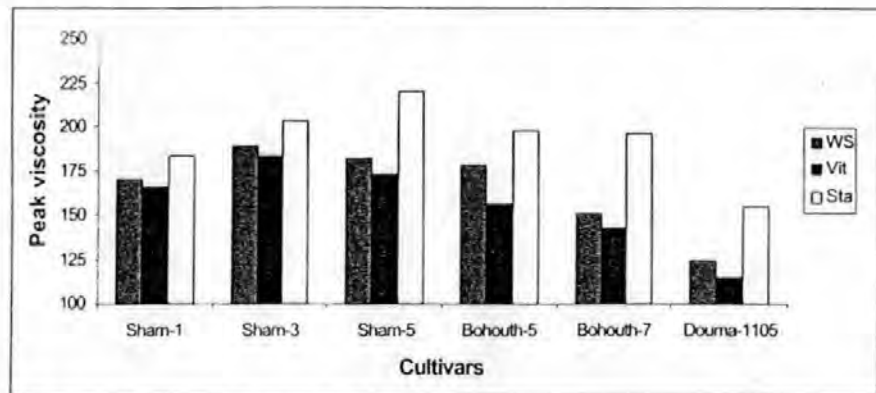


Figure 3. Peak viscosity (RVU) of the tested cultivars.

Breakdown values of the flours were also seen to be higher in the starchy kernel flours than the vitreous flours. This could be due to the higher amount of total starch in the starchy kernels compared to the vitreous kernels, or conversely the greater amount of protein in the vitreous kernels. However, when examining the data for correlation fits, the amylose content of grain was found to have a high negative correlation to both the peak viscosity (Figure 4) and the breakdown (Figure 5) characteristics of the varieties examined.

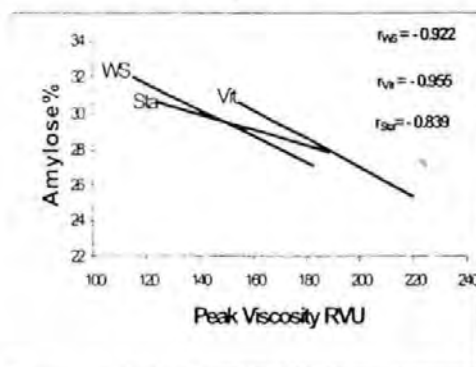


Figure 4. Correlation amylose between peak viscosity.

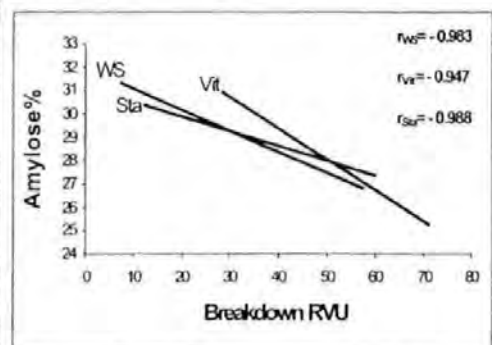


Figure 5. Correlation amylose between breakdown.

The main variation in composition of starches has previously been attributed to the relative proportions of amylose and amylopectin in the starch granules (Hermansson and Svegmarm, 1996). Results from our research indicate that differences in amylose content may have a greater effect on the swelling and disruption of the granule, rather than the subsequent realignment of the starch components during retrogradation.

Thermal properties

DSC analysis of the fractions showed non-significant variations in gelatinisation on-set, peak and end-set. Greater variation was observed in the total enthalpy (ΔH) of gelatinisation from each of the fractions (Table 1). Generally speaking, vitreous grains exhibited lower total

energy of enthalpy when compared to starchy grains of the same cultivar. This may be due to the higher amylose content in vitreous grains depressing the enthalpy energy, or just a result of higher starch content in the starchy grains. No correlation could be found between amylose content and thermal properties of the Syrian durum wheat cultivars investigated in this report.

Table 1. Enthalpy energy of the wholemeal durum wheat cultivars.

Cultivars	Enthalpy (ΔH)-J/g		
	WS	V	S
Sham-1	3.6 \pm 0.0	4.0 \pm 0.3	4.7 \pm 0.0
Sham-3	4.7 \pm 0.2	3.6 \pm 0.1	4.4 \pm 0.1
Sham-5	4.2 \pm 0.3	3.9 \pm 0.2	4.8 \pm 0.1
Bohouth-5	4.3 \pm 0.4	4.1 \pm 0.0	4.4 \pm 0.1
Bohouth-7	3.9 \pm 0.1	3.4 \pm 0.2	4.6 \pm 0.0
Douma-1105	4.1 \pm 0.2	3.3 \pm 0.2	3.8 \pm 0.2

CONCLUSION

Variation in apparent amylose content exists on a genetical basis between whole grain samples of Syrian durum wheat cultivars. Grain samples classified as starchy have an increased total starch content but a generally lower amylose content when compared to grain classified as vitreous. This difference in starch characteristics may explain the increased visco-gelatinisation properties (peak viscosity, breakdown and final viscosity) in starchy grains compared to vitreous grains coupled to a similar trend to elevated total enthalpy (ΔH). The clear negative correlation observed between amylose content and peak viscosity and breakdown illustrates the importance of amylose content when evaluating the potential use of durum wheat cultivars.

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DURUM WHEAT PASTA QUALITY: COMPARISON OF FLOUR PASTING AND STARCH CHARACTERISTICS OF NEW SYRIAN *TRITICUM DURUM* CULTIVARS

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Developing new high quality durum wheat cultivars is beneficial for both producers and consumers. Durum wheat production in Syria has historically been used to fulfil internal demands, however more recently wheat from Syria has been exported for pasta manufacture. The current project examined a range of established, and new, durum wheat lines in relation to their physico-chemical and processing characteristics. Significant differences were observed in grain hardness related to the protein content of the grains and the ratio of starchiness: vitreousness within the lines. Quantitative and qualitative variations in starch characteristics (amylose:amylopectin content, pasting and gelatinisation profile) were observed between cultivars, and between vitreous and starchy kernels of the same cultivars. Cultivars which have a higher degree of vitreousness (Sham-1 and Douma-18861) exhibited an increase in both protein and amylose content, that was associated with lower starch content compared with the other cultivars having lower vitreousness (Douma-26827 and Douma-29019). Pasta quality (cooking time and texture) could also be shown to be related to the characteristics of the starch granules within durum wheat flours. The results will prove a useful tool in predicting suitability of wheat varieties for pasta manufacture and improving wheat crop quality.