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SUMMARY - The technological quality of durum wheat covers an array of characteristics ranging from semolina yield to the ability of semolina to be processed into pasta. The aim of this paper is to define the grain characteristics that influence these aspects. Semolina yield is a fusion of grade, intrinsic properties and ash content. Pasta quality can be considered either from the visual or cooking point of view. The visual aspect considers pasta colour, which is due to the combination of two components; yellowness and browness. The yellow colour is a function of the carotenoid content and the lipoxygenase activity, whereas the brown colour is attributed to peroxidase and polyphenoxydase. Cooking quality is associated with gluten properties. Protein content may account for 30-40% of the variability in cooking quality, but the protein type has a strong effect on quality. The paper also reviews the protein components, gliadin and glutenin components, and the association of gamma 42 and 45, and two molecular weights (LMW) 1 and 2 with gluten strength. The role of high molecular weights (HMW) and starch components is also discussed.

Key words: Durum wheat, *Triticum turgidum* var. *durum*, pasta quality, storage proteins, wheat quality.

RESUME *- "La qualité du blé dur dans les pays méditerranéens". La qualité technologique du blé dur englobe toute une série de caractéristiques qui vont du rendement semoulier jusqu'a l'aptitude à la transformation de la semoule en pâ tes. Le propos de cet article est déffinir les caractéristiques du grain qui influent sur ces aspects. Le rendement semoulier est une combinaison du calibre, des propiétes intrinsèques et de la teneur en cendres. La qualité pastière peut être considérée du point de vue soit visuel soit culinaire. L'aspect visuel tient compte de la couleur de la pâte, qui est due à la combinaison de deux composantes : les couleurs jaune et brune. La couleur jaune est une fonction de la teneur en carotenoïdes et de l'activité de lipoxygénase, tandis que la couleur brune est attribuée à la péroxydase et à la polyphénoxydase. La qualité culinaire est associée aux propriétés du gluten. La teneur en protéines peut expliquer 30-40% de la variabilité de la qualité culinaire, mais le type de protéine a un fort effet sur la qualité. Cet article passe également en revue les composantes de la protéine, les composantes gliadine et gluténine, et l'association de gamma 42 et 45, et deux des hauts poids moléculaires (HMW) et des composantes amylacées est également discuté.*

Mots-clés : *Blé dur, qualité du blé, Triticum turgidum var. durum, qualité pastière, protéines de réserve.*

Introduction

Domesticated from wild grasses, present in the steppes and dry areas of Southwest Asia, some 10-15,000 years ago, wheats have allowed the first human settlements and consequently higher levels of social life.

Tetraploid forms were deeply involved in this process along with diploid ones, as documented by archaeological findings and by the fact that hexaploid forms originated and evolved only later, in cultivated fields.

Today, durum wheat (*Triticum turgidum* var. *durum*) covers approximately 20 million hectares world wide, which represent less than 10% of the total wheat areas. More than half of its hectarage lies in the Mediterranean region, where it may account for more than 50% of the land area under wheat (Bozzini, 1988).

Annual production is estimated around 30-35 million tons, one fourth of which in the European Union, followed by Southwest Asia and America (Bozzini, 1988). Production fluctuations are mainly due to climatic conditions, especially erratic rainfalls, which heavily affect the per hectare crop yield (Bozzini, 1988).

The main use of durum wheat grain is for pasta making, including couscous and burgul, although in the Mediterranean countries a large part of the harvest is devoted to bread preparation (Quaglia, 1988). Part of this latter is, however, non-fermented bread, whose characteristics rest on a set of technological properties will consequently concentrate on pasta production.

The different use of the harvested grains makes it difficult to assess quality properties, since, as for other industrially processed commodities, the quality concept is closely linked to that of the processing industries, as well as to that of the final product.

The expression "technological quality of durum wheat", therefore, covers an array of characteristics ranging from semolina yield, namely the quantity of semolina extracted from a unit of grain processed, to the ability of semolina to be processed into pasta, that meet the consumer's requirements.

This paper attempts to define the grain characteristics that influence these aspects. Nutritive values are deliberately omitted, since differences among varieties are very small, and the role of wheat products in every day meals is decreasing rapidly.

Semolina yield

The amount of semolina that can be extracted from a unit of commercial grain is function of three main factors or groups of factors, that can be summarized as follows.

Grade

The first group of factors to be considered is usually named grade. Grade systems are different from country to country. Usually they include factors related to growing, harvesting, and storage conditions - such as water content, foreign matter, other types of wheat, broken, starchy, and sprouted kernels, etc.- assessed at dockage, more than variety properties. Their importance on semolina yield is quite obvious, but there is no scope for breeders to consider them. In addition they may affect test weight, a rough measure of the grain density and consequently of its soundness and higher milling yield.

Intrinsic properties

The second group of factors includes intrinsic properties, such as grain vitreousness, 1000 kernel weight, and endosperm-outer layers separation, which have a genetic basis, although largely affected by environmental factors. Their importance is more intuitive than scientific, nevertheless they are considered important by milling industry.

Grain vitreousness has a considerable impact on milling value, since vitreous and hard kernels tend to break into semolina, whereas even partially starchy grains tend to break up into fine products, thus reducing the semolina yield. In traditional milling, where given sizes of semolina grains are obtained, the negative influence of non-vitreous kernels is beyond question, but the present industrial trend toward fine semolina has greatly reduced the real influence of these kernels. It is worthwhile, however, to stress that couscous preparation requires large size semolina, and consequently vitreousness is still very important.

In addition, vitreousness is correlated to other factors, such as protein content, cooking quality, pasta colour, etc., and industry continues to prefer wheat low in non-vitreous grain.

The factor 1000 kernel weight is a rough measure of grain size and endosperm-bran ratio. No valid study demonstrates that small grains, low 1000 kernel weight, varieties have a lower semolina capacity; however, a low 1000 kernels weight resulting from grain shrinkage has a highly negative effect on semolina yield.

The easy separation of the endosperm from the outer layers is another characteristic that may prevent a satisfactory separation of the bran, whereas bran particles adhering to the endosperm may cause the presence of specks in the semolina and ultimately in the pasta.

Ash content

The third group contains a single factor, grain ash content, the percentage of which affects the semolina extraction rate. Semolina ash content, the upper limit of which is subject to regulation in most of countries, is in fact correlated to that of the whole grain as well as to the extraction rate; more specifically parts close to the bran contain more minerals than parts in the centre of the endosperm; consequently when the grains are high in mineral elements, less semolina can be extracted as compared to semolina from grains containing lower amounts of mineral elements. Mineral composition is thought to depend on minerals availability in the soil to the plant, but different varieties of wheat appear to absorb different levels of them from the same soil (Dikeman *et al.*, 1982), bringing opportunity for selection.

Pasta quality

Pasta quality can be considered either from a visual or cooking point of view.

Visual aspects

As for the visual aspect is concerned, the main factor to be considered is the pasta colour, which is controlled by grain properties (Dexter and Matsuo, 1977b), whereas chapping, white, brown, and block specks and/or roughness are the result of improper processing conditions, and/or impurities.

Pasta colour is due to the combination of two components: yellowness and browness. The yellow component is function of carotenoid content and lipoxygenase activity (Irvine and Winkler, 1950; Irvine and Anderson, 1953), with the latter promoting the oxygenation of the former, during processing, and the disappearance of yellow. Carotenoids include carotene and xanthophylls; among these latter predominate free lutein, lutein monoester, lutein diester, triticoxanthin, taraxanthin, flavoxanthin and canthaxantin (Laignelet, 1983), with some variation in content among varieties. Also lipoxygenase varies widely among durum wheats, it is an inherited characteristic (Lee *et al.*, 1976), with three isoenzymes, designed as L-1, L-2 and L-3 (Hsied and McDonald, 1984), and good opportunities for selection. However, Matsuo *et al.* (1970) found that the adding of purified wheat lipoxygenase to the dough did not affect the final pasta colour, and considered the substratum availability more important than the lipoxygenase activity, the role of which was questioned also by Burov *et al.* (1974).

Undesirable browness is attributed to peroxidase and polyphenoxydase (Laignelet *et al.*, 1972), contained in the grain (Kobrehel *et al.*, 1972). Durum wheat has lower polyphenoloxydase activity than other types of wheat. The existence of multiple forms of the enzymes, with different electrophoretic mobility, has been demonstrated along with their independence from the growing conditions (Kobrehel and Gautier, 1973, 1974), and selection for low peroxidase activity was consequently recommended as a mean to reduce pasta browning.

Cooking quality

Apart from small differences due to the taste of every single consumer, the cooking quality of pasta is generally regarded as the capacity of the product to maintain good texture after cooking, and not to become a thick, sticky mass. Aroma and taste are also important to the consumer, but they may be strongly affected by seasoning.

Cooking quality essentially depends on the intrinsic properties of the durum wheat used, although it can be affected by manufacturing conditions as well as by semolina extraction rate.

De Cillis (1942) was one of the first to show that pasta produced by using vitreous grains, which possess higher protein content, has better cooking quality than that obtained from starchy grains, which possess lower protein content. The same conclusion was reached by Matweef (1963), who later on (Matweef, 1966) showed the existence of a consistent relationship between grain protein and gluten content *vs* pasta cooking quality; he also pointed out that wheats with at least 13% of protein can provide an excellent product, whereas those with protein content below 11% give lower quality products.

Gluten properties were also identified as an essential factor of cooking quality (Matweef, 1966; Sheu *et al.*, 1967; Matsuo and Irvine, 1970). These results were confirmed by many other scientists (Matsuo *et al.*, 1972; Feillet *et al.*, 1977b; Dexter and Matsuo, 1977a; Donnelly, 1979; Grzybowski and Donnelly, 1979; Irvine, 1979) and numerous procedures were proposed to evaluate gluten strength (Matweef, 1966; Matsuo and Irvine, 1970; Feillet *et al.*, 1977a; Matsuo, 1978; Dexter *et al.*, 1980; Matsuo *et al.*, 1982). It is usually accepted that protein content may account for some 30-40% of the variability in cooking quality (Damidaux and Feillet, 1978; Dexter *et al.*, 1980), but also protein type has a strong (up to one third) effect on quality (Feillet and Abecassis, 1976).

The importance of protein composition emerged in the early 70's, when Walsh and Gilles (1971) found that durum wheat varieties with high glutenin content tend to show good cooking quality, and high gliadin content was related to low cooked spaghetti firmness. Wasik and Bushuk (1975) found that glutenin/gliadin ratio, rheological and cooking tests ranked a set of durum wheat varieties in the same order. The relationship between glutenin/gliadin ratio and cooking quality was confirmed by Dexter and Matsuo (1977a), who later on (Dexter and Matsuo, 1978, 1980) demonstrated, by protein fractionation, that insoluble residue protein fractions were most responsible for variation in gluten strength and spaghetti quality. These findings promoted a wide array of studies on gliadin and glutenin composition, inheritance, etc. the results of which can be summarized as follows:

(i) Gliadins are monomers having low Molecular Weight (MW: 25-70 Kd), known for conferring extensibility. They are classified in alfa, beta, gamma and omega according to their relative mobility upon gel electrophoresis with aluminium lactate, and in alfa, gamma, and omega, according to their N-terminal aminoacid sequence, with the first two classes containing cystein, which may form intra-molecular disulfide bonds; omega gliadins do not contain sulfur aminoacids.

(ii) Glutenins are protein complexes having high molecular weight, made up of numerous polypeptidic subunits, joined together by inter-molecular disulfide bonds. Glutenin subunits are grouped into two distinct fractions, classified, according to their mobility in SDS-PAGE under reducing conditions, in high (HMW: 80-140 Kd) and low (LMW: 40-55 Kd) molecular weight glutenins. HMW subunits contain higher amounts of glycine and lower amount of proline (Shewry *et al.*, 1986). LMW subunits are similar to gliadins as for aminoacid composition and molecular weight, but dissimilar from gliadins, they may form inter-molecular disulfide bonds, binding themselves and HMW glutenin subunits to form alcohol insoluble complexes.

(iii) Wheat protein components are inherited as single co-dominant genes.

(iv) Gliadins components are coded by genes located on short arm for the homologous chromosomes 1 (*Gli-1*) and 6 (*Gli-2*) of both A and B genomes (du Cros *et al.*, 1983; Lafiandra *et al.*, 1983), and closely linked to form complex loci, or blocks (Sozinov and Popereleya, 1982).

(v) Loci for LMW glutenin subunits (*Glu-3*) are located on short arm of chromosomes 1 of both A and B genomes, and are closely linked to *Gli-1* (Pogna *et al.*, 1990).

(vi) Genes for HMW glutenin subunits are located on long arm of chromosomes A and B (Payne *et al.*, 1981), on complex loci indicated as *Glu-A1* and *Glu-B1*, each of which contains two structural genes, coding for two subunits, possessing different MW and indicated as x and y. Penetrance of *Glu-A1* subunit is almost equal to zero in durum wheat, whereas that of genes for other HMW subunits is intermediate.

(vii) A tremendous amount of variability exists for gliadin components and glutenin subunits, both in cultivated forms and wild relatives (Waynes and Payne, 1987; Levy *et al.*, 1988; Branlard *et al.*, 1989; Ciaffi *et al.*, 1990), offering wide opportunity for selection. Analyses also allowed the identification of lines which lack entire groups of gliadin components or glutenin subunits (null forms), coded by genes at specific complex loci (Lafiandra *et al.*, 1987, 1988, 1989) and wild relatives which show good penetrance also for those genes which usually are silent in the cultivated forms (Waynes and Payne, 1987).

(viii) Aminoacid sequences, derived from nucleotide sequences, indicate that polypeptides contain both repeated and unrepeated domains, with sulphur groups mainly located in the unrepeated domains.

(ix) Gliadins possess an even number of sulphur groups as expected by monomers having intramolecular bonds (Shewry *et al.*, 1989).

(x) HMW glutenin subunits are formed by a long series of repeats with two short lateral domains, containing cystein residues, whereas LMW glutenin subunits contain a shorter central domain and the cystein residues are scattered along the longer lateral domains.

(xi) Two gamma gliadins, indicated as gamma 42 and gamma 45, according to their relative electrophoretic mobility, were identified as responsible of or linked to weak and strong gluten and to poor and good pasta quality respectively (Damidaux *et al.*, 1978).

(xii) Since gamma gliadins 42 and 45 were found linked to two allelic variants of LMW glutenin subunits having different molecular weight and isoelectric points, and indicated as LMW1 and LMW2, Payne *et al.* (1984) suggested that the relation between gluten strength and gamma gliadins 45 and 42 was likely to be caused by LMW glutenin subunits. Pogna *et al.* (1988), utilizing a recombinant line containing gamma gliadin 42 and LMW-2 firstly reported by Margiotta *et al.* (1987), were able to show the functional direct role of LMW subunits in gluten viscoelastic properties.

- The presence of cystein residues along a relevant part of the aminoacid sequence would, in fact, allow for interpeptide bonds at different positions through most of the sequence and between different polypeptides, giving rise to a compact and complex multidimensional structure.
- This fact supports the hypothesis that the ability of proteins to form, during pasta preparation, an insoluble network, capable of retaining the other components of semolina, and especially starch granules, during cooking, could be responsible for the quality of cooked pasta, as reported by Matsuo *et al.* (1982), Resmini and Pagani (1983), and Feillet (1986).
- The observation that LMW-2 is expressed in much greater amounts than LMW-1 pushed Autran *et al.* (1987) to hypothesize that higher amounts of glutenins may be responsible for gluten strength much more than the sequence of their polypeptides. While this hypothesis opens new research fields, with the analysis of gene promoters, in order to understand relationships existing between structure in this region and efficiency of gene transcription and translation, results already supply breeders with new screening methods to identify high quality durum wheat lines.

(xiii) The involvement of other genes at *Glu A3*, *Glu A1* and *Glu B1* loci cannot be ruled out as found by Leisle *et al.* (1981); du Cros *et al.* (1982, 1983); Autran et Feillet (1987); Autran *et al.* (1987); Pogna *et al.* (1990) and Tomassini *et al.* (1988).

(xiv) The ways by which proteins control this process have yet to be clarified.

From a research point of view, also the hypothesis put forward by Feillet (1988) is stimulating. During processing, the dough is forced by kneading worm into the press head, where the pressure may reach 150 kg cm^{-2} and later on heated to temperatures between 50-120°C for drying. In this process, proteins are submitted to intense mechanical and physico-chemical stresses, which may modify their physico-chemical properties. As a matter of fact, decrease in the sulphydril groups and increase in disulphide groups (Nazarov and Shebershneva, 1973) and disulphide bonds (Nazarov, 1970) have been reported. Additional modifications may be easily hypothesized. Feillet *et al.* (1977b) indicated, in fact, that mechanical shearing, due to sheeting mixing and extruding, may break glutenins into highly reactive new polypeptide chains that may be merged and oriented when passing through the extrusion die, and cross linked by disulphide bonds, arising from reactions between sulphydril groups, to form a more stable network.

It is worth mentioning, in this context, that Petruzzelli *et al.* (1981) found a significant and negative correlation between proteolytic activity and cooking quality and did not exclude the possibility that proteases could significantly affect the ability of semolina to produce high quality spaghetti by enzymatic breakdown of peptide chains. A similar conclusion was reached by Dal Bellin Peruffo and Pallavicini (1980), who determined that HMW proteins were primarily hydrolysed. These findings and hypotheses, and the observation made by Resmini and Pagani (1981) that the protein matrix in durum wheat semolina is uniformly dispersed into granular spaces with particles of 70-1000A, whereas, in dried spaghetti, the particles have clearly interacted, so that empty spaces are not more visible, and that, after cooking, the protein matrix is structured in a fibrilar network of polymerized subunits which appears before cooking when high temperature systems are used in drying, bring the possibility of a role of interactions not only among different protein types but also between proteins and carbohydrates in determining the pasta quality.

Starch, although it may represent up to 80% of semolina dry matter, has not been studied so deeply as protein, at least with regard to the evaluation of its role in determining the quality of alimentary pasta. The lack of interest may be attributed to the opinion that a substance as chemically uniform as starch cannot have the high reactivity of proteins, but the difficulties in analyzing them must not be underestimated. The presence in starch of two components, amylose and amylopectine, assuming different relative positions, makes the starch granule a physically heterogeneous structure with regard to its behaviour in relation to other semolina components.

Attempts to correlate the starch content of semolina with the cooking firmness of the obtained pasta have always indicated a negative correlation; however, it should be noticed that such correlation values may be heavily affected by the high negative relation between protein and starch content.

Gelatinization data for durum starches isolated from semolina and spaghetti showed that semolina starch has a higher peak viscosity than the starch isolated from spaghetti (Lintas and D'Apollonia, 1973). This decrease in peak viscosity, as result of processing, indicated that starch damage occurred to some extent during processing.

Experiments on water binding capacity and starch damage revealed that the percentage of damaged starch had greatly increased during pasta processing. Further studies showed that some starch was damaged during the extrusion phase but the greatest change occurred during the drying step (Lintas, 1972). A certain degree of variability among different wheat varieties was also noticed.

Analyses carried out by D'Egidio *et al.* (1983), measuring the pasta cooking and rinsing water, indicated that, in good quality pasta, amylose content increased in the starch that leached into the cooking water and decreased in the starch on the surface of the cooked pasta, as recovered in the rinsing water, whereas the amount of amylopectin leached into the rinsing water was almost twice what would be predicted on the basis of the amylose content in the cooking water. It was hypothesized that, in poor quality wheats, amylose and amylopectin are more loosely bound and form areas of less resistance to the action of the boiling water.

However, there were differences depending on whether semolina or dry pasta was used in the analyses. When semolina was used, the role of proteins was prevalent and that of other components was irrelevant. When pasta was use, the dominance of proteins decreased and the role of starch increased and was positive; but whereas amylopectin behaves in the same manner as starch, amylose had a significant negative regression coefficient (D'Egidio *et al.*, 1983), indicating that starch change at the expenses of amylose is to be preferred.

Quite similar results were obtained with pentosans, which, as known, consist of highly branched linear xylanes, with single L-arabinose side chains, mostly protein free (araboxylanes) and highly branched galactose backbone chains with single L-arabinose side chains, containing about 8% of proteins, mainly HMW, covalently bound through hydroxyproline residues. Medcalf *et al.* (1968) showed that water soluble pentosans from durum wheat are more branched than those from hard red spring wheat, and even small differences in the degree of branching may greatly alter the degree and type of interactions of polysaccharides with proteins; interactions may be also altered by MW, and they may affect such things as water absorption.

The yield of water soluble pentosans from spaghetti is much higher than that from semolina, whereas the opposite is true for the water insoluble ones (Lintas and D'Apollonia, 1973), supporting the observation of Neukom *et al.* (1962) that insoluble pentosans are degraded during pasta processing by the action of pentosanases, causing an increase in the amount of insoluble pentosans.

Results from starch and pentosans experiments pushed Fortini (1988) to indicate, echoing Feillet *et al.* (1977b), that chemical composition of semolina does not take into account the reactions that may take place between semolina components, during pasta processing, and the consequent formation of aggregates, with properties different from that of individual components.

Not many experiments have been designed with this approach, but the isolation of a protein fraction able to form complexes with starch and the linear disappearance of both protein and amylose from the solution (D'Egidio *et al.*, 1984), indicated to Fortini (1988) that, in some wheats, improvements in pasta quality can be better explained by an increase in the protein fraction interacting with other components than by an increase in protein content itself.

Further research on the interactions occurring among different semolina components during processing and among pasta components during cooking would help in elucidating processes occurring and roles played by different wheat properties in determining pasta quality.

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