NUTRITIONAL AND MIXING CHARACTERISTICS OF ORGANICALLY GROWN WHEAT GENOTYPES

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Figure 1 reprinted with kind permission of 'orders@biomatrixone.com' **and** also available at www.biomatrixone.com/support_anti-ox.html

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Summary

The topic of this introductory paper is nutritional and mixing characteristics of organically grown wheat genotypes. Due to large consumption of wheat based products, they are among the main sources in the world of nutrition for human. The wheat grain contains e.g. proteins, carbohydrates, minerals and vitamins. The composition of various compounds in the wheat grain depends upon different factors such as variety, soil, environment, management practice, grain processing and post harvest methods etc. Organic cultivation similarly as other cultivation practices influence amounts of different compounds in the wheat grain. Organic conditions are thought to influence amount of antioxidants and other nutritional compounds in the wheat and is also known to influence bread making quality. Therefore it is important to study those parameters of different wheat varieties grown under organic conditions. This review paper is also discussing the mixing behavior of organically grown wheat being important in determining bread making quality.

Preface

Dramatic changes have taken place in the food preferences by people. The consumer demand for high quality food products has been increased. Today, consumers do not think only of food to be good and contain the needed nutrients but food can also act as “preventive medicine”. Organic food products are appreciated in the market. Wheat food products are among the most consumed foods in the world. For most wheat food products, bread-making is an important aspect. This introductory paper is a review about nutritional aspects and bread making quality of organically grown wheat flour. It intends to be a background for PhD-education aiming to investigate nutritional and mixing characteristics of organically grown wheat cultivars of Sweden.

Contents

Introduction

Today, wheat is a dominant cereal crop in the world (Davidson and Passmor, 1986). Total world wheat production is about 250 grams per person per day. It nourishes more people than any other type of cereal grains. Wheat production in Sweden has varied between 1.55 and 2.28 million metric tones during 1995-2003 and about 1/3 of the Swedish wheat production is used for human consumption (FAO data base, 2004). Examples of wheat food products are bread, pasta, macaroni, crackers, spaghetti etc. Bread is an important product of wheat flour and part of daily food consumption in many parts of the world. It is an important source of carbohydrates, proteins, minerals and antioxidants.

Consumers demand for quality food is continuously increasing and thereby also the need of information about nutritional aspects. Evaluation of the quality of wheat includes functional properties for bread making and nutritional composition. About 70% of consumers use food choice to demonstrate their attitude (Hansen *et al*., 2001). In the Nordic countries 50% of the consumers are conscious about ethical issues, environmental problems and animal welfare. Reasons of buying organic food are related to health security and environmental safety (Meier-Ploeger, 2005).

Nutritional composition of bread might influence health of humans. The main factors that influence the nutritive value of wheat include: genetics, environment (soil type, structure and microorganisms; climate, management practices) and post harvest practices (harvest time, handling and processing method) (Hornick, 1992). The development in agriculture during last five decades has not only increased the production tremendously, but it has also given rise to increased amount of environmental problems.

Wheat

Wheat domestication started 10,000 years ago with cultivation of einkorn, a diploid wheat with seven chromosome pairs. Later tetraploid wheats known as emmer and durum evolved (Heun *et al*., 1997). Common wheat, which is used to make most of the wide variety of products today, is hexaploid. Three species of wheat are grown today, common or bread wheat (*Triticum aestivum)*, Durum wheat (*Triticum durum)* and spelt wheat *(Triticum spelta)*. In USA and Canada the common or bread wheat (*Triticum aestivum)*, form five classes: hard red winter, hard red spring, soft red winter, hard white and soft white. Different wheat classes show variation in nutritional characteristics and uses (Table 1). Durum wheat (*Triticum durum)* includes today, the durum and red durum wheat classes, and spelt wheat *(Triticum spelta).* Currently about 4000 wheat cultivars are grown all over the world (Posner, 2000).

Table 1: Wheat classes, their general characteristics and uses (Atwell, 2001).

Class	General Characteristics	General uses
Hard red winter (HRW)	High protein, strong gluten, high water absorption	Bread and related products
Soft red winter (SRW)	Low protein, weak gluten, low water absorption	Cakes, cookies, pastries, pie crusts, crackers, biscuits
Hard red spring (HRS)	Very high protein, strong gluten, high water absorption	Bread, bagels, pretzels and related products
Hard white	High protein, strong gluten, high water absorption, bran lacks pigment	Bread and related products
Soft white	High protein, strong gluten, high water absorption	Noodles, crackers, wafers and other products in which specks are undesirable
Durum	High protein, strong gluten, high water absorption	Pasta

Organic Farming

Introduction and history

According to the International Federation of Organic Agriculture the term "organic farming" can be defined as:
"Organic farming is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic farming combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved" (IFOAM, 2007).
According to FAO definition;
Organic farming is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes, the use of management practices in preference to the use of off –farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system (FAO, 1999).

In simple words organic farming is the practice of growing crops without the use of chemical pesticides, herbicides and fertilizers. It relies mainly on crop rotation, organic fertilizers and plant-based pesticides and herbicides to maintain soil productivity and tilth. Organic agriculture is the oldest form of agriculture on earth. Farming without the use of fertilizers and pesticides was the sole option for farmers until the end of World War II. The war brought with it technologies that were useful for agricultural production. For example, ammonium nitrate used for munitions during World War II evolved into ammonium nitrate fertilizer; organophosphate nerve gas production led to the development of powerful insecticides. These developments gave economic benefits as well as environmental and social disorders (Bourn and Prescott, 2002). Biological, cultural and physical methods are used in organic farming to control pests and weeds.

Principles of organic agriculture

Organic agriculture is based on four principles (IFOAM, 2007):

1. Health: organic agriculture should sustain and enhance the health of soil, plant, animal and human beings.
2. Ecology: organic agriculture should be based on living ecological systems and cycles, work with them and sustain them.
3. Fairness: It should build on relationships that ensure fairness with regard to the common environment and life opportunities.
4. Care: Organic agriculture should be managed in a responsible manner to protect the health and well being of current and future generations.

Why is organic farming important?

Consumers demand for organic foods has been increased during the last decade. The consumption of organic agricultural products has increased from 1.5-2.5% during 2003-2004 in Europe (Willer and Yussefi 2005, Oberholtzer *et al*., 2005).
The factors that effect the purchasing of organic food may vary from region to region. Pesticide residues in food have been found more important in the decision to purchase organic food products than concerns for the environment as a whole, although the later factor is more important in some countries (Byrne *et al*., 1992). The environmental issue most drastically influencing organic farming is global warming. Chemical fertilizers, pesticides and herbicides increase yield of crops but might also have harmful impact on the atmosphere and on the quality of food. Conventional agriculture relies heavily on chemicals, although they might disturb eco-system if they enter the soil and seep into water supplies (Hansen *et al*., 2001).

Production of organic wheat

Statistical information about the production of organically grown wheat in the world is limited. International Federation of Organic Farming Movements (IFOAM) is supposed to calculate the area under organic cultivation world wide. The certified organic production area in Europe (EU25) was 5.76 million hectares according to the Council Regulation (EEC) 2092/91 at the end of 2004 (Willer and Yussefi, 2006). More than 2/3 of EU arable organic production is located in Italy (32%), Germany (25%) and Austria (11%) (Yussefi and Willer, 2002). The area under organic wheat production was 290346 hectares in 2005-06 which accounts 18% of total arable organic land in Europe (Mäder *et al.,* 2007).

Organic wheat field in Alnarp, Sweden

Nutritional characteristics of wheat

Antioxidants

Introduction and importance

An antioxidant is a donating atom of an electron to a free radical. A molecule is only a free radical if it possesses one or more unpaired electron (Fig 1). Thus an antioxidant is any substance that delays or prevents oxidation also when the antioxidant is present in low concentrations compared with those of the oxidizable substrate (Halliwell and Gutteridge, 2007). Mechanisms of antioxidants consist of free radical quenching, transition metal chelating, reducing peroxide, and simulation of in vivo antioxidative enzyme activities (Zhou and Liangli, 2004). Oxidation reactions can produce free radicals, which start chain reactions that damage cells. Antioxidants terminate these chain reactions by removing free radical intermediates. In addition, antioxidants provide defense by chelating transition metals and preventing them from catalyzing the production of free radicals in the cell (Bonoli *et al.,* 2004). Antioxidants include beta-carotene, the vitamins A, C, E and certain trace elements, such as copper (Cu), manganese (Mg), selenium (Se) and zinc (Zn). In addition, phenols and many other non-nutrients to plants may act as antioxidant (Stanner *et al*., 2004). Antioxidants may change oxidative condition and prevent biologically significant molecules such as DNA, proteins, and membrane lipids from oxidative damage (Zhou *et al*., 2004).

The pathology of a number of chronic diseases including cancer, involves damage to cellular components by free radical, i.e. Reactive Oxygen Species (ROS). ROSs are generally very small molecules and are highly reactive due to the presence of unpaired valence shell electrons. ROSs are capable of causing damage to DNA, which is associated with coronary heart disease. ROS include oxygen ions, free radicals, and peroxides. During environmental stress conditions ROS levels can increase dramatically, resulting in significant damage to cell structures. As ROSs are free radicals, antioxidants might terminate ROS attacks and thereby being of primary importance in prevention of diseases (Yu, 2008).

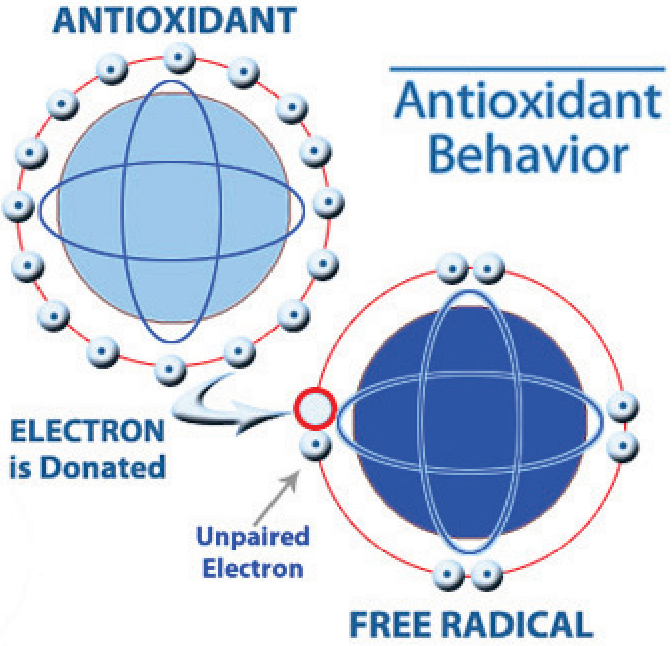


Figure 1: Antioxidant molecule (www.biomatrixone.com)

Cereals, fruits and vegetables are major sources of antioxidants, containing hundreds of beta carotene, vitamins and trace elements with antioxidant activity. Thus consuming cereals, fruits and vegetables result in a potentially beneficial effect on human health by providing defense against oxidative damage (Miller *et al*., 2000). In grain, antioxidants are concentrated in the bran fraction, mainly as phenolic compounds in the form of insoluble bound ferulic acid (Hatcher and Kruger, 1997; Adom and Liu, 2002; Saadi *et al*., 1998). A previous phytochemical investigation established that phenolic acids, tocopherols, and carotenoids are the natural antioxidants present in wheat grain and its fractions (Cheng *et al*., 2006). In wheat, antioxidants like carotenoids and vitamin E content vary according to growth location (Yu *et al*., 2003). Resistance of wheat varieties to diseases such as fusarium head blight or orange wheat blossom might be linked to phenolic compounds contents (Abdel-Aal *et al*., 2001; Atroshi *et al*., 2002). The effect of phenolic compounds in bread dough is not clear but this could be related to dough elasticity through oxidation reaction (Labat *et al*., 2000; Wang *et al*., 2002). Antioxidants play a fundamental role in plants by protecting them from elements such as sunlight and severe oxygen stress (Tominaga *et al.,* 2005). The compounds most frequently damaged during biochemical processes in humans are unsaturated fatty acids in lipids, cholesterol, different functional polypeptides and proteins, and nucleic acids (Stratil *et al.,* 2006).

Activity of antioxidants in foods and biological systems depends on systems' system composition and partitioning properties of the antioxidants between lipid and aqueous phases (Diaz-Reinoso *et al*., 2006).

Tocopherols (Vitamin E)

Vitamin E is the generic term used to describe a family of eight lipid-soluble antioxidants, the tocopherols (*α*-, *β*-, *γ*- and *δ*-tocopherol) and tocotrienols (*α*-, *β*-, *γ*- and *δ*-tocotrienol). Tocopherols and tocotrienols are collectively named as tocols. The basic structure of tocols comprises a 6-hydroxychroman group and a phytyl side chain made of isoprenoid units (Fig 2). The chroman group may be methylated at different positions to generate different compounds with antioxidant activity (Liu, 2007). Tocopherol and tocotrienol have similar structures except that tocopherols contain saturated phytol side chains while tocotrienols have three carbon-carbon double bonds in the phytol side chain. Tocol compounds are found in many foods including whole grains, where they are mostly present in the germ fraction. High levels of tocols are also present in oils, nuts, fruits and berries.

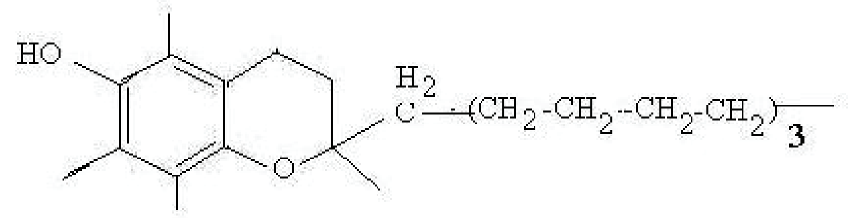


Figure 2: Chemical structure of tocols (www.benbest.com)

Vitamin E is a potent antioxidant by itself, but its effectiveness is magnified when taken with other antioxidant especially vitamin C, selenium (Se) and beta-carotene. Higher vitamin E intake is associated with decreased incidence of heart disease in both men and women (Yu, 2008). Tocopherols help to prevent the peroxidation of membrane phospholipids, and to avoid cell membrane damage through its antioxidant action. The most important function of vitamin E in the body is antioxidant activity and maintenance of membrane integrity by inhibiting peroxidation (Liu, 2007).

In humans absorption is believed to be associated with intestinal fat absorption, in which 40% of the ingested tocopherol is absorbed. All types of vitamin E were shown to accumulate in adipose fat tissue of human (Cuthbertson *et al.*, 1940). The phospholipids of the mitochondria, endoplasmic reticulum, and plasma membranes in the adipose fat tissues of human, are the sites for alpha tocopherol concentration. Tocopherols prefer lipids for their storage so this character of tocopherols makes them possible to locate in the interior of the cell membrane bilayers (Halliwell, 1992; Borg 1993). Tocopherols go into the blood by means of lymph where they are coupled with plasma proteins and form chylomicrons (Liu, 2007).

Carotenoids

Carotenoids are the most widespread pigments of nature with yellow, orange and red colors. They have received substantial attention because of both their role as pro-vitamins and antioxidants. Carotenoids are classified into hydrocarbons (carotene) and their oxygenated derivatives (xanthophylls). More than six hundred different carotenoids have been identified, which occur widely in plants, microorganisms and animals (Liu, 2007).

Carotenoids have a 40- carbon skeleton of isoprene units. Isoprene is a hydrocarbon with double bond, insoluble in water but soluble in organic solvents. The structure of carotenoids may be cyclised at one or both ends. Thus it has ability to accept different numbers of hydrogen atom and oxygen-containing functional groups. Some examples of acyclised and cyclised carotenoids are shown in Figure 3 (Liu, 2007).

The antioxidant function of beta-carotene is to remove the free radicals from cell membrane lipids and protect it from the destructive effects of oxidative degradation. The quenching involves a physical reaction in which the energy of the excited oxygen is transferred to the carotenoid, forming an excited state molecule (Krinsky, 1993).

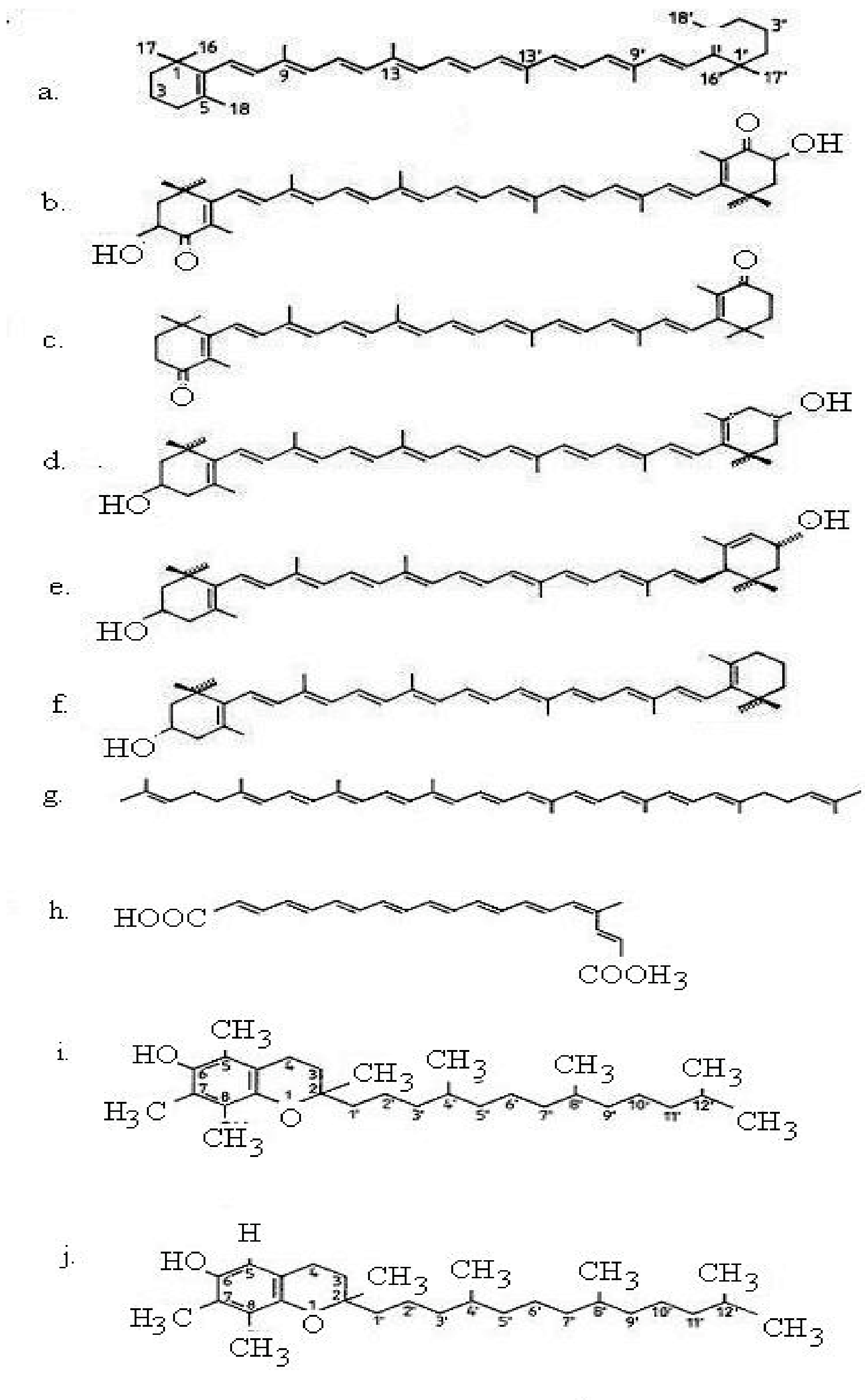


Figure 3. Chemical structures of carotenoids and tocopherols. (a) *β*-Carotene, (b) astaxanthin,(c) canthaxanthin,(d) zeaxanthin,(e) lutein, (f) *β*-cryptoxanthin, (g) lycopene, (h) bixin, (i) *α*-tocopherol, (j) *γ*-tocopherol, (modified from Straub, 1987).

Proteins

Proteins are an important source of energy and an essential component of our diet. Proteins from different foods in our diet contain a number of amino acids. There are 22 amino acids, divided into essential and non-essential amino acids. Essential amino acids must be included in our diet since they cannot be synthesized within the body. Nutritional value of the food depends on proteins composition and upon their specific amino acid composition (Friedman, 1996). Wheat is an important source of proteins since large amounts of wheat is often included in the diet, and wheat contains 8-20% proteins. Wheat proteins are classified into several groups on the basis of their solubility properties, genetic background and amino acid composition etc (Loponen *et al*., 2004). The most well known classification system classifies the wheat proteins into albumins, globulins, gliadins and glutenins on the basis of solubility (Osborne, 1924) (Table 2).

Table 2. The systematics of wheat proteins is classified into groups on the basis of their solubility by Osborne (1924).

Proteins		**Soluble in**	**Location in**
Non-gluten protein	Albumins	Water	Embryo (metabolic proteins) and endosperm cells (cytoplasmic proteins)
	Globulins	Dilute salt solutions (0.5 M NaCl)	Embryo and aleurone layer (storage proteins) and endosperm cells (cytoplasmic proteins)
Gluten proteins	Gliadins	70-80% ethanol	Endosperm (storage proteins)
	Glutenins	Dilute acids or alkali solutions (0.05 M acetic acid)	

The amount of different proteins varies according to the type of wheat, cultivars and growing conditions (Payne *et al.,* 1981; Johansson and Svensson, 1998; Wieser and Seilmeier, 1998; Johansson *et al.,* 2000). The protein composition of typical hexaploid wheat grain is shown in Table 3 with references to studies from different countries.

Table 3. Protein composition of typical wheat grain.
I, Australia (Stone and Savin, 1999), II, USA (Shukla, 1975); III, Canada (Orth and Bushuk, 1972); IV, Germany (Wieser *et al.,* 1980); V, FAO (Aykroyd and Doughty, 1970).

Protein		**I**	**II**	**III**	**IV**	**V**
Non-gluten	Albumins	22%	3-5%	8-9%	15%	15%
	Globulins	15%	10%	4-5%	7%	
Gluten	Gliadins	40%	69%	35-40%	33%	45%
	Glutenins	23%	16%	35-50%	46%	40%

The major wheat storage proteins are gliadins and glutenins present in the starchy endosperm cells of the grain. They are synthesized and deposited in the endosperm through the secretory system. Ribosomes and rough endoplasmic reticulum are the synthesis place for polypeptides. After synthesis polypeptides are translocated into the lumen (Shewry *et al*., 2002). Disulphide bond and protein folding take place in the lumen. The final destination of the proteins may also vary with the protein type and with the age and stage of development of the tissue. Some of the proteins appear to be transported via the Golgi apparatus into the vacuole, where they form protein deposits (Shewry, 1999).

Albumins and globulins

Albumins and globulins are the non-gluten proteins in wheat and they are water-soluble and salt-soluble, respectively. The albumins and globulins are considered nutritionally better than the gluten proteins because of the amino acid compositions with higher contents of essential amino acids (lysine and methionine contents in the albumins and globulins) (Lasztity, 1984).
Albumins and globulins constitute from 12 to 37% of total wheat flour protein (Table 2). Albumins are known to have many different functions and are thus of different types e.g. glycoprotein, amylases inhibitors, serpins, purotionins etc. The glycoproteins are covalently linked with carbohydrates. Many albumins are enzymes such as carbohydrases like α-amylases, β-amylases, or proteolytic enzymes etc (Matz, 1991). Albumins such as α-amylase/trypsin inhibitors (Buonocore *et al*., 1985; Shewry *et al*., 1984), serpins (Østergaard *et al*., 2000) and purotionins (Garcia-Olmedo *et al*., 2002) are considered to have a function of nutrient storage and inhibitor of insect and pathogen attack on

germinating seed. Puroindolines influence grain hardness (Morris, 2002). The globulins are divided into two groups on the basis of sulphur containing amino acids, these are the 7S and 11S globulins. Both the 7S and 11S globulins are composed of multiple subunits (Shewry, 2000).

Gluten

Gluten is the elastic, rubbery protein present in wheat, rye, barley and to a lesser degree in oats. Rice and maize do not contain gluten. Gluten can be readily prepared by gently washing flour under a stream of running water. This removes the bulk of the soluble and particulate matter to leave a protein aqueous mass that retains its cohesiveness on stretching (Shewry *et al.*, 2002). The proteins present in gluten are normally called prolamins. The prolamins or gluten proteins in wheat can be classified as are shown in Figure 5. The gluten proteins are divided into three groups: HMW proteins (HMW glutenin subunits), the sulphur-rich proteins (LMW glutenin subunits, γ-gliadins and α-gliadins) and the sulphur-poor proteins (ω-gliadins) on the basis of amino acid composition and molecular weight (Miflin *et al.*, 1983; Madgwick *et al.*, 1992; Shewry, 1996, 2000). Gluten proteins substantially control the quality of wheat and allow the dough to be processed into a lot of different end-use products including breads (MacRitchie, 1984). The structures of gluten proteins and properties make them interesting for studies relating to functional properties (Shewry and Tatham, 2000).

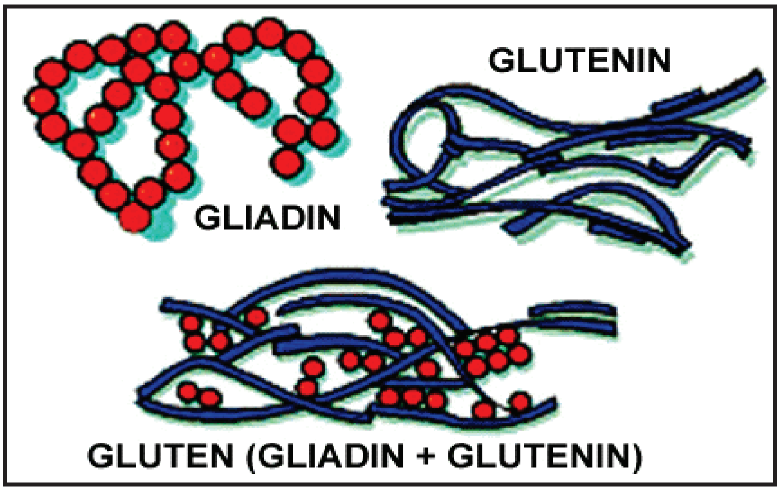


Figure 4. Gluten structure (www.landfood.ubc.ca/.../301/protein/protq4.htm)

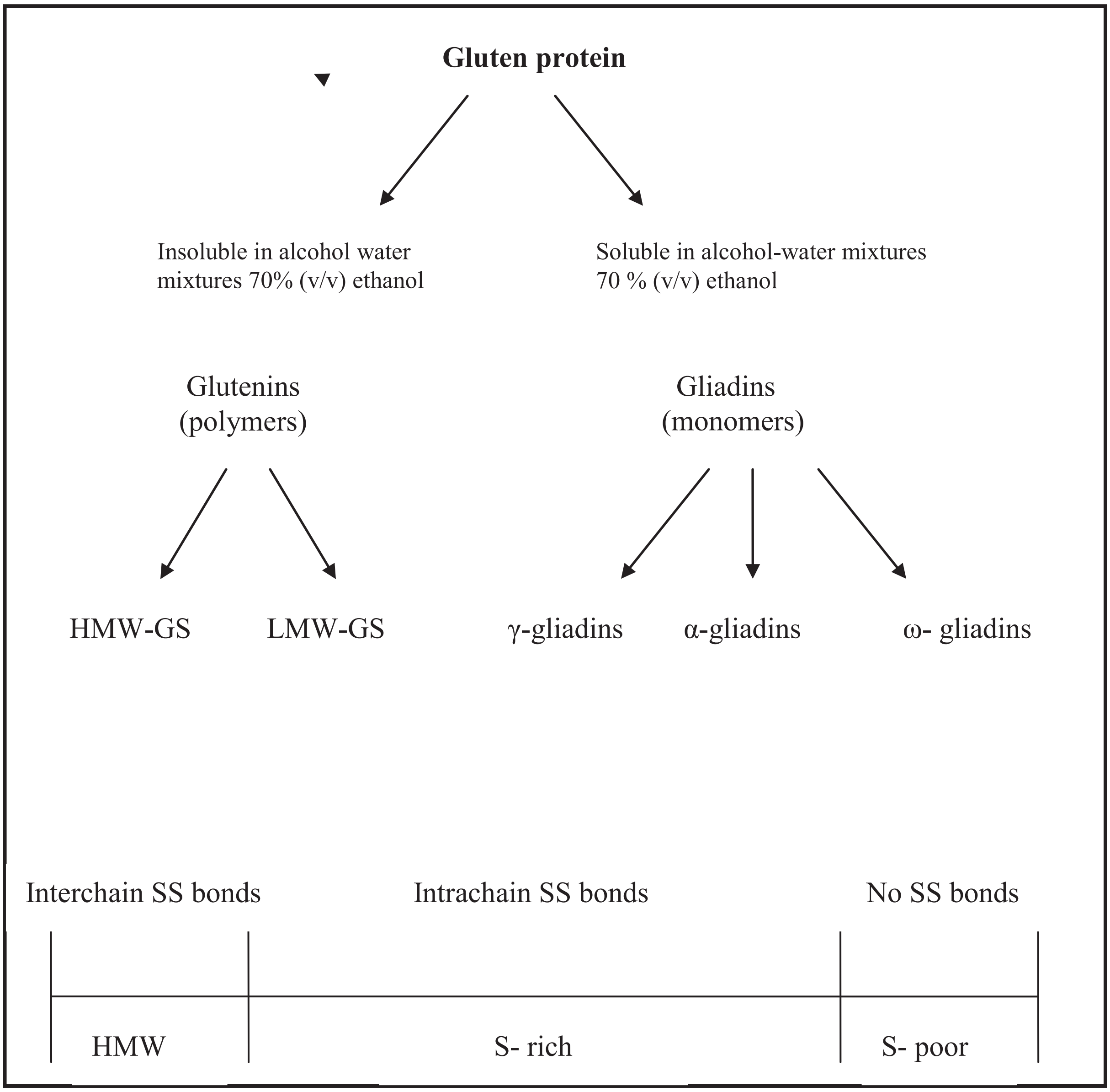


Figure 5. Summary of classification and nomenclature of wheat gluten proteins. HMW glutenin subunits are classified as HMW proteins and form interchain disulphide bonds. LMW glutenin subunits, γ-gliadins and α-gliadins are classified as S-rich prolamins and form intrachain disulphide bonds. The ω-gliadins are classified as S-poor proteins and form no disulphide bonds (Madgwick *et al*., 1992; Shewry, 1996).

Carbohydrates

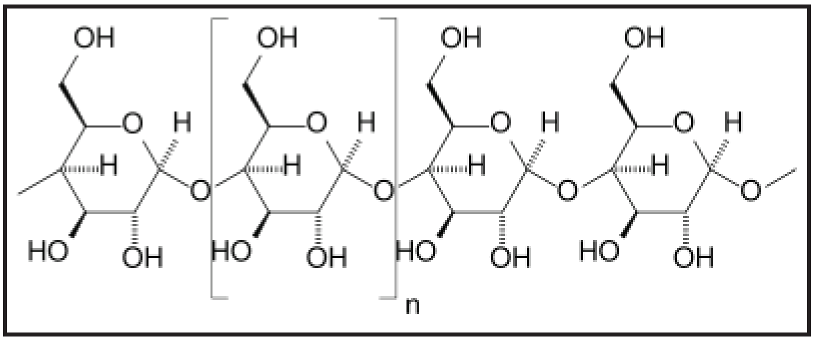
Starch polysaccharides

Starch is the most important polysaccharide and found in abundance in many plants. Starch is also a major component of wheat grain and present in its endosperm. Wheat grain contains about 63-66% of starch, figures being higher for soft wheats than for hard wheats (Toepfer *et al*., 1972). The major components of starch are amylose and amylopectin. The contents of amylose and amylopectin are significantly different among varieties of cereals. The ratio of amylose and amylopectin differs among starches. The level of amylose and amylopectin in wheat flour is 25–28 and 72–75%, respectively (Shibanuma *et al*., 1994). However, some mutant wheat genotypes as well as maize, barley, rice etc. contain either increasing amylose content or increasing amylopectin content (Kiribuchi-Otobe *et al*., 1997).

Structures of amylose and amylopectin

Amylose and amylopectin both are homopolysaccharides and based on D-glucose, the size and shape of these molecules differ enormously. Different methods such as methylation and hydrolysis including end group analysis and periodate oxidation are important in providing information on the types of linkages and the sizes of the molecules (Cornell and Hoveling, 1998).

The structure of amylose consist of α-(1,4)-linked D-glucopyranosyl units and contains five hundred to six thousand glucose molecules. It is well known that a fraction of the amylose molecules is slightly branched by α-(1,6)-linkages (Hizukuri *et al*., 1981; Shibanuma *et al*., 1994). In contrast, amylopectin is a very large, highly branched chain molecule with a DP ranging from 3×10^5 to 3×10^6 glucose units and consists of α-(1,6)-linked D-glucopyranosyl units attached to α-(1,4)- bonds (Zobel, 1988) (Fig. 6).



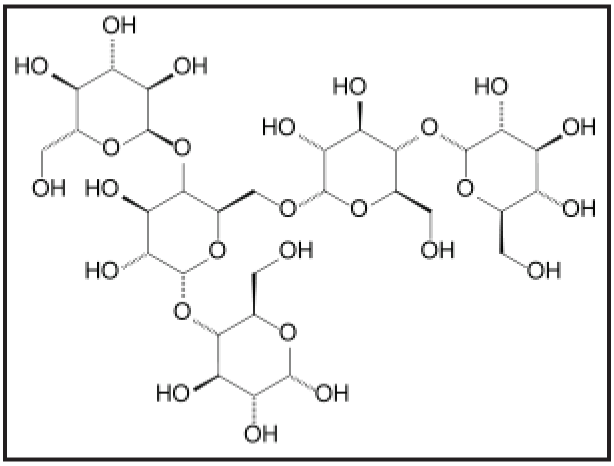


Figure 6. General structure of amylose and amylopectin.
(http://en.wikipedia.org/wiki/File:Amylopectin.svg)

Studies about structures of amylose and amylopectin can be carried out in different solvents using viscometry. It has been shown that 0.5 mol/l of KOH, dimethyl sulfoxide (DMSO) and formamide were good solvents for amylose (Banks and Greenwood, 1975).

The molecular size distribution of amylose changes with respect to the crop. Most starches showed molecular weights for amylose from 150 000 to 400 000 (800 to 2200 glucose units). The value obtained depends on both the solvent used and the method used for the estimation. Commonly, viscometric methods using an Ubberlohde capillary flow viscometer are applied. Estimation of the molecular size of amylopectin is more difficult mainly because of a wide variation in the distribution of molecular size (i.e. heterodispersity). Amylopectin is a much larger and less coiled molecule than amylose (Cauvain, 2003).

Properties of wheat starch

Starches have different distribution of the granule size among crops. The largest granule size of starch is about 50μm and the smallest 2μm. Wheat starch granules show concentric shells under scanning electron microscopy when treated with enzymes (French, 1984). The lipid content of wheat starch is roughly proportional to the surface areas of the fractions, thereby strongly suggesting that the lipid is concentrated near the surface of the granules (Whattham and Cornell, 1991). Different methods are used to find the particle size of wheat starch among which sedimentation and centrifuge are important (Cornell and Hoveling, 1998). Laser beam diffraction methods are common because they are rapid, use little quantity of sample and are applicable to samples with larger particles. In other methods, low-angle laser light scattering (LALLS) relies on a gas laser passing through a stirred suspension of the material being tested, the focused rays pass to a photosensitive detector for measurement of light intensity and diffraction angle.

Starch granules are insoluble in water, although swelling of the granules are noticed due to the splitting of surface membranes. Starch in grains contains about 12-18% water and half of this bounded chemically, form a type of crystal lattice called 'spherocrystal'. Formation of pastes on heating in water is one of the most important physical properties of starch (Cauvain, 2003). The temperature at which the granules swell and burst to form pastes depends upon the plant source of the starch and are affected by the concentration of the starch, the rate of heating and the presence of sugars, fats and other food components. Microscopy and differential scanning calorimetry are used to estimate these changes to the granules (Hung *et al.,* 2007). One of the most important chemical properties of starch is its hydrolysis, using acids or enzymes. When starch pastes are treated with acids, amylose and amylopectin are hydrolysed to lower molecular weight carbohydrates known as dextrins and finally to oligosaccharides and simple sugars. This breakdown occurs because of attack on the glycosidic bonds by H^+ ions. The complete breakdown to glucose in quantitative relationship of reactants and products can be represented as follows:

$(C_6H_{10}O_5)\ n+nH_2O \rightarrow nC_6H_{12}O_6$ (glucose)

Starch pastes give smaller molecules after the action of amylases. α-amylase give the product named dextrins, but with β-amylase maltose is formed. With the enzyme β-glucosidase, dextrins can be converted to glucose (BeMiller, 1991).

Uses of starch

Starch is important in homes and industrial uses. In the food industry its pasting properties are utilized for gravies, soups, custards and desserts of various types. Wheat, corn and potato starches and their derivatives are commonly used. These derivatives have special properties, such as starch ethers and esters (e. g. phosphates) giving better clarity and stability to the product (Englyst and Hudson, 1997). Baked products like biscuits and cakes etc have starch in them. The addition of starch to flours with less protein, improves the lightness of texture required in baked goods such as sponges and pastry. Syrups from starch are used in the confectionery and brewing industries. Its adhesive properties provide low cost bonding to make cardboard boxes. Starch and its modified forms are also used for the sizing of paper and fabrics (Cauvain, 2003).

Non-starch polysaccharides

Cellulose

Cellulose contents in wheat are about 3% (Toepfer *et al*., 1972). It is a β -1,4' glycan, also called an equatorial group when the oxygen attached to carbon 1 is more in the plane of the ring. The structure brings considerable difference to the physical and chemical properties of the polymer. Cellulose is more fibrous than starch and α –amylase has no activity on it. Cell walls of the lignified bran layers have more amounts of cellulose (Matz, 1991). Cellulose contents of white flour are less than 1%, but other non-starch polysaccharides are also present to the extent of about 3%. Wheat bran contains more percentage of non-starch materials, normally about 9% cellulose and 29% of other non-starch polysaccharides (Fincher and Stone, 1986). Thus, whole meal flour is a better source of these polysaccharides than is white flour.

Pentosans

Pentosan is considered as the main component of the non-starch polysaccharides in cereal. Pentosans in wheat dominantly are comprised of pentosan sugar that is L-arabinose and D-xylose. Pentosans are normally called hemicelluloses and play an important role in food absorption by decreasing absorption of lipid and cholesterol, therefore pentosan is very useful in human diet (Mohammadkhani, 2005; Lineback and Rasper, 1988).

Wheat grain pentosans contribute to water absorption of flour and viscosity of doughs. In bread making industry loaf volume, improved crumb and crust characteristics are due to pentosans, especially when treated with pentosanase enzymes (Higgins, 2002). Dough rheological characteristics and macaroni production processing are correlated with the amounts of pentosans in flour (Menger, 1976). Pentosan increase the dough extensibility in durum wheat and also have effect on time of dough development and dough viscosity (Jelaca and Hlynka, 1971; 1972).

Minerals

Introduction and importance

Wheat grain and its products are known to be important sources of minerals for man and livestock (Iskander and Murad, 1986). Mineral are vital components of plant metabolism and often stored in seeds (Peterson *et al*., 1983). For plant growth and development, minerals play an important role either as essential nutrients or through their effect on enzyme systems (El Gindy *et al*., 1957). In wheat grain 1.6 percent consists of minerals but the contents decreases to 0.4 percent after milling to white flour (Fujino *et al*., 1996). There is variability in mineral element contents among different parts of wheat grains. Except for amounts of C and O in grains, grain cortex contains mainly K, P and Se while amounts of Cl, Si, S, Mg and Ca are low. The aleurone layer of wheat grains contain high amount of P, K and Mg while amounts of Si, Se, S, Ca, Cl and Fe are low. The concentration of minerals in the endosperm layer was low except for C and O.

The mineral contents of cereal grains are affected by a number of factors including soil, climate and cultural practices. There is genetic differences in case of mineral element contents among wheat cultivars (Dikeman *et al*., 1982).

Mineral composition of wheat grown under different environments revealed that there were differences in ash, K, Mn and Mg contents, while only minor differences in Fe, Zn, P and Cu contents were found. Organic and conventional farming were shown to have a great effect on mineral contents of wheat grain (Bourn and Prescott, 2002). The extractability of P and Mg was significantly higher in wheat varieties grown under inorganic conditions as compared with those grown under organic conditions. The reason for higher amount of P and Mg in inorganic conditions is high application of fertilizers. Correlation between P and Mg contents was found significant (Koivistoinen *et al*., 1974). Significant differences have also been found for the contents of Ca, Cu, Mn, P and Zn between cultivars grown organically and inorganically. Significantly higher contents of Cu and Mn was found in inorganically as compared to organically grown wheat (Punia and Khetarpaul, 2007; Ryan *et al*., 2004).

Minimizing the loss of aleurone layer in the milling process can improve the nutrient value of wheat flour (Li *et al*., 2007). Bioavailability of the minerals from cereal food also depends upon the extent of milling. Milling of wheat into flours caused a decrease in Se contents also influenced by extraction percentage of flour (Lorenz *et al.,* 1980). Wheat bran contained the highest quantity of Se, while white flour showed the lowest (Ferretti and Levander, 1974).There is difference of mineral contents in soft and hard wheats. Soft wheats contained significantly less Se relative to hard wheats (Lorenz *et al.,* 1980). Table 4 data show the mineral content in cultivars of HRS (Hard Red Spring) and HRW (Hard Red Winter). All minerals, with the exception of B and Cd, are higher in HRS as compared to HRW wheats.

Table 4. Mineral content (%) in cultivars of hard red spring (HRS) and hard red winter (HRW) wheats (Erdman and Moul, 1982).

Mineral Elements	HRS	HRW
K	0.48	0.37
P	0.33	0.27
S	0.20	0.14
Mg	0.18	0.15
Ca	0.037	0.03
B	0.96	0.99
Ba	4.2	4.1
Cd	0.065	0.096
C	4.5	4.1

Interactions between phytic acid and minerals

Phytic acid, myo-inositol hexakisphosphate or IP6, is a naturally-occurring compound found in all seeds of plants. The phytic acid has beneficial as well as anti-nutritional effects for humans (Feil, 2001; Fredlund, 2002). Phytic acid plays a positive role in some processes in human body due to its antioxidant and anti-carcinogenic effects (Alabastar *et al*., 1996). However, it also strongly inhibits the absorption of iron and other essential minerals in human intestine (Hallberg *et al*., 1987; Alabastar *et al*., 1996). Furthermore, phytic acid has an influence on postprandial glucose absorption and also cause decrease in plasma cholesterol and triglycerides (Yoon *et al*., 1983; Katayama, 1995). Consumption of phytic acid by humans and animals is mainly through cereal grains and legumes or foods made from them. A high level of phytic acid (6-10 mg/g) has been observed in wheat flour, while in the refined flour, concentration was reduced to 2-4 mg/g. In commercially milled flours the concentration of phytic acid is lower than in flours produced in a domestic environment. Whole meal bread is an important source of minerals but also contains high amounts of phytic acid, which is known to impair their absorption in human body (Febles *et al*., 2002).

Phytic acid is the major phosphorus (P) storage compound in plant seeds and 80% of seed total P is bounded in it. The remaining P is represented by soluble inorganic phosphate and cellular P (P bound in nucleic acids, phosphorylated proteins, P-lipids, P-sugars). Due to the presence of negatively charged phosphate groups, phytate forms mixed salts with mineral cations which are assumed to play an important role in mineral storage. However, it reduces the availability of essential nutrients, thus being considered a natural anti-nutrient substance (Ko and Gold, 1990). Phytic acid is found in the form of mono and divalent cations, it also make complexes with proteins. (Harland and Morris, 1995).

Phytate salts are called phytins and they contain major amount of K and Mg, whereas other metals such as Ca, Zn, Fe or Cu are found in much smaller amounts (Lopez *et al*., 2002). Phytic acid forms complexes with metallic ions and is thereby decreasing bioavailability of mineral elements. Interaction of phytate with proteins, vitamins and minerals are also factors that limit the nutritive value of wheat (Smith and Circle, 1978).

Bread making

History and importance

Bread is used as a staple food; it is made and eaten in most countries of the world. The term 'bread' is used to describe a wide range of products with different shapes, sizes, crusts, textures, colors, softness, eating qualities and flavors, thus the terms good or bad quality tend to have no real meaning, except to the individual making the assessment (Cauvain, 2003). Bread is made from four main ingredients that are flour, water, yeast and salt (Mckevith, 2004).

Bread making goes back to prehistoric time, when seeds from a mixture of grasses were ground to flour and water was added to form dough (Patient and Ainsworth 1994). In many parts of world the nature of bread making has retained its traditional form, while in some it has changed dramatically (Cauvain, 2003).

Bread may be made from various cereals, grains and legumes. However wheat's unique properties like flavor, nutrients, long shelf life, and gluten forming make it an important cereal for bread making (Nelsson, 1985; Jenkins, 1975).

Bread making is both a chemical (e.g. actions of oxidants) and a physical process (e.g., expansion of gas bubbles, heat transport) affected not only by material but also mechanical processing like kneading, molding and baking parameters and recipe (Kokelaar, 1994).

The viscoelastic properties of wheat gluten give major contribution to baking quality and these are due to interactions among the gluten proteins, i.e. the gliadins and glutenins and the other components, i.e. lipids, carbohydrates and soluble proteins (Pomeranz, 1968; Shewry and Tatham, 1999).

It has been proposed that the β-spiral structure of High Molecular Weight Glutenin Subunits (HMW-GS) may contribute to the elastic mechanism of gluten (Belton, 1999). The good correlation between the amount of linked prolamins (disulfide linkage) and dough strength shows the importance of polymers in determining the viscoelastic properties of dough (Field *et al*., 1983).

Role of gluten proteins in bread-making

Wheat (*Triticum aestivum* L.) seed-storage proteins represent an important source of energy, being also involved in determination of bread-making quality (Cooke and Law, 1998). The gluten proteins (gliadin and glutenin) constitute 80 to 85% of total flour protein, and contribute to the properties of elasticity and extensibility to doughs that are essential for functionality of wheat flours (Shewry *et al*., 1995).

Gliadins

Gliadins are soluble in ethanol and play a role in the formation of gluten (along with glutenins) although they form intra-molecular disulfide bridges due to their low content of charged amino acids (Wieser, 2007). Charged amino acids in dough normally cause reduction during the formation of disulfide bonds (Belitz and Grosch, 1986). Gliadins have a high content of proline and glutamine and are grouped into *α*-, *β*-, *γ*-, *ω*-gliadins in order of decreasing mobility in gel electrophoresis (Mitofanova, 1976; Pomeranz, 1988). The α- and γ-gliadins have restricted role in formation of gluten polymers via interchain disulphide linkage, but their disulphide bonds are important in retaining the folding structure that provide information about non-covalent bonding in proteins (Wrigley *et al*., 1998; Shewry, 2000). The strong non-covalent protein-protein interactions (mainly hydrogen bonds and hydrophobic interactions) of the gliadins gives viscosity and extensibility to the gluten (Madgwick *et al*., 1992; Shewry, 2000). High concentration of gliadins in the grain gives a poor nutritional quality of the flour, because the gliadins are very poor in some essential amino acids i.e. lysine and tryptophan (Shukla, 1975).

Glutenin

The glutenins consist of polymeric proteins which are linked by interchain disulphide bonds. After reduction process of glutenin the electrophoresis give two groups of proteins on the basis of molecular weight: HMW-GS and low molecular weight glutenin subunits (LMW-GS) (Wang *et al*., 2006). HMW-GS make the high contribution to the doughs elastic properties by being the main responsible for the gluten network (Cornish *et al.,* 2006). Bread-making performance of wheat flour has also been related to the glutenin polymer size distribution (Huebner and Wall 1976; Bottomely *et al.,* 1982). The molecular weight (MW) distribution of glutenin polymers has been shown to have main role in dough properties and baking performance. The largest polymers termed 'glutenin macro polymer' (GMP) make the greatest contribution to dough properties. GMP contents in wheat flour are strongly correlated with dough strength and loaf volume. The molecular weight of glutenins is ranging from about 500,000 kDa to more than 10 million kDa. (Wieser *et al*., 2006). Due to large MWs, glutenins belongs to the largest proteins in nature. HMW-GS constitute only around 8-10% of the gluten protein (Halford *et al*., 1992). LMW-GS are nearly 20% of total gluten proteins (Wieser and Kieffer, 2001).

All hexaploid bread wheat cultivars contain six HMW subunit genes, of which three to six are expressed (Margiotta *et al.,* 1996). Each expressed gene gives an average 2% of the total seed proteins (Shewry, 1999).

Sensory quality of bread

It is well known that composition of flour has a strong impact on sensory quality of bread. Whole-meal flour bread is different in term attributes such as colour, aroma, flavour and texture compared to the white flour (Kihlberg, 2004). In leavened bread, texture is the key factor for quality perception. Texture is mainly influenced by protein content and composition (Finney and Barmore, 1948). Texture is also used as a parameter in evaluation of bread quality (Lawless and Heyman, 1999). The bread crumb also depends upon textural properties and attributes such as softness and strength. Flour possessing strong dough mixing chracterstics correlates with strong bread crumb (Scanlon *et al*., 2000). Taste of wheat flour varies by the extent of grinding (Gesslein, 1995).

The sensory quality of bread is influenced by many factors at each step in the bread making process, from wheat cultivation to final bread for consumers. Growth location influences rheological properties of dough made with inorganically and organically grown wheat (Gunnarsson and Haslund, 1995). Factors such as type of soil, climate, genotype (Samuel and East, 1990; Johansson *et al.,* 2001; Zhu and Khan, 2002), time and year of harvest (Andersson *et al*., 1994; Graybosch *et al.,* 1995; Johansson *et al.,* 2002) influence the quality of wheat, but also the type of milling and baking technique affect the sensory quality of the bread (Kihlberg *et al*., 2004).

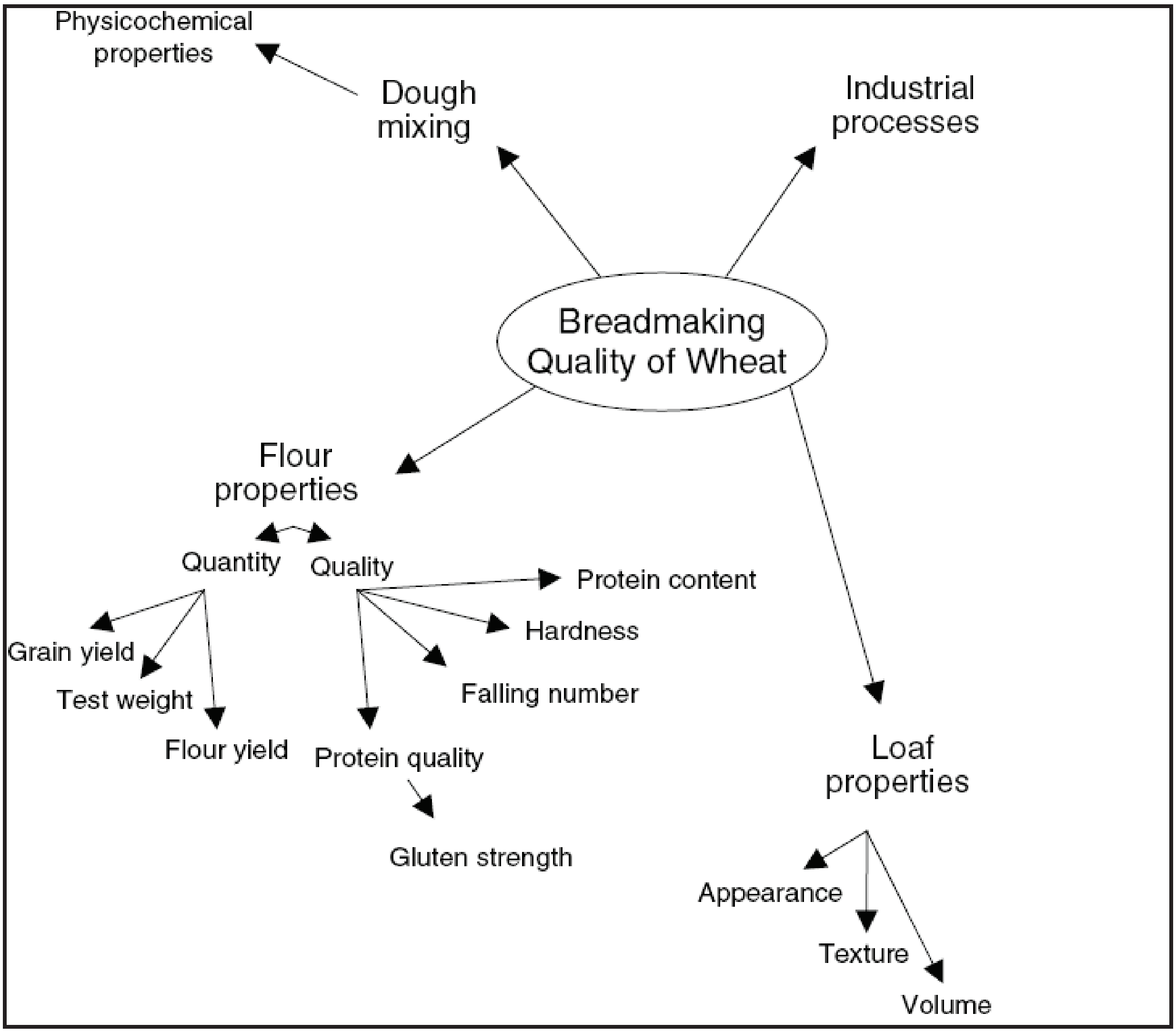


Figure 7: Flow chart describing components that determine breadmaking quality (Mason *et al*, 2007)

Rheological Behavior of Dough

Rheology is the study of the flow and deformation of materials (Barnes, 2000). Rheological behavior of a material is measured by applying a controlled strain or deformation on it for a unit time and resulting force response is measured. The main responses are hardness modulus, viscosity, stiffness and toughness of the material (Dobraszczyk and Morgenstern, 2003). There are two types of flows: shear (liquid elements flow over each other) and extensional (adjacent elements flow away from each other) (Barnes, 2000).

The purpose of rheological measurements is to get a description of mechanical properties, obtain information related to molecular structure and composition and simulation of material performance during processing (Dobraszczyk and Morgenstern, 2003). It is difficult to take out samples during different bread making processes without disturbing those processes. Therefore, prediction of a range of conditions for these processes has to be determined by the use of mathematical modeling system (Scott and Richardson, 1997). For example, the mixing and sheeting process of bread making has been simulated (Love *et al*., 2002). Rheological techniques are based on extensional and shear flows. The main techniques used for cereal properties measurement are divided into descriptive empirical techniques and fundamental measurements (Bloksma and Bushuk, 1988). Descriptive empirical techniques involve measurements by Texturometer, Consistometer, Amylograph, Farinograph, Mixograph, Extensigraph, various flow viscometers and fermentation recording devices (Table 1) (Muller, 1975).

The most common types of the fundamental rheological tests for cereals are: small deformation dynamic shear oscillation, small and large deformation shear creep and stress relaxation, large deformation extensional measurements and flow viscometry (Table 5).

Table 5. Methods for determining rheological bahaviour in cereal products (Dobraszczyk and Morgenstern, 2003).

Method	Products	Property measured
Empirical methods		
Mixers: farinograph, mixograph, reomixer	Dough	Mixing time/torque apparent viscosity
Extensigraph	Dough	Extensibility
Alveograph	Dough, Gluten	Biaxial extensibility
Amylograph,RVA	Pastes, Suspensions	Apparent viscosity, gelatinization temp
Consistometer	Sauces, Fillings	Apparent viscosity
Flow viscometers	Fluids, Pastes	Apparent viscosity
Fermentometers	Dough	Height, volume
Penetrometers	Semi-solid foods, Gels	Firmness, Hardness
Texturometers, TPA	Solid foods	Texture, firmness
Fundamental methods		
Dynamic oscillation, concentric cylinders, parallel plates	Fluids, Pastes, Batters, Doughs	Dynamic shear moduli, dynamic viscosity
Tube viscometers: capillary, pressure, extrusion, pipe flow	Fluids, Sauces, Pastes, Doughs	Viscosity, in-line viscosity
Extension: uniaxial, biaxial, dough inflation system, lubricated compression	Solid foods, Doughs	Extensional viscosity, Strain hardening

Role of mixing in dough development

The bread-making involves a number of technological processes such as, mixing, fermentation and baking. Mixing of flour and water give rise to a homogenous viscoelastic dough and helps the air movement of doughs (Bloksma, 1990). Mixing has a significant effect on the rheological properties of wheat dough and determines the quality characteristics of wheat products. Dough mixing action develops viscoelastic properties of wheat gluten and induces changes in the gluten protein composition (Skerritt *et al* 1999). Most of rheological studies indicate the occurring changes within the specific gluten protein fraction, i.e. polymeric, during mixing and resting of dough.

Mixing consists of three basic elements: distribution of materials, hydration and energy input to stretch protein molecules. The energy input phase of mixing cause protein development due to shear and extensional deformation (Bloksma and Bushuk, 1988).

The development of a gluten protein network during dough mixing can be monitored by dough mixers such as the Farinograph and the Mixograph (Goesaert *et al*., 2005). During mixing, the resistance of dough mixing first increases, then reaches an optimum development phase and decreases during what is called ‘over-mixing’.

During dough fermentation, gluten proteins become less extractable due to changes in the gluten protein network (Veraverbeke *et al.,* 1999). The gluten protein network retains the carbon dioxide produced during fermentation and during the initial stages of baking (Goesaert *et al*., 2005).

Glutenin is responsible for the character of vital wheat gluten during mixing. Increased amount of glutenin increases the strength and toughness of bread dough and additions can be used as a functional protein source in processed products. The use of too much glutenin produces overly strong dough (Boland *et al*., 2000).

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