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The effects of storage conditions on the quality of wheat flour during post-milling maturation

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled **“The effects of storage conditions on the quality of wheat flour during post-milling maturation”** independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 25.4.2024

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Bc. Johanka Barsová

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Abstract

The aim of this work is to investigate the effect of the storage time of flour and the method of preservation - in paper or leakproof plastic packaging - on the rheological properties of the dough and the resulting baking quality of the flour. The hypothesis expects minimal changes in the flour in the plastic wrapper and evolving rheological properties of flour in the paper wrapper. For flour enclosed in a paper wrapper, rheological changes leading to better baking properties are expected. The practical part of the thesis is devoted to the evaluation of flours from the state of freshly milled flour up to the age of one month. During this period, 5 parameters were measured with a frequency of one measurement every three days. A baking experiment was also carried out two times a month – the first and the last day, with the formation of a common baking clones to allow monitoring of other parameters. The methods used in the practical part include moisture determination, Mixolab measurement, wet gluten status and gluten index, and Falling number. In the baking experiment, the volume, height to width ratio, volumetric yield, Zeleny test were measured and sensorics evaluation was made. The parameters found were then compared and the difference in these two storage methods was defined. The most significant difference was the change in moisture content of the flour stored in the paper packaging. Changes in this parameter were probably the main reason for changes in other parameters. The predicted and demonstrated changes with a positive effect on the development of baking properties were measured and monitored mainly on flour sealed in paper packaging. Flour in plastic sealed packaging showed less marked changes. It is recommended that a follow-up study be conducted to examine changes over a longer period of time to obtain a more complete picture of the evolution of flour rheological parameters over time.

Key words: Mixolab, rheology, wheat, flour, quality, baking

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1. Introduction and Literature Review

1.1. Introduction

Cereals are species of noble grasses of the Poaceae family. Wheat (*Triticum aestivum* L.) is one of the "big three" cereals of the world, along with rice and maize. It is associated with many cultures and religions, for example, in Christianity it is the main ingredient for making hostas, or in Judaism for making unleavened matzo bread. But even in Muslim cultures, wheat bread (naan) is considered holy and is worshipped daily. The origins of wheat culture can be found in the Middle East where "wheat was worshipped as a sun god or as the sun itself" [1].

Wheat is grown in more than 120 different countries spread over Europe, Africa, the Americas, Asia, and Oceania. Asia has the largest production (44%), followed by Europe (34%), then the Americas (15.2%), Africa (3.5%), and Oceania (3.4%). Wheat is grown by millions of smallholder farmers in Asia, Africa, and South America for their own consumption and economic gain. Globally, the average yearly per capita food intake of wheat is 65.6 kg. The average person's wheat consumption is especially high in nations with significant wheat dietary traditions, such as those in Northern Africa, West and Central Asia, and Europe. The consumption per capita is in Northern Africa even higher than the average per capita consumption in Europe and anywhere else. In terms of regions with tropical conditions, South Asia has the highest per capita consumption of grain or cereal products with 67.6 kg and tropical Oceania with 75.4 kg (the figure relates to the entire Oceania region), while the lowest consumption is monitored in sub-Saharan Africa with 25.2 kg per person per year [2]. For example Africa's annual import expenses of wheat grew to 9% due to dietary changes and an increasing urban population (2023). Despite different degrees of regional increases in wheat production over the past few decades, the continent's wheat supply has not been able to keep up with the rapidly rising demand for wheat. Wheat yield gap analyses demonstrate that there is a good chance of improving wheat production in Africa by utilizing better agronomic and genetic techniques. In many African nations, this could promote wheat self-sufficiency at the national level and decrease reliance on imports [3].

In temperate regions, wheat is the most frequent crop grown for human consumption and animal feed [4]. A study by Pequeno et al. on climate impact and on ways of adaptation to heat and drought stress of regional and global wheat production expects climate change to reduce global wheat production by 1.9% by mid-century. The decline in production will be most pronounced in the developing countries of the tropical belt, where food security is already an issue. The study projects that by 2050, yields will fall by 15% in African countries and 16% in South Asian countries [4]. Wheat is adaptable, has a high yield potential, and contains the protein gluten, which is responsible for the viscoelastic properties of the subsequently processed grain. Thanks to these properties wheat is commonly used in form of flours and further processed foods such as bread or pasta [1]. Another advantage of wheat is that it contains all the essential nutrients. The most abundant is starch with 60-80 %, followed by protein 10-12% and 2-6% is fibre [5].

More than 402 million tonnes (2018) of wheat are milled annually for flour production [6]. It is used to produce various types of flour, bran and feed. Flour is the basic raw material for all bakery products. In most doughs, it accounts for more than 60% of the dough weight. The properties of the flour, the production technology and other raw materials determine the character of the dough and the final product. Some of the properties change during the time of ageing of the flour [5].

During the storage process, the flour undergoes physical and chemical changes as it is aging. During this aging, the flour develops properties leading to better baking performance than freshly milled flour has. The changes that happen in flour during storage are a complex and poorly understood phenomenon [7]. At the same time, however, it has also been shown that too long time of storage of flour can lead to total destruction of its quality [8]. During aging, flour components such as proteins, starch and lipids change, and these changes directly affect the properties of the dough in rheological characteristics and so the baking performance. Storage conditions determine the rate of ripening and the changes occurring in the flour. The effect of storage temperature, relative humidity, atmospheric oxygen content, light and microbial activity in the environment accelerates or slows down the ripening of the flour [7]. It is said that wheat flour should ripen for 10 to 14 days, and that if fresh, i.e. unleavened, flour is processed, the quality of the products deteriorates. After two weeks of maturing the flour, the products made from it have more volume and a better shape [5].

The aim of this thesis will be to observe the changing characteristics of bakering wheat flour during its maturation. The purpose of the study is to monitor changes in selected rheological and pasting properties of the flour or dough from the flour samples, as well as sensory and dimensional changes on baked goods made from the tested flour samples. Identical types of flour stored in different packaging, i.e. in paper packaging and in a plastic leak-proof bag, will be investigated.

1.2. Literature review

1.2.1. Wheat

Wheat belongs among the 'big three' cereal crops, with over 800 million tonnes being harvested annually [9]. The majority of wheat is eaten as bread or other baked products made primarily of flour [10]. Wheat, however, has no competitor in its cultivation range, ranging from 45° S in Argentina to 67° N in Scandinavia and Russia, covering high tropical and subtropical zones [11]. Its diversity and the degree to which it has assimilated into many countries' cultures and even religions make it unique.

In essence, the first wheat varieties that were cultivated were landraces that farmers selected from native populations according to several factors, such their higher production. This was an early instance of plant breeding [12]. Another trait that was later monitored was the fraying of the mature cob, which affects seed drop from the cob [13]. The shift from hulled forms—where the glumes stick firmly to the grain—to free-threshing naked forms is the third significant characteristic of suitable form of wheat variety [14].

Except for the spelt type of bread wheat, all cultivated varieties of diploid, tetraploid, and hexaploid wheat have a robust rachis. Similar to this, current tetraploid and hexaploid wheat varieties are free-threshing, whereas the early domesticated varieties of einkorn, emmer, and spelt are all hulled [15]. The primary wheat varieties encompass all potential combinations of hard and soft, red and white, and spring and winter classes. All of them are members of the *vulgare* subspecies of the genus *Triticum aestivum.* Three further species - the *Triticum durum*, *compactum*, and *spelt*a - are also well-represented in trade [10].

Hexaploid bread wheat currently accounts for around 95% of wheat grown globally, with tetraploid durum wheat making up the majority of the remaining 5% [15].

Particular regions of Spain, Turkey, the Balkans, and the Indian subcontinent continue to cultivate small amounts of other wheat species, such as emmer, spelt, and einkorn. While spelt is still produced throughout Europe, especially in the Alpine regions, these hulled wheats are collectively referred to as “faro” in Italy [16].

In temperate regions, wheat is the most common crop grown for human consumption and animal feed. Its versatility and high yield potential are important factors, but the gluten protein fraction—which provides the viscoelastic qualities that enable dough to be made into bread, pasta, noodles, and other food products—is especially crucial to its success [15]. The potential growth of high value specific markets might come from a new interest in spelt and other ancient wheats as healthy options for bread wheat, including kamut, a tetraploid wheat with unclear taxonomy and relation to durum wheat [17].

Consumers eat a significant amount of wheat products and commodities made from grain every day. A single individual's daily average consumption of wheat is 318 grams, representing 83% of all cereals consumed [18]. Protein, vitamins, calories, and minerals are the main supplies obtained from wheat. In terms of nutritional value, it is comparable to different cereals [18].

World area harvested wheat corresponds to 219,153,830 ha and the world production is about 808,441,568 t (2022). With its production, it is the third most produced commodity in the world after sugar cane, and maize. Biggest share on production of the wheat as a continent has Asia with 42.2%, Europe with 35%, and America with 14.7%. Among the top producers are China, India, Russian Federation, United States of America, Australia, and France [19].

1.2.1.1. Wheat grain anatomy

Cereal grain anatomy plays a crucial role in evaluation, storage, and subsequent processing of flour [20]. The wheat plants fruit is a single-seeded achene grain. The grain is composed out of three layers: bran, endosperm, and germ, which make up 13-17%, 80-85%, and 2%, respectively, of the grain weight [21]. These three major parts, each of which differentiates from the other chemically and structurally, are the endosperm, which covers more than half of the grain and supplies the growing plant as the kernel develops; the germ, referred to as the embryo, which is found at the tip of the grain and resembles a tiny, yellow mound; and the external seed crust and cover, which lies underneath and contains protein cells that cover the entire kernel and prevent the embryo and the endosperm from or after injury during the grain's subsistence [22]. Endosperm is starchy part which contents protein, and a very few fibers (around 2%). Germ, the smallest part of the wheat grain, contains the higher percentage of antioxdants, lipids, vitamin E and B, and enzymes. The third part, bran, is composed out of 5 outer layers – aleurone layer, hyaline layer, testa, two layers of inner pericarp, and outer pericarp. Aleurone layer, which is the outer part of the starchy endosperm, makes 6-9% of the seed, and contains insoluble fiber and a small amount of soluble fibers (less than 5%), proteins, enzymes, phenolic compounds, lignans, vitamins E and B, minerals and phytic acid, lipids and plant sterols. During milling, the aleurone layer remains joined to the hyaline layer and is thus separated from the endosperm together with the outer layers of the grain [23]. The testa is a hydrophobic layer that is high in lignin and is distinguished by the presence of lipidic substances such alkylresorcinols, which are found in a cuticle on the tissue's surface [24].

With respect to the distinct functions of each of the three parts, there is a significant difference in the chemical composition of their components; thus, there is a great diversity in their nutritional value.

While nearly all of wheat kernels are elliptical, certain varieties have quite long, crushed, thin, and spherical kernels. The kernel's usual sizes are 5–9 mm in length and 35–50 mg in weight [25]. Due to a high concentration of ferulic acid (FA) dimers, the outer and inner pericarps are made up of empty cells that are mostly constituted of branching heteroxylans, cellulose, and lignin. These polymer chains have many cross-links between them. The outer pericarp constitutes 3 -5% of the grain, it contains insoluble dietary fibers, xylans, cellulose, and lignins, and antioxidants.

The mass proportion of the various grain components, however, varies as a result of internal and external variables [26]. As a result, neither a uniform nor a quantitative representation of chemical compounds can be found in each individual region of the grain [27].

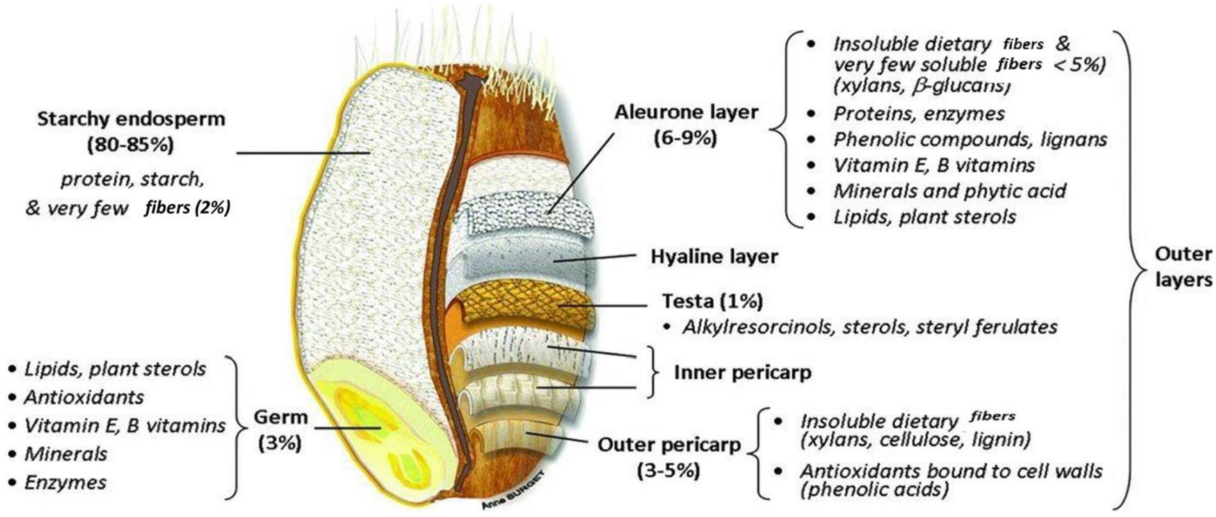

Figure 1: Chemical constituents in different parts of wheat grain [23]

1.2.2. Wheat Flour

Wheat Flour is a powdery substance derived from grinding wheat grains into a fine powder. The flour is milled wheat in flour mills. Depending on the milling method, different types of flours and meal can be obtained.

For the bakery industry, flour is the basic raw material for all production. In doughs it is the main ingredient creating more than 60% of the dough weight [5]. There are numerous types of wheat flours. Each of them is designed for its specific purpose. The most common types include All-purpose Flour, Bread Flour, Cake Flour, and Whole wheat Flour. All-purpose Flour provides a balance, it is suitable for a broad range of recipes. Bread Flour contains a higher protein content, providing structure and elasticity to bread. Cake Flour, with a lower protein content, yields lighter and softer baked pastry. Whole wheat flour retains the bran and germ, offering a higher fibre and nutrient content, among other things, it is used to enrich the nutritional profile of the dough and to give it nutty flavour. All of these types of flour are made of *Triticum aestivum*. Another important types of flour are made out of *Triticum durum* - Semolina Flour and Durum Flour. Semolina Flour is traditionally used to make pasta and couscous [28]. It has a coarse texture and high gluten content, giving pasta its characteristic chewiness [29]. Durum flour is finer and softer compared to semolina. It has a powderier consistency as is finer grind of durum wheat. Durum flour is used for bread and pizza crusts but sometimes also in pasta making.

The chemical and physical composition of the flour determines how it behaves during processing.

1.2.2.1. Basic component in the flour dry matter

In general, plain wheat flours are nutritionally poor, containing only small amounts of fat, fibre, minerals and vitamins. The component of flour dry matter with the largest representation is starch, an easily digestible polysaccharide, which makes up 75-79% of common wheat flour. Another 10-12% of flour is then composed out of protein, of which approximately 75% is gluten, and the vast majority of the rest consists of the protein prolamin [5,30]. Fat makes 1.1-1.9% of the flour composition, non-starch polysaccharides makes 2.0 -2.5%, fibre makes 0.1-1%, slime 2.5-3.4%, and ash content 0.4-1.7% [5].

Carbohydrates in wheat flour

There are several types of carbohydrates in the wheat grain. Some of them are present only in trace amounts, others in tens of percentages. The composition and carbohydrate content may vary from variety to variety, depending on climatic conditions and soil conditions and agrotechnical methods [31]. From a technical perspective, polysaccharides are the most significant type of cereal biopolymers, following proteins. These substances have a high molecular weight and are made up of more than ten monosaccharide units, though typically hundreds to millions of building units [32]. Cereal macromolecules of polysaccharides are typically made up of one or, at most, two different kinds of monosaccharides. There are two main purposes for cereal polysaccharides. A building's function and a storage function. Cereals get their energy from storage polysaccharides, of which starch is the primary representation in plants. Plant cell walls and, by implication, the supporting framework of plant tissues are derived from the building (structural) polysaccharides. Examples of them include cellulose, hemicelluloses, pentosans, lignin, and so on [31].Wheat flour contains the highest proportion of starches (65-74%), followed by insoluble fibre (2.3-5.6%), hemicellulose (2.4%), soluble fibre (1.7%), free sugars (1.2-2.1%), pentosans (1.1-1.6) and finally cellulose (0.3%) [33].

There are two types of polysaccharides in wheat grain: starchy polysaccharides and non-starchy polysaccharides. Starch is a polymer of the disaccharide maltose and isomaltose [34].Starch polysaccharides make up 60-75% of the dry matter of the grain. Wheat starch grains have two characteristic forms, large granules (type A), which are lens-shaped and 20-30 μm in diameter, and small granules (type B), which are spherical in shape and 2-8 μm in diameter [35,36]. Type B starch granules have the effect of impairing the quality of gluten in doughs, reducing starch yield, and also contain a higher amount of nitrogenous substances than type A starch granules [37]. The basic building blocks of both types of starch grains are glucose molecules [34].

Among the physical properties of starch, the most important are swelling, lubricating and retrogradation. Grain starch is water insoluble. Cells absorb water, expand a little in cold water, and then gradually start to alter structurally. The swelling gets stronger as the temperature rises. When the temperature rises to 60 °C, the intermolecular hydrogen bridges break, the grain volume increases several times, amylose diffuses into solution, the temperature increases and hydration continues, the grains rupture and release their contents into the surrounding air, forming a highly viscous gel known as starch grease [38].

Carbohydrate-amylase complex

The activity of amylolytic enzymes (amylases) influences the state of the starch. In appropriate amounts, they break down starch into dextrin, up to maltose and glucose. Products made from flours with too high amylase activity have a sticky to shaky crumb and a small volume. Conversely, products from flours with too low amylase activity may have a dry, crumbly crumb and too fine pores.

Lipids in wheat flour

The lipid content of light flour is around 1.5%, with linoleic acid being the predominant fatty acid. Unsaturated fatty acids make up mostly over 75% of all fatty acids. This determines the high nutritional value of cereal lipids and the instability of fatty acids during prolonged storage of flours. Although the lipid content is relatively low, fats play an important role in the formation of the dough as they bind to the gluten structure. Polar lipids are very important, they make about 30% of fat found in wheat. The aforementioned linoleic acid is very susceptible to oxidation, which results in rancidity of the flour during long-term storage. In connection with lipids, it is also worth mentioning lipophilic pigments, especially carotenoids, yellow and orange dyes. Lutein is a particular representative and results in the yellowish colour of flour. It is mainly found in *Triticum durum* wheat, which is used to make semolina flour for Italian pasta. In contrast, a high lutein content is undesirable for the production of white bread [31].

Proteins in wheat flour

Genetic and environmental factors - most significantly, the availability of nitrogen fertilization - determine the protein content of grains [39]. Protein content in varieties of wheat cultivated in fields typically ranges from 10% to 15% of the dry weight. There is an unequal distribution of protein in the grain; the pericarp has 5.1% protein, the testa has 5.7%, the aleurone 22.8%, and the germ 34.1% [40]. As with wholegrain protein content, the protein content of starchy endosperm, or white flour, fluctuates with the environment, especially with regard to nitrogen availability. In white wheat flour, the protein content is typically 2% lower in dry weight than in wholegrain.

Protein molecules are always composed of various lengths of amino acid chains joined together by a peptide bond. Protein is necessary for every biological activity and provides energy for grain germination and storage. They determine the technical, nutritional, feeding and biological value of the product and are an essential part of the product [41].

The wheat variety and growth circumstances - soil composition, growing season weather, and applied agrotechniques determine the protein content. Wheat flour contains 10-12% of protein, 10-15% of the protein content make albumins and globulins, and the rest 85-90% is made of gluten. Albumins are water soluble, globulins are soluble in salt solutions, prolamins are soluble in 70% ethanol, while glutenins are partially soluble in dilute solutions of acids and bases [31,42]. The smallest wheat proteins are albumins and globulins. Basically, albumins and globulins are metabolic enzymes that play a part in several metabolic processes that occur during grain launching, such as folding, protein synthesis, starch synthesis, and energy metabolism. Gliadins and glutenins, or storage proteins, make up around 75% of the total protein composition of a wheat kernel. Typically, storage proteins are not present in the germ or seed coat layer, but rather in the starchy endosperm. In technical terms, wheat storage proteins are dynamic. Despite not acting as enzymes, these proteins help in the formation of dough; for instance, they can retain gas, which results in soft baked goods [43].

Gluten

The complex structure of proteins that comprise up gluten contributes to the rheological properties of dough and its baking characteristics. Individual gluten proteins are bound by strong covalent and non-covalent forces.

Gluten in wheat flour is responsible for the viscoelastic characteristics of the dough, absorbing the carbon dioxide that is produced during leavening. It contributes significantly to the appearance, structure and texture of the bread [44].It is composed out of glutenins and prolamins – gliadins which are complex proteins with high molecular weight [45]. During dough development, hydration of gluten proteins and interactions between glutenins and gliadins occur [46]. Glutenins and gliadins react in the presence of air oxygen, water, and mechanical energy (kneading) and form a solid gel. This gel is called gluten. Thanks to gluten, wheat dough has unique properties – elasticity, and ductility. Wheat gluten can be isolated from dough by so-called washing. This involves washing the flour with water to get rid of water-soluble particles and starch. Washed-out gluten is called "wet gluten". In dry matter, it is composed out of proteins (90%), lipids (8%), and saccharides (2%). The proteins - glutenins and gliadins are represented in a ratio of 3:2. Glutenins in gluten form supramolecular, fibrous structures in gluten, supermolecules, with a relative molecular weight of 10^3 to 3 million. Gliadins are made up of approximately 40 proteins of relatively low molecular weight (20,000 - 50,000) [31]. Glutenins contribute to the strength of the dough, while gliadins are responsible for the cohesion, and extensibility of the dough [47,48].

The evidence of significant positive correlations between the representation of gliadin and glutenin markers of baking quality and the actual quality, as indicated by the baking test result or the Zeleny test value, is a prerequisite for the use of gliadin and glutenin markers of baking quality in the construction of wheat varieties with higher baking quality [49].

Vitamins and minerals

In general, the endosperm of the wheat from which the flour is made is very poor in vitamins. Most of the vitamins would be found in other parts of the grain, especially in the grain envelope or in the germ. Wheat is a source of B vitamins. However, only 10-20% (depending on the degree of milling) of the whole grain content is found in light milled flours. The rest of the B vitamins, thiamine and riboflavin are found in the husk and germ of the grain. Nicotinic acid and nicotinamide are also present in wheat. The lipophilic vitamin E, tocopherol, is found in high concentrations in wheat germ, from which it is also isolated for the production of pharmaceutical preparations and dietary supplements [31]. Wheat in normal human consumption under our conditions covers 30% of the nutritional requirements for thiamine, 15% for riboflavin and 25% for niacin [50].

Beta-carotene is also present in small amounts [51]. Minerals in flour are collectively called ash. It is an inorganic residue after incineration of plant material. Depending on the variety, soil, and growth circumstances, whole wheat grains can have an ash level of 1.25 to 3%, with the endosperm having the lowest concentration and the envelope having the greatest concentration. Phosphorus oxide makes up the majority of cereal ash. Other most prevalent elements are iron, calcium, and magnesium. Additionally, heavy metals and other mineral pollutants are frequently found in the ash. The degree of milling improves the flour's ash content [31].

Enzymes

Enzymes in wheat flour are macromolecular protein biocatalysts. Their activity depends on the temperature and acidity of the environment. The most important enzymes in terms of baking technology are amylolytic and proteolytic enzymes [5].

Amylolytic enzymes

Amylase is the most important enzyme in flour. In flour we find two types on amylase, namely α-amylase and β-amylase. α-amylases cause the breakdown of starch into dextrin. β-amylases cleave the last two molecules of starch or dextrin to form maltose. Excess amylase leads to dough fluidity, but a small amount of amylase is desirable because it speeds up the maturation of the dough and leaven [5].

Proteolytic enzymes

Proteolytic enzymes or proteases break down proteins in flour into amino acids. For baking purposes, proteinase is of greatest importance. Proteases have the ability to separate gluten and thus facilitate the machining of dough. In order to activate the proteases, it is necessary to supply an activator, for example from yeast, the glutathione tripeptide [5].

1.2.3. Processing flour from wheat

The processing of flour from the wheat starts with wheat storage which purpose is to achieve ideal technological quality of the wheat grains and to prepare them for admission to the mill in adequate quality. After transport to the mill, the mill processing follows. Briefly described, these are the processes of grain cleaning, conditioning, milling, sifting, purifying, blending and then packaging.

1.2.3.1. Technology of long-term wheat storage

The aim of long-term storage is to achieve ideal technological grain quality and to maintain this quality for the required period of time. Grain is stored for several months to years. Gradually, it is released for milling as required. Some grain may even be stored for several years as a strategic stock.

Immediately after harvesting, the wheat is stored. In the first phase lasting a few weeks, post-harvest ripening occurs. this process is technologically very important. During post-harvest ripening, the formation of tertiary and quaternary structures of endosperm biopolymers occurs. If the grain is accepted for processing before it reaches post-harvest maturity, it has poor milling and baking quality. The post-harvest ripening period depends on the condition of the grain at the time of harvest and the storage conditions. However, the post-harvest ripening period is usually given as between 3 and 6 weeks.

For the milling industry, but especially for the baking industry, it is essential that the grain retains its biological value, i.e., the structure of storage proteins and polysaccharides, and enzyme systems during storage. During storage, the aim is to prevent the consumption of storage substances by the grain that cause the enzymes, lipases, proteases, and amylases, present in the grain. To maintain maximum grain quality, it is necessary to keep the grain in a state of so-called anabiosis. The state of anabiosis essentially means that the grain is kept alive, but its biological functions are reduced to a minimum. There are no changes to the external or internal structures. The only process that continues to occur in the grain is very slow respiration. Even in this process, the grain loses quality because its biopolymers are converted into carbon dioxide and water, thus losing usable mass. The storekeeper's aim is therefore to keep respiration to a minimum [31].

During grain storage, we are concerned with maintaining the best possible quality of the grain for technological and bakery use. The state we are trying to achieve is already mentioned anabiosis. The two main adverse factors affecting anabiosis are temperature and humidity. Successful storage depends on the ability to maintain appropriate temperature and humidity. Normal humidity and temperature values during storage are shown in Figure 2. In special cases, other storage methods may also be used, namely storage under anaerobic conditions or chemical preservation. The basic technological procedures for grain storage are dry grain storage, chilled grain storage, storage under active ventilation, and storage under anaerobic conditions or chemical preservation.

It is common to store food wheat in silos using the dry grain storage technology with partial aeration or cooling. Grain in silos has a moisture content of between 14 and 15%. The grain is moved from chamber to chamber of the silo several times during the storage period, or this movement may be replaced by active aeration. Ventilation takes place by means of cool air at low temperature and low relative humidity. The cold air flow is used to regulate the humidity and cool the mass at the same time.

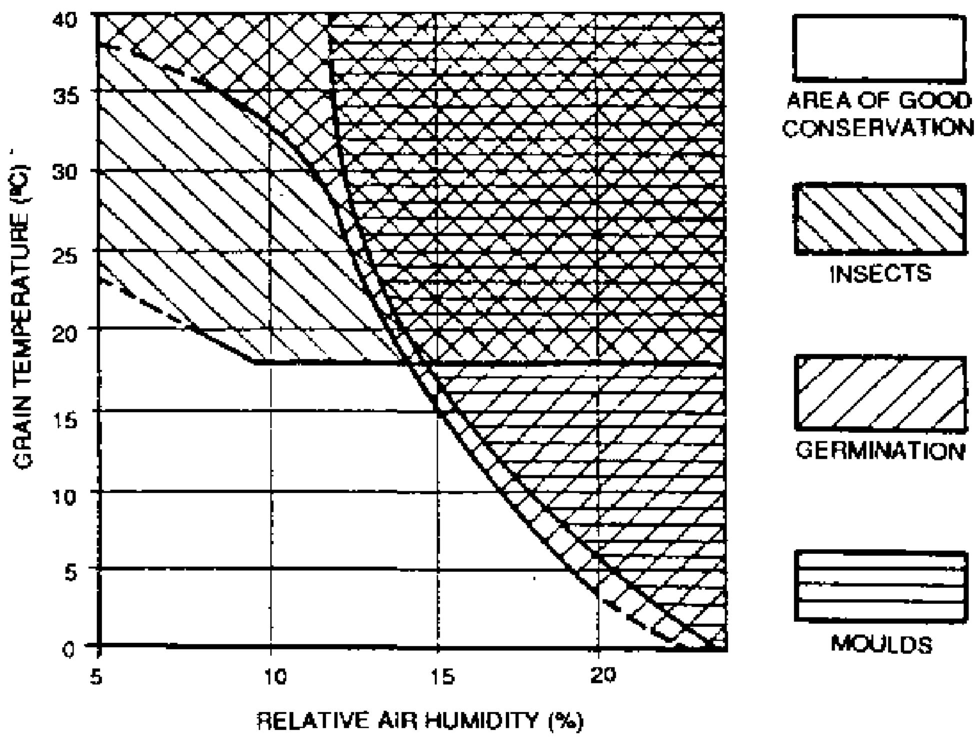

Figure 2: Diagram of cereal conservation, FAO [51]

Before the harvested grain enters the silo, it must have the required moisture content, up to 15%. If harvest conditions are favourable, the grain may already have the required moisture content at harvest. However, it is usually necessary to dry the grain before storing it in the silo.

The actual technological process of storage begins with the receipt of the grain from the primary producers. The grain is transported by lorries or tractors with a roller. Quality control is carried out by sampling with a manual sampler or automatic pneumatic samplers. Admixtures and impurities are determined during the initial inspection. The presence of pests, sensory evaluation of odour and appearance, bulk density, moisture content, nitrogen content, gluten content, sedimentation test and falling number are also examined. Depending on the quality found, the grain is then graded or discarded.

Cereal mass also undergoes a coarse cleaning stage, where impurities and impurities are reduced so that it meets the requirements for its intended use - i.e. for food or feed purposes [31].

1.2.3.2. Wheat processing in the mill

Flour milling is a complex process in which the hulls (husks) are removed from the kernel (endosperm). The whole process in the mill begins with the receipt of the grain. Cereal intaking is given due attention because of its diversity. The grain is stored in mill silos and a silo contains only one type of grain of the same quality at any one time. Within the silo, it can then be expertly blended into a so-called 'intent', which must always be of identical quality. A quality check is carried out when the grain is received at the mill. After receiving the grain into the mill, the grain is pre-cleaned to remove coarse dirt, dust from the grain surface, micro-organisms, and ferromagnetic impurities such as screws, pins, etc.

The grain needs to go through three preparatory stages before it can be processed in the mill. These three technical processes include surface treatment, hydrothermal preparation, and grain calibration.

During the grain calibration process, foreign objects which does not belong into the flour such as tiny, immature seeds, cracked grains, and most importantly, dust, microbes, ferromagnetic particles, stones, weeds, etc., are removed from the wheat. After cleaning, the hydrothermal preparation follows [5,52].

Hydrothermal preparation involves the so-called "moistening and resting" procedure. To soften the inner endosperm and stiffen the bran, a certain amount of water is applied to the grain mass, and it is then let to rest for some time. The grain is kept for a while in a warmer atmosphere after becoming moistened [53]. The type, variety, and initial moisture content of the grain all affect the length of time and temperature at which it is hydrothermally treated [54]. The grain gains improved qualities as a result of this process, which are subsequently reflected in the milling procedure, but primarily in the flour or meal's yield and purity [5]. Making ensuring the bran progressively separates during milling is the goal of this procedure [54].

After that, a surface treatment is applied with the intention of eliminating any debris that is clinging firmly to the grain's surface as well as some of the packing layers, including microorganisms [5].

After surface treatment, the milling process may start. It is important to note that different cereals are milled in different ways [5]. The deep crease in the kernel makes it necessary to extract flour by a series of breaking, sifting, and size-reducing passages that together form the milling graphic. Through this procedure, the bran and germ regions may be separated simultaneously, and the endosperm cells can be broken down into a very thin product that is ideal for quick hydration and the production of gluten. Both the milling conditions and the wheat varietals have a strict relationship with the milling yield and the flour refinement. The latter have a significant impact on bread qualities and flour technological performances, which are assessed using a number of instrumental tests [55].

The mill machinery is arranged in process lines. The main equipment is the cylindrical bench, the planar seeders, the supplementary seeders, the semolina cleaners, and the supplementary milling machines.

For the milling of wheat, 5-6 milling scrap passages are used, which are further divided into coarse and fine. There are also semolina and grits passages, which are three to four, which process cleaned first-class semolina on semolina cleaning machines. The semolina passages process second-grade and third-grade semolina, of which there are usually seven to nine. The semolina obtained from the flat seeders is further cleaned in the semolina cleaning plants and wheat germ, which is said to be among the most promising and great sources, and at a relatively cheap cost, of essential vitamins, minerals, dietary fibre, calories, proteins, and some functional micro-compositions, is also obtained [56]. The passage flours from the plain drills are distributed into three collection augers. These augers then carry flour of a particular type - special flour, plain flour, and bread flour. Semi-coarse and coarse flour is obtained on the semolina cleaning machines [5]. The flour is aerated during the mixing process after the end of the actual production in order to ripen better and faster. In the flour mixing plant, the flours are mixed in order to homogenise them. The mixing process aerates the flour, which in turn helps the flour to ripen [31].

A by-product of (25–40%) is typically released by the wheat milling industry, and this by-product is used for a variety of purposes, including animal feed, the synthesis of bioethanol, succinic acid, cosmetics, meat substitutes, pharmaceuticals, and animal nutrition, among many others [57].

1.2.4. Ageing of flour

Ageing is seen as a natural phenomenon brought about by flour's exposure to light and air. Wheat and flour ageing directly affect the dough rheological properties [58]. The aging process of wheat flour is considered very important to achieve the desired changes in order to obtain quality baked goods. Nevertheless, due to the lack of space for aging flour, flour which is freshly milled and delivered is usually processed in normal operations.

Because of the oxidation of the fatty acids and proteins in the wheat, maturing causes specific chemical changes in the composition of the flour. The gluten network that forms during the production of the dough is strengthened as a result of these advantageous modifications in protein structure [59]. In a study that investigated the effect of aging flour in polyethylene packages, it was shown that aging is crucial for structural alterations in the gluten network that might provide the dough viscoelastic qualities, which are advantageous for producing high volume baked items. With prolonged storage, changes in rheological parameters occur. These further affect the final quality of the flour product. The fatty acid profile also changes, which has an effect on the gelatinisation temperature of the starch and the swelling capacity of the gluten [60]. By maturing of flour we can obtain improved amount of free unsaturated fatty acids, which can improve the gluten development, and thus better baking performance [61].

It was also showed that the volume of bread prepared from freshly milled flour was lower than that from identical flour that had been aged for 20 days [62]. The outcomes from study by Aghababaei et al. showed that rheological characteristics such dough stability, dough development time, and farinograph quality number could be enhanced by extending the storage period to eight days and raising the temperature to 40°C. This effect might be caused by disulphide bond oxidation and rearrangement, which would increase strength and improve flour quality. Rheological characteristics were weakened by adding more moisture and storing at higher temperatures [63].

During storage and maturation, the status of proteolytic enzymes also changes, and leads to changes in the elasticity and extensibility of the dough [60]. Also water binding capacity, or water absorption, improves with wheat flour aging [64].

Shelke et al. reported that the onset temperature of starch gelatinization increased 2-3°C after wheat was aged for 3 weeks [65]. Cosgrove (34) and Smith and Andrews (35) demonstrated that as flour aged, it also affected the doughs' ability to absorb oxygen during mixing [66][67]. According to Shelke et al., the cake's volume increased, and its crumb and crust quality improved with ageing wheat and flour. The cakes made from freshly milled flours had a high specific gravity, which decreased with storage time [65].

The rate and intensity of change depends on external conditions. Ambient temperature and humidity play a role in the maturation of flour [65]. The method of storage is of particular importance for the values of moisture, acidity, and falling number. During the storage period, the temperature course has a substantial impact on the moisture content of the flour. According to Hrušková, the viscoelastic properties of wheat doughs change more significantly with storage in the case of weaker flour in the sense of improved quality [68].

1.2.5. Quality of flour for baking purposes

In the baking industry, flour is commonly classified according to the "Quality of Flour for Baking Purposes". This Flour Quality can be defined by three main parameters - Flour Strength, Flour Gas Forming Capacity, and Flour Binding Capacity. Flour Strength is related to the quantity and quality of gluten, i.e., wheat protein, in the flour, and is reflected in the physical properties of the resulting dough. The Gas Forming capacity of flour is determined principally by the form of starch and by the activity of the amylolytic enzymes which are present in the flour to break down the starch. The Binding Capacity of flour expresses the ability of flour to bind water molecules to itself. The higher the binding capacity of the flour, the higher the yield of the dough. The binding capacity of flour depends mainly on the quality and quantity of gluten contained in the flour, but it is also affected by other flour components such as pentosans or the amount of damaged starch.

The most important parameters monitored to determine the baking properties of flour are the carbohydrate-amylase and protein-proteinase complexes[5].

The ability to produce bakery goods of the necessary quality, defined as having the maximum volume, a loose, elastic, and finely porous crumb with a sufficiently thick crust, as well as a pleasing taste and aroma, will determine how wheat flour used for baking will be assessed. The quality of wheat techniques used for baking is evaluated using a number of tests [49]. Objective assessment of flour properties using specialised instruments include: fall number, rheological properties, wet gluten, moisture, Zeleny test and crude protein content. The baking testing is a direct measure of baking quality [69].

1.2.6. Rheology

Rheology is a subfield of physics that studies the way materials deform or flow in reaction to applied forces or stresses. Rheological properties are physical characteristics that determine the specific way in which the material reacts by deformation or flow to different stimulus [70]. Rheology plays a crucial role in understanding the behaviour of dough during kneading. The gluten network, formed by proteins in the flour, develops during kneading and affects the dough's elasticity and extensibility. Proper kneading ensures the formation of a strong gluten network, contributing to the structure and texture of the final baked product [71]. Determining the rheological characteristics of wheat flour dough is crucial to the effective production of bread since these characteristics impact the dough's behaviour during mechanical manipulation, which in turn affects the final product's quality [72]. These properties will be monitored using Mixolab 2

1.2.7. Mixolab

A laboratory tool called the Mixolab is used to evaluate the rheological characteristics of dough while it is mixed and warmed up. It is frequently used in the fields of baking technology and cereal science. An apparatus called the Mixolab 2 - Chopin Technologies, Villeneuve la Garenne, France (Fig. 3), which was used for our measuring can screen the rheological properties of dough in real time, during mixing, and at greater temperatures. As a result, this device gives us data on the dough's thermomechanical state, rheological characteristics, and bread-making quality. It provides starch features and α-amylase activity screening and evaluation. Important information on wheat flour quality and appropriateness for different baking applications may be found on the Mixolab.

Figure 3: Mixolab 2 – Universal Dough Characteriser [64]

The first step in utilizing Mixolab is to prepare a dough sample, which is usually created with water and wheat flour. Additional substances, such yeast or salt, could be added based on the particular needs of the analysis. Water and a sample of wheat flour were used in our research.

In the Mixolab, the dough sample is mixed in mixing bowl (Fig. 4) under regulated conditions. The device monitors the torque applied to the mixing blades as they spin through the dough at this point. The torque measurement shows readers how resistant the dough is to mixing. Mixing stability is an indication of the compatibility of raw material.

A heating system is included inside the Mixolab to simulate baking. A temperature ramp that involves heating and cooling cycles is applied to the dough sample. This enables the device to replicate the heat profile that dough experiences when baking. Initial resistance to heating indicates the resistance of gluten structure to heating.

Figure 4: Mixing bowl of Mixolab 2 [64]

The dough's starch gelatinization is monitored by the Mixolab. The process of gelatinization involves the expansion and wetness of starch particles, increasing the dough's viscosity during heating. Based on these results, the properties of the crumb structure can be assumed. The chilling phase that follows evaluates the process of retrogradation, in which starch molecules reassembly and create a more structured network. Based on these results we can expect the shelf life, which is impacted by starch retrogradation.

Viscosity at high temperatures indicates how amylase activity has affected the product's colour. The device analyses the dough's absorption of water, giving information on its hydration characteristics. The Mixolab also evaluates gluten formation, an important factor that affects the dough's elasticity and strength.

The Mixolab provides real-time torque, temperature, and time data during the process. After that, this data is evaluated in order to determine a number of factors, including baking performance, mixing tolerance, and dough stability [73,74].

1.2.7.1.1 Mixolab measurements

The parameters displayed on the typical Mixolab curve are as follows: stability (min), water absorption WA (%), dough development time DDT (min), initial maximum consistency C1 (Nm), mechanical weakening (Nm) - the torque difference between C1 and C1.2; minimum consistency C2 (Nm), peak torque (Nm) - C3, minimum torque (Nm) – C4, breakdown torque (Nm) – calculated as the difference between C3 and C4; final torque (Nm) – C5, setback torque (Nm) - the difference between C5 and C4 torque. The Mixolab profile is shown in Fig. 5.

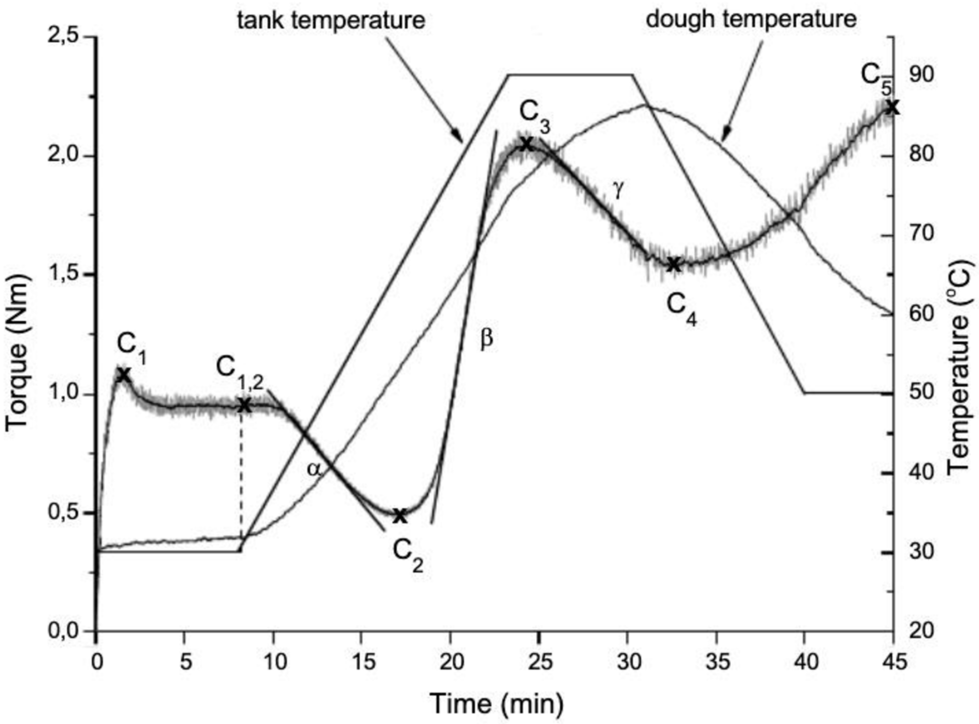

Figure 5: Mixolab profile [66]

An initial maximum consistency C1 (Nm) is used to determine the water absorption. Higher C1 values may indicate stronger gluten in the dough, which may be desirable for bread baking. Dough development time (min) is the time to reach the maximum torque at 30 °C. Using the initial maximum consistency (Nm) - C1, the water absorption is calculated. Minimum consistency (Nm) - C2 is the lowest torque value that the dough can produce as it passes through mechanical and thermal restrictions. The difference between the stage in 30 °C and C2 torques is known as thermal weakening (Nm). Peak torque (Nm) is the greatest torque generated during the heating phase, and it is shown by C3. Lower C3 values may mean less breakdown of the dough structure, which may be desirable for some types of bakery products. Minimal torque (Nm) is the minimum torque attained while cooling to 50 °C, it is shown by C4. Breakdown torque (Nm) is calculated as the difference between C3 and C4. C5 is final torque, it is a torque after cooling at 50°. It reflects the retrogradation behaviour of the starch and provides information about the tendency of the starch to recrystallize and firm up as the dough or product cools [75].

The slope of the curve between C2 and the period's end at 30 °C is denoted by α. The pace at which heat causes proteins to fade is expressed by the value of α [76]. A higher number suggests that the dough will be able to hold onto more gas during the fermentation and baking processes, which will improve the pastry's volume and texture. For baked goods that do not rise, such as biscuits or sliced cakes, lower α values may be desirable. Higher α can lead to a finer consistency and a soft, soluble dough. Alpha is associated to gluten as well as glutenin content [77]. β represents the curve's slope from C2 to C3. It describes the rate at which starch gelatinizes. The curve's slope between C3 and C4 is denoted by γ. It shows the rate at which an enzyme is degraded [76].

The precise kind of baked good we aim to make, and the desired qualities of the dough or pastry may influence the optimal values on Mixolab. Standard ideal values can change based on the particular recipes and kind of baked good being made. It is crucial to consider the particular specifications called for in the recipe as well as the desired characteristics of the finished product.

Water absorption

Water absorption (WA) of wheat flour, which is sometimes referred to as water hydration or water binding capacity, has traditionally been considered a crucial quality criterion in assessing the functional characteristics of flour. Water absorption (%) is the percentage of water required for the dough to produce a torque of 1.1 Nm. Water binding capacity, has traditionally been considered a crucial quality criteria in assessing the functional characteristics of flour [78]. In its most basic form, WA is the volume of water needed in the mixing process to bring the dough to the correct consistency at the best possible stage of gluten formation. WA can vary significantly depending on the wheat variety and class, and is directly related to the end-use applications of the flour. For making large quantities of pan bread with better dough handling qualities, fermentation and proofing tolerance, bread/dough yield, and end product features, hard wheat flour with a greater water absorption content is recommended [79]

For bread making, it is preferable to use flours that demand high absorption levels in order to create doughs with a certain consistency. As the water content or absorption rises, a given amount of flour yields a greater quantity of dough [79].

Development time, amplitude, and stability of the dough

The dough's development time, or the amount of time needed to attain its maximum consistency, reveals the flour's strength. The longer the development time, the stronger the flour [80]. The amplitude indicates the elasticity of the dough, the higher the value, the greater the elasticity of the flour. Stability is the amount of time until consistency loss is less than 11% of the maximum consistency reached during mixing. Higher stability values may indicate a good resistance of the dough to deformation, which may contribute to the volume of the pastry [75].

2. Aims of the thesis

The aim of the theses was to determine how the baking properties of the flour sample change as a function of time over a period of one month. Furthermore, the study investigated the difference in the changing properties of flour in a paper packaging and in a plastic airtight packaging.

The hypothesis was that the flour would improve its properties as a result of maturation. It was expected that the changes in flour sealed in plastic packaging would be less than the changes in flour sealed in paper packaging.

3. Methods

3.1. Flour used

The research investigates the properties of flour from the Czech Perner mill. Mill Perner wheat suppliers are mostly local Czech farmers and agricultural cooperatives. So, the majority of wheat used comes from the Czech Republic.

The specific milling identification type of flour used is T 530, i.e., Plain Baking Wheat Flour Special, which is suitable for baking purposes. This product is specified in the Czech Decree No 18/2020 Coll. as a white cereal product with a yellowish tint. The physical and chemical parameters that the plain wheat flour must meet are as follows: the moisture content of the flour must not exceed 15%, it must be unbleached, the granulation requirements, where the maximum permitted drop is 96% for a sieve with a mesh size of 257 μm, and 75% permitted drop for a second sieve with a mesh size of 162 μm. The Decree also specifies a maximum permitted content of ash of 0,6% for plain light wheat flour [81].

The flour with the best gluten quality is considered to be flour T 530, Plain Baking Flour Special. The gluten in this flour has the ability to give a good stable shape to the product. These flours are made up of the middle parts of the grains and are suitable for the production of both fine and common bakery products [5]. This flour is commonly used for the preparation of various types of yeast doughs, for thickening soups and sauces, for the production of croissants, waffles, pancakes, cakes, muffins, sweets, and other sweet and savoury dishes. It is also suitable for combining with other types of wheat and non-wheat flours [82].

Table 1: Nutritional value of used flour per 100 g [74]

Energy value (kJ/kcal)	Fats / of which SFA* (g)	Usable carbohydrates / of which sugar (g)	Proteins (g)	Salt (g)	Fibre (g)
1514/357	1.1/0.6	72.4/0.9	12.5	0.0	3.7

*SFA = Saturated Fatty Acids

3.2. Storage conditions

The flour was received freshly milled in the mill, in paper packaging, in a quantity of 15 kg. In the first case, the flour was approximately 7 hours after milling separated into plastic zip lock bags. It was stored in the dark, at room temperature. In the second case, the flour was left in a paper wrapper. The storage conditions - temperature, darkness, and humidity - were identical.

3.3. Determination of flour properties

Rheological behaviour of different raw materials was determined by Mixolab. The quality of flour for baking purposes is determined mainly by the strength of the flour, which we can determine by gluten index and by quality of the gluten – Zeleny test, and its gas-forming capacity expressed in terms of the volume of pastry from the baking experiment. The gas-forming capacity of the flour depends on the state of starch and on activity of the amylolytic enzymes - saccharide-amylase complex which can be expressed by falling number. Another important property of flour is its moisture. Moisture may further affect the properties of the dough, e. g., binding capacity.

3.3.1. Mixolab measurements

Rheological behaviour of the dough made out of the flour samples was determined by Chopin Mixolab, Villeneuve-la Garenne, France and Chopin+ protocol with the slight modification in dough weight from 75 g to 90 g. The following parameters were monitored using Mixolab: stability, dough development time, amplitude, binding capacity, and values of torques C1 to C5.

3.3.2. Falling number

The way to evaluate the carbohydrate-amylase complex is to determine the falling number. The falling number, or fall number, indicates the time of falling of the viscometer body in an aqueous suspension of flour that gels in a boiling water bath. The falling number values are given in seconds and are the total time for the stirrer to mix and for the body to fall a certain distance. Optimal values of falling number in wheat flour are from 200 to 250 seconds. Values under 150 seconds are likely to be sticky crumb, and values over 350 seconds are risky due to the dry crumb and the small volume of the bakery product [5].

3.3.3. Moisture content

One of the critical quality parameters influencing the performance and shelf life of wheat flour is its moisture content. Weather and environmental factors, including temperature and humidity, can affect flour moisture content [83]. Moisture content, defined as the amount of water present in the flour, plays a pivotal role in determining the flour's physical and chemical characteristics. Moisture content of cereal, buckwheat and rice flours may not exceed 15% [5]. The moisture content of wheat flour significantly affects its storage stability. Excess moisture can create a conducive environment for microbial growth, leading to spoilage and compromising the flour's safety and edibility [84]. Maintaining optimal moisture content is essential for ensuring the quality and consistency of wheat flour. Fluctuations in moisture levels can lead to variations in product attributes, such as texture, taste, and colour.

The moisture content of flour is directly related to its ability to absorb liquids. Flours with higher moisture content may absorb less liquid during the mixing process, while drier flours can absorb more. Moisture also has a big impact on insect infestation, mould development, crude protein, and crude fat [85].

The moisture content was determined using the oven drying or gravimetric method. This traditional method involves drying a sample of wheat flour and measuring the weight loss to calculate moisture content. It is a reliable technique. In the Moisture Analyser from the company Radwag, MA 110.R, 10-gram flour sample is heated for a determined amount of time at a specific temperature. The moisture content is then calculated using the weight lost during heating.

3.3.4. Wet gluten content

The wet gluten is given as % of dry matter of the flour. [5]. Wet gluten content as well as gluten index were measured on the Glutomatic System Glutomatic 2200 & Centrifuge 2015 of Perten production.

The determination of wet gluten is carried out by washing the protein, gluten, from a dough prepared from a given flour and 2% NaCl solution. After removing the excess water from the gluten and weighing it, the weight of the so-called wet gluten is obtained.

After conversion to dry matter of the flour, the percentage of wet gluten in the dry matter of the sample is obtained. The percentage of wet gluten is usually between 21 and 36%. If the percentage of gluten is over 40, the baking qualities are not usually the best as the gluten is usually very stretchy and not very elastic. The resulting products are low in shape [5]. Table 2 shows the assessment of the quantity of wet gluten and the estimated corresponding amount of total protein.

Table 2: Wet gluten content values and their evaluation [3]

Wet gluten in %	Evaluated as	Amount of proteins in %
over 40	very high	over 14
35–40	very good	12–14
30–35	good	10–12
20–25	weak	6–10
less than 20	very weak	less than 6

3.3.5. Gluten index

gGluten index is a value that partially indicates the quality of the gluten in the flour. The method for its determination was carried out on the Perten Glutomatic System 2200 analyser apparatus and follows the experiment for the determination of the wet gluten content. It is the percentage of wet gluten that passes through the centrifuge sieve. The best quality of gluten for bakery purposes is when GI is between 82-92%. If the value of GI is lower than 60%, the quality of flour proteins is referred to as bad quality [5].

The gluten index (GI) is calculated by weighing the portion of gluten passed through the sieve and the rest of the gluten according to the formula:

$$GI = ((m - m_1)/m) \times 100$$

Where m_1 is the weight of gluten passed through the sieve and m is the whole weight of the wet gluten (both in grams)[5].

3.3.6. Zeleny test

The Zeleny sedimentation test monitors the sedimentation of a flour suspension in a lactic acid environment in specific conditions. The value of the Zeleny sedimentation test is given in volume of sediment in ml and indicates the quality and quantity of gluten in the flour. Values of 30-40 ml correspond to good gluten quality; values of 40-50 ml correspond to very good gluten quality. Flours with values of Zeleny test below 30 ml are not suitable for baking purposes.

The Zeleny test provides an indication of the quality and quantity of wheat protein. The quality and quantity of wheat protein is related to the high binding capacity of the flour [86].

The test is carried out in a sedimentation cylinder to which bromophenol blue and a sample of flour are added. Together they are then shaken briefly to mix the flour with the solution. This is followed by rocking the cylinder for five minutes. After the cylinder has finished rocking, the sedimenting agent is added and the cylinder is stirred again. After the mixing is complete, the cylinders are in the vertical position and an eight-minute sedimentation is followed and the sediment volume is subtracted. The sedimentation value is calculated using the formula: (deducted value × 86) / dry mass.

3.4. Baking experiment

3.4.1. Farinographic kneading of the dough

According to the recipe of the farinograph kneading machine, the flour and other ingredients were prepared to be tested. In this case, it is 300 g of flour, 4.8 g of salt, 6 g of yeast and approximately 150 ml of 30-degree Celsius distilled water. The amount of water added depends on the binding of the flour. The ingredients were mixed, except for the water, and placed in the prepared farinograph. The mixture was stirred by Farinograph and the water was added after one minute of mixing. We allowed the resulting dough to knead in Farinograph for five minutes from the time of the first drop in the curve in wanted values of farinographic units. For baking purposes, the ideal value for the consistency of the dough on the farinograph is 550-650 farinographic units which has been achieved every time. The farinograph was used as an instrument for constant kneading of the dough. The amount of water added also determined the binding capacity of the flour.

3.4.2. Dough rising and baking

The dough was removed from the kneader of the farinograph and allowed to rise, covered, for 45 minutes in a proofing oven at 30 degrees. After the first rising, it was divided into 80 g portions and rolled out with a rounder to form a ball. These lumps were transferred to greased baking sheets and left in the proofing oven for a further 50 minutes. After the rising time has elapsed, the rolls were baked in a preheated oven at 240 degrees Celsius. To make them steam, 70 ml of distilled flour were poured into the oven at the beginning of baking. The rolls were baked for 14 minutes, then removed from the oven and left to cool for at least 90 minutes.

3.4.3. Evaluation of bakery products

All the parameters were measured and evaluated 90 minutes after baking. The height and width of the pastry were measured with a sliding scale and are given in centimetres. These parameters were measured on three representative samples of bakery products and averaged for each baking experiment.

3.4.3.1. Sensorics evaluation of bakery products

Sensory analysis of prepared clones was also done 90 minutes after baking. During the sensory evaluation, taste, visual and smell sensations were characterized. The technical characteristics of the dough, shape of the product, colour of the crust, parcellation and properties of the crumb, porosity, and the overall taste perception were evaluated. Sensory evaluation of the baked clones was carried out in four stages. For clones from both plastic and paper packaged flour, the samples were evaluated by first evaluating the clones prepared from the flour sample from day 1, and one month later the clones from the flour sample from day 30. One evaluator participated in the evaluation. A sensory evaluation table was chosen for the evaluation (see Table 3). The evaluator had to classify the test sample into one of the indicated rating levels. Properties of the pastry crumb, elasticity, and porosity of crumb were evaluated on the section of the clones. The technical properties of the dough were evaluated on the basis of the state of the dough after mixing in the Farinograph, before the first rise. The other parameters were evaluated from whole baked clones that had also been rested for 90 minutes.

Table 3: Characteristics for sensorics evaluation of bakery products

Character	1	2	3	4	5
Technical features of the dough	very elastic, non-sticky	elastic, non-sticky	less elastic, non-sticky	little elastic, somewhat sticky	non-elastic, sticky
Shape	well-arched	medium arched	less arched	round	very low, irregular
Colour of the bread crust	normal, typical pastry	darker, glossy	lighter, glossy	dark, matt	very light, matt
Parcelization	very good	good	less distinctive	little distinctive	undetectable
Properties of the pastry crumb – elasticity	very good, fine	good, fine	sufficient	low, crumbly casing	inflexible, sticky
Porosity of crumb	uniform, fine walls, medium pores	less uniform, fine walls, medium pores	uneven, fine walls, smaller cavities	uneven, thicker walls, smaller cavities, blown crust	uneven, thick walls, dense pores, blown crust
Overall taste impression	very good, typical pastry	good	not so good	faint	foreign taste, foreign smell

3.4.3.2. Determination of the volumetric yield of the bakery products

The mass replacement method was used to determine the volume. Pastry volume was measured by the replacement method. The container was filled with rapeseed up to the aligned rim. Then about 2/3 of the seeds were removed and three pieces of cooled pastry clones were placed in the container. These were again covered with seeds and aligned. The excess rapeseed was caught in a measuring cylinder and its volume is equal to that of the three pieces of rolls. The volume of one piece of pastry is equal to one third of the measured volume.

Calculation of volumetric yield (cm^3/100 g pastry):

1) calculation of the amount of flour for 3 pieces of pastry

Weight of flour for 3 clones of pastry (g):

$$\frac{\text{weight of the 3 clones} \times \text{weight of flour in the recipe (g)}}{\text{total weight of dough (g)}}$$

2) calculation of the volumetric yield (cm^3/100 g pastry):

Volumetric yield:

$$\frac{\text{determined volume of 3 pieces of pastry (cm3)}}{\text{weight of flour for 3 pieces of pastry (g)}} \times 100$$

3.4.4. Statistical evaluation

All variables were tested for normality of data distribution. Based on this test, another test was then selected for testing.

In the case of moisture, using Lilliefors Significance Correction, which is a normality test based on the Kolmogorov-Smirnov test, the data was found to be normally distributed. Here we further tested the standard deviation and means. Moisture was further tested with the Mann-Whitney test with the null hypothesis - namely that there is no statistically significant difference between the variables.

Based on Lilliefors Significance Correction, data for Binding capacity, Amplitude, Dough development time and stability from the flour stored in plastic packaging were also tested. A normal distribution was found for some of the data, but the other part of the data was not normally distributed. Thus, Pearson's coefficient was used for variables with normal distribution while Spearman's rho was used for variables that did not have normal distribution. A normality test was also performed for the same variables, with the difference of storage, of the flour in paper packaging. Here a normal distribution of the variables was found. Therefore, Pearson's coefficient was used to evaluate the correlations.

The values of torque in the plastic and paper packaging were also tested by the normality test. A normal distribution was found for 4 values of torque in both types of packaging. However, one of the torque values from both types of storage showed a non-normal distribution. Therefore, the torque data from both plastic and paper packaging were tested with both Pearson's correlation coefficient and Spearman's rho.

A normal distribution was found for the falling number data. Thus, the data were tested by Pearson's coefficient, followed by T-test for Equality of Means and Independent Samples test to test the means.

Wet gluten and Gluten index were also tested for normality of data distribution. It was found that among the values there are some that are normally distributed, but also some that do not have a normal distribution. Pearson's correlation coefficient was used for variables with normal distribution, and non-parametric Spearman's rho was used for variables without normal distribution.

The significance level in all statistical tests is at 0.05 level.

4. Results

4.1. Moisture

Moisture was measured on Moisture Analyser MA 110.R Radwag. The value of moisture is calculated as an average of three measuring. See the values of measured moisture in the Table 4. The table also shows the deviated value at day 14 for flour wrapped in plastic. In addition to this value, it is possible to see a decreasing moisture in both samples, while the flour in paper packaging lost moisture faster.

Table 4: Moisture of flour (%)

Day	Plastic packaging	Paper packaging
1	14.9	14.6
4	14.9	14.6
7	14.9	14.6
11	14.9	13.9
14	14.7	13.5
17	14.9	13.5
20	14.9	13.5
24	14.8	13.2
27	14.8	13
30	14.7	13

Table 5 shows mean moisture and standard deviation of moisture in paper and plastic packaging. Based on Lilliefors Significance Correction, which is a normality test based on the Kolmogorov–Smirnov test, we found that the standard deviation of moisture content of flour sealed in plastic packaging is 0.084% and that of flour in paper packaging is 0.65%. The total standard moisture deviation corresponds to 0.723%. Mean moisture in flour in plastic packaging was 14.8% and in paper packaging the mean value is 13.7%. The total mean moisture is 14.29%.

Table 5: Mean moisture, standard deviation (%)

Package	Mean	Std. Deviation
Plastic	14.8400	.08433
Paper	13.7400	**.65013**
Total	14.2900	.72250

Since the values do not have a normal distribution, the Mann-Whitney test, which is a non-parametric alternative to the two-sample t-test, was used to test for statistically significant differences (see in Table 6). From this test, statistically significant differences were found between plastic and paper packaging. There are also statistically significant differences between the moisture content of flour in paper and plastic packaging. This implies that the null hypothesis, that "there is no statistically significant difference between the variables”, was rejected.

Table 6: Mann-Whitney test of moisture

Mann-Whitney U	.000
Wilcoxon W	55.000
Z	-3.847
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000
Exact Sig. (2-tailed)	**.000**
Exact Sig. (1-tailed)	.000
Point Probability	.000

Figure 6 demonstrates the development of values in moisture from paper and plastic packaging in a month (in %). From the Figure 6 we can see that moisture of flour from both types of packaging was declining. The moisture of flour from paper packaging decreased in 30 days much more than the moisture of flour from plastic packaging.

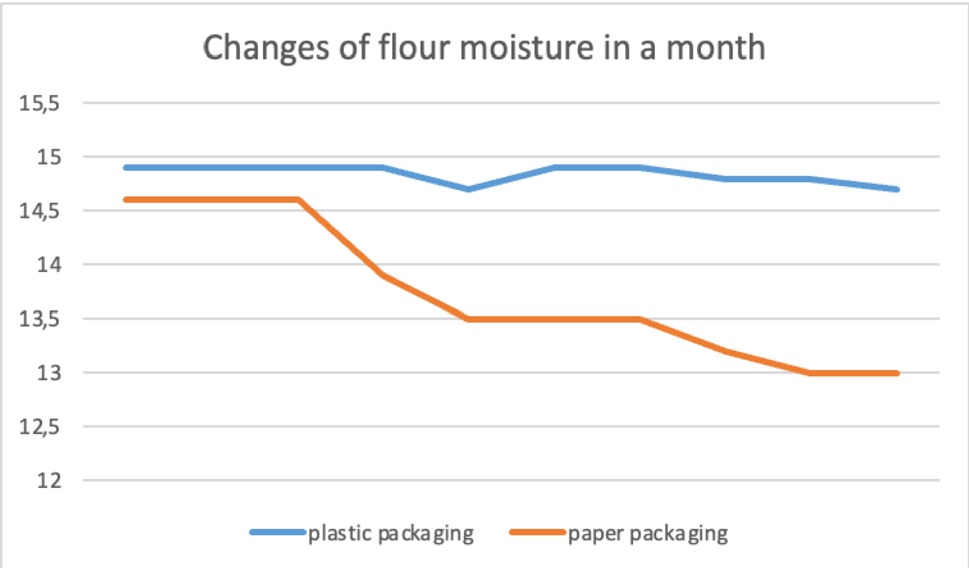

Figure 6: Changes of moisture of flour from paper and plastic packaging (in %)

4.2. Mixolab measuring's

4.2.1. Binding capacity, Dough development time, Stability and Amplitude

The parameters monitored to evaluate the baking properties on Mixolab are Binding capacity (BC), development time (DDT), water absorption (WA), stability, and amplitude. All the values listed in Table 7 of the particular parameters are average values of two measurements. Measurements were made from two types of flour. The first kind was sealed in plastic packaging, the second in paper packaging. Both measurements were made during one month of regular measurements (every three days). Values of binding capacity, DDT, stability, and amplitude of the flour from plastic packaging and paper packaging are shown in Table 7 and Table 10. Desirable are higher binding capacity, higher stability, and higher amplitude values. The binding capacity in all cases of measurement corresponded to the average binding of European flours, which is 53 to 60% [87].

Table 7: Rheological characteristics of flour in plastic packaging

	Binding capacity (%)	Dough development time	Stability (min)	Amplitude (Nm)
1st day	54	1.32	3.5	0.06
	53	1.49	3.75	0.07
	54	1.03	3.7	0.08
	53.5	1.11	3.9	0.08
	54.5	1.36	4.35	0.07
	54.3	1.33	4.25	0.07
	54.5	1.43	4.55	0.07
	54.5	1.32	4.05	0.08
	54.5	1.55	4.3	0.06
	54.5	1.17	3.95	0.06
30th day	54.5	1.3	4.5	0.06

In plastic packaging using the Shapiro-Wilk test, we found that dough development time and stability have normal distributions, while Binding capacity and amplitude do not have normal distributions. Pearson's coefficient was therefore used for variables with normal distribution while Spearman's Coefficient was used for variables that do not have normal distribution.

Table 8: Pearson correlation of rheological parameters of flour in plastic packaging

		BC (%)	DDT (min)	Stability (min)	Amplitude (Nm)
BC (%)	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	11			
DDT (min)	Pearson Correlation	.077	1		
	Sig. (2-tailed)	.822			
	N	11	11		
Stability (min)	Pearson Correlation	**.629**	.402	1	
	Sig. (2-tailed)	**.038**	.220		
	N	11	11	11	
Amplitude (Nm)	Pearson Correlation	-.319	-.438	-.184	1
	Sig. (2-tailed)	.340	.178	.588	
	N	11	11	11	11

Based on Pearson correlation coefficient, which is a correlation coefficient that measures linear correlation between two sets of data, statistically significant correlations were found between stability and binding capacity (Table 8). The significance level of the correlation is at 0.05 level (2-tailed). Using Spearman's rho, which is a non-parametric test used to measure the strength of association between two variables, we confirmed a positive statistically significant correlation between stability and binding capacity at the 0.05 significance level.

Table 9: Spearman's rho test of rheological parameters of flour in plastic packaging

		BC (%)	DDT (min)	Stability (min)	Amplitude (Nm)
BC (%)	Spearman's Coefficient	1.000			
	Sig. (2-tailed)	.			
	N	11			
DDT (min)	Spearman's Coefficient	.199	1.000		
	Sig. (2-tailed)	.557	.		
	N	11	11		
Stability (min)	Spearman's Coefficient	**.765**	.415	1.000	

		BC (%)	DDT (min)	Stability (min)	Amplitude (Nm)
	Sig. (2-tailed)	**.006**	.205	.	
	N	11	11	11	
Amplitude (Nm)	Spearman's Coefficient	-.358	-.302	-.202	1.000
	Sig. (2-tailed)	.280	.367	.551	.
	N	11	11	11	11

Table 10 shows the averages of the measured values of the properties of dough made from flour that has been aged in a paper packaging. In the table we can see a significantly lower value of 3.7 in stability values, which has an absolute deviation from the average of 2.1.

Table 10: Rheological characteristics of flour in paper packaging

	Binding capacity (%)	Dough development time (min)	Stability (min)	Amplitude (Nm)
1st day	54.5	1.42	5.5	0.07
	55.7	1.32	5.7	0.07
	56.7	1.3	7.8	0.09
	55.6	1.03	5.5	0.08
	55.6	1.32	5.4	0.08
	55.6	1.57	5.8	0.09
	56.1	1.38	5.9	0.07
	55.8	1.55	6.4	0.07
	55.1	1.35	6	0.06
	56.6	1.37	**3.7**	0.08
30th day	57.3	1.42	6.1	0.08

In Table 11 we can see a correlation analysis of rheological parameters measured in time. Based on the Shapiro-Wilk test of normality, we found that the variables have a normal distribution. Therefore, we used Person's correlation coefficient. Based on Pearson correlation, which is a statistical measure of the strength of a linear relationship between paired data, we found the correlation measures between the parameters. No statistically significant correlation was found at the 0.05 significance level.

Table 11: Pearson correlation of rheological parameters of flour in paper packaging

		BC (%)	DDT (min)	Stability (min)	Amplitude (Nm)
BC (%)	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	11			
DDT (min)	Pearson Correlation	.009	1		
	Sig. (2-tailed)	.979			
	N	11	11		
Stability (min)	Pearson Correlation	.134	.067	1	
	Sig. (2-tailed)	.695	.845		
	N	11	11	11	
Amplitude (Nm)	Pearson Correlation	.486	-.026	.146	1
	Sig. (2-tailed)	.130	.939	.668	
	N	11	11	11	11

4.2.1.1. Mean values of torques measured on Mixolab

The measured torque values C1 - C5 are shown in this chapter. The torques were measured using Mixolab, at different stages of dough development and processing. Mixolab measures these parameters simultaneously with the heating, cooling and continuous mixing of the dough.

4.2.1.1.1 Plastic packaging

Table 11 shows the evolution of the torque values measured for flour dough stored in a plastic airtight package. A significant deviation of 1.492 and 1.146 Nm was found for minimum torque C4 (see in Fig. 7). Apart from the already mentioned outliers, the torque values were relatively stable over time.

On the basis of Pearson's coefficient, a statistically significant correlation was found between minimum torque C4 and minimum consistency torque C2, and between peak torque C3 and minimum torque C4.

Table 12: Torques of flour packed in plastic packaging, measured on Mixolab in (Nm)

	Mean C1	Mean C2	Mean C3	Mean C4	Mean C5
1st day	1.09	0.31	1.461	0.752	1.2215
	1.124	0.336	1.508	0.7725	1.301
	1.093	0.296	1.543	**1.492**	1.396
	1.1175	0.3145	1.5285	**1.146**	1.393
	1.1185	0.3375	1.559	0.8415	1.2935
	1.0855	0.3195	1.5445	0.7655	1.2095
	1.0785	0.3325	1.5555	0.793	1.2215
	1.0795	0.3265	1.5685	0.81	1.2475
	1.087	0.332	1.585	0.81	1.2825
	1.11	0.3275	1.6065	0.8315	1.2825
1 month	1.0685	0.324	1.591	0.814	1.3355

Torque C1 and C2, followed by slightly increasing C3, proved to be the most stable parameters. Using the Shapiro-Wilk normality test, it was found that the C4 values do not have a normal distribution, which is also evident from Figure 7, while the C1, C2, C3 and C5 values have a normal distribution.

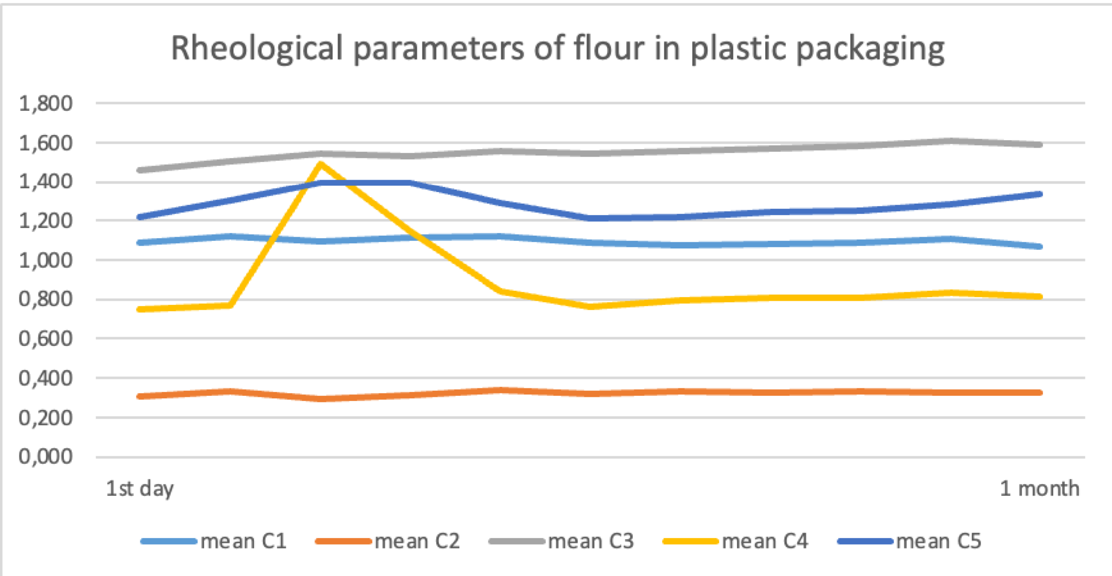

Figure 7: Development of torque in flour from plastic packaging

For values with a normal distribution, Pearson's coefficient was used for testing (Table 10).Based on Pearson's correlation coefficient, statistically significant correlations were found between C4 and C5, and between C2 and C4 at the 0.05 level of significance.

Table 13: Pearson correlation of torque of flour from plastic packaging

		Mean C1	Mean C2	Mean C3	Mean C4	Mean C5
Mean C1	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	11				
Mean C2	Pearson Correlation	.185	1			
	Sig. (2-tailed)	.585				
	N	11	11			
Mean C3	Pearson Correlation	-.244	.363	1		
	Sig. (2-tailed)	.469	.273			
	N	11	11	11		
Mean C4	Pearson Correlation	.153	**-.733**	-.038	1	
	Sig. (2-tailed)	.654	**.010**	.912		
	N	11	11	11	11	
Mean C5	Pearson Correlation	.342	-.399	.120	**.793**	1
	Sig. (2-tailed)	.303	.225	.726	**.004**	
	N	11	11	11	11	11

Spearman's coefficient, which can be used in situations when one or more of the variables are skewed, non-linear, ordinal, or contain outliers, was used to determine the connection between the variables that do not have a normal distribution (Table 13). Based on the Spearman coefficient, a statistically significant positive correlation between C4 and C5 at the level was confirmed at significance level of 0.05.

Table 14: Spearman's coefficient of torque of flour in plastic packaging

		Mean C1	Mean C2	Mean C3	Mean C4	Mean C5
Mean C1	Spearman's Coefficient	1.000				
	Sig. (2-tailed)	.				
	N	11				
Mean C2	Spearman's Coefficient	.209	1.000			
	Sig. (2-tailed)	.537	.			
	N	11	11			
Mean C3	Spearman's Coefficient	-.400	.336	1.000		
	Sig. (2-tailed)	.223	.312	.		
	N	11	11	11		
Mean C4	Spearman's Coefficient	.282	-.109	.305	1.000	
	Sig. (2-tailed)	.400	.749	.361	.	

	N	11	11	11	11	
Mean C5	Spearman's Coefficient	.416	-.137	-.023	**.785**	1.000
	Sig. (2-tailed)	.204	.688	.947	**.004**	.
	N	11	11	11	11	11

4.2.1.1.2 Paper packaging

Table 15 shows the evolution of torque at different stages of dough development. In general, with the exception of the differing C4 values of 1.492 and 1.146 Nm for the flour from the plastic wrapper, it is clear that, especially in the second part of the measurement period, the torque values were less stable for the flour from the paper packaging compared to those from the plastic wrapper. Values of C5 torque of the dough from the paper-packed flour were the least stable, but even the other values do not indicate a clear development.

Table 15: Torques of flour packed in paper packaging, measured on Mixolab

	C1 (Nm)	C2 (Nm)	C3 (Nm)	C4 (Nm)	C5 (Nm)
1st day	1.146	0.376	1.454	0.736	1.141
	1.1175	0.368	1.473	0.7535	1.154
	1.06	0.361	1.472	0.73	1.148
	1.086	0.349	1.492	0.722	1.212
	1.1	0.364	1.486	0.7465	1.1795
	1.108	0.375	1.49	0.721	1.144
	1.088	0.323	1.455	0.699	1.21
	1.136	0.387	1.516	0.748	1.179
	1.138	0.356	1.516	0.746	1.275
	1.088	0.323	1.455	0.699	1.147
1 month	1.125	0.38	1.522	0.748	1.165

The measured parameters were tested for normal distribution. According to the Shapiro-Wilk test, a normal distribution was found for values C1 - C4. C5 values do not have normal distribution. Pearson's coefficient was used for parameters with normal distribution. This revealed a statistically significant correlation between C4 and C2 values, and between C3 and C4 values at the significance level 0.05.

Table 16: Pearson correlation of torque of flour from paper packaging

	Mean C1	Mean C2	Mean C3	Mean C4	Mean C5

Mean C1	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	11				
Mean C2	Pearson Correlation	.577	1			
	Sig. (2-tailed)	.063				
	N	11	11			
Mean C3	Pearson Correlation	.412	.566	1		
	Sig. (2-tailed)	.208	.069			
	N	11	11	11		
Mean C4	Pearson Correlation	.579	**.811**	**.614**	1	
	Sig. (2-tailed)	.062	**.002**	**.045**		
	N	11	11	11	11	
Mean C5	Pearson Correlation	.158	-.269	.426	.073	1
	Sig. (2-tailed)	.640	.424	.191	.831	
	N	11	11	11	11	11

For the parameter C5, which does not have a normal distribution, Spearman's rho was used for testing (see Table 17). This test confirmed a statistically significant strong positive correlation between C2 and C4 at the 0.05 significance level.

Table 17: . Spearman's coefficient of torque of flour in paper packaging

		Mean C1	Mean C2	Mean C3	Mean C4	Mean C5
Mean C1	Spearman's Coefficient	1.000				
	Sig. (2-tailed)	.				
	N	11				
Mean C2	Spearman's Coefficient	.644	1.000			
	Sig. (2-tailed)	.033	.			
	N	11	11			
Mean C3	Spearman's Coefficient	.256	.403	1.000		
	Sig. (2-tailed)	.447	.219	.		
	N	11	11	11		
Mean C4	Spearman's Coefficient	.549	**.696**	.502	1.000	
	Sig. (2-tailed)	.080	**.017**	.115	.	
	N	11	11	11	11	
Mean C5	Spearman's Coefficient	-.100	-.355	.502	.123	1.000
	Sig. (2-tailed)	.769	.284	.115	.718	.
	N	11	11	11	11	11

Figure 8 shows the evolution of individual C1-C5 parameters over time. The figure shows that C1 and C5 values fluctuated from the very beginning of the measurements, while C2 and C3 values started to fluctuate around the middle of the measurements.

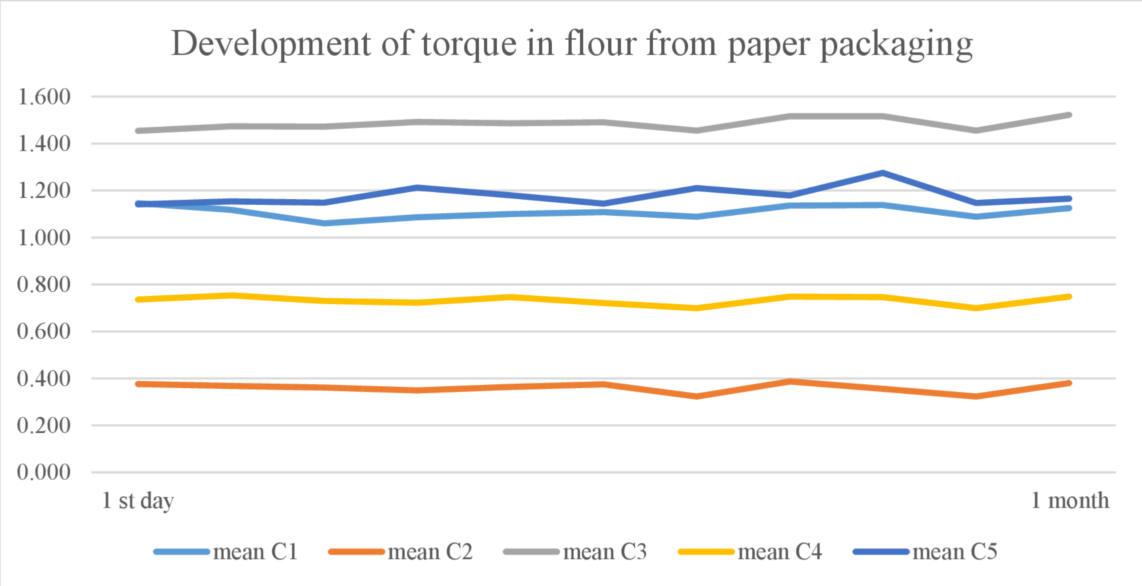

Figure 8: Development of torque in flour from paper packaging

4.3. Falling number

Falling number (FN) was determined with The Perten Falling Number® System. The falling number in both cases is around the lower limit for the optimal value of alpha - amylase activity. We can see that the values of the fall number of flour from both types of packaging had an uneven increasing trend.

Table 18: Falling number (FN) changing in time in plastic and paper packaging in seconds

Day	FN - Plastic bag (s)	FN - Paper bag (s)
1	194	188
4	199	199
7	203	198
11	204	192
14	210	194
17	208	200
20	209	199
24	206	197
27	209	210
30	210	208

The Shapiro-Wilk test was used to test the normality of the data. The test showed that all variables have normal distribution. Therefore, the Pearson correlation coefficient was used to test the correlation. This test showed that there is no statistically significant correlation between the measured Falling numbers of flour in plastic and paper packaging.

Table 19: Pearson correlation between Falling number of flour packed in plastic and paper packaging

		Falling number – Plastic packaging	Falling number – paper packaging
Falling number – Plastic packaging	Pearson Correlation	1	.615
	Sig. (2-tailed)		.058
	N	10	10
Falling number – Paper packaging	Pearson Correlation	.615	1
	Sig. (2-tailed)	.058	
	N	10	10

Subsequently, T-test and Independent Samples Test were used to evaluate the mean values. The average value is higher for flour in plastic packaging, while it was already higher at the beginning of the measurements. The falling number of the flour sample from the paper packaging increased almost twice as much as that of the flour sample in the plastic packaging.

Table 20: T-test of falling numbers of flour packed in plastic and paper packaging

	Package	N	Mean	Std. Deviation	Std. Error Mean
Falling number	Plastic	9	206.4444	3.77859	1.25953
	Paper	10	198.5000	6.67083	2.10950

The Independent samples test, which compares two independent groups' means to see if there is statistical support for the idea that the related population means differ noticeably, shows that the average value of the falling number is statistically significantly different between the two types of packaging.

Table 21: Independent samples test of falling number in flour packed in plastic and paper packaging

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t*	df**	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	1.032	.324	**3.142**	**17**	**.006**	7.94444	2.52824
Equal variances not assumed			3.234	14.489	.006	7.94444	2.45691

4.4. Wet gluten

The amount of wet gluten from which the percentage was calculated, was measured on the Glutomatic System Glutomatic 2200 & Centrifuge 2015 of Perten production as well as gluten index.

As shown in Table 22, all measurements of samples from plastic packaging except one found weak quality in ranges 20-25%. In one measurement the quality is higher than 25% and thus the quality is evaluated as good. The best quality of gluten for bakery purposes is when gluten index is between 82-92%. This requirement was met in all measurement cases.

Table 22: Gluten index and % of wet gluten in samples of flour in plastic package

	% of wet gluten	Gluten Index (%)
1st day	24.40	91
	23.60	90.25
	23.70	88.78
	28.50	90.84
	24.40	88.11
	22.20	87.34
	20.90	90.00
	22.30	94.53
	22.10	91.04
30th day	22.90	91.48

The percentages of wet gluten in the samples sealed in paper packaging were around the borderline between good quality and poor-quality gluten. The gluten index corresponds in all cases of measuring to the high gluten index, the values being slightly higher than in the ideal condition [5]. For flours with higher quality protein, it is highly likely higher binding ability, longer dough development time, and greater dough stability.

Table 23: Gluten index and % of wet gluten in samples of flour in paper package

	% of wet gluten	Gluten Index (%)
1^{st} day	24.2	94.79
	22	91.45
	25.5	95.73
	25.6	96.25
	25.5	95.18
	25.3	94.94
	24.9	96.47
	24.9	94.82
	25.6	93.91
30^{th} day	25.4	93.62

Based on the normality test, we found that wet gluten in plastic packaging, and Gluten index in both packaging have normal ratings. Therefore, we can test the gluten in plastic packaging using Pearson correlation (see Table 24).

Table 24: Pearson correlation of wet gluten and gluten index in plastic packaging

		Wet gluten	Gluten index
Wet gluten	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	10	
Gluten index	Pearson Correlation	-.030	1
	Sig. (2-tailed)	.934	
	N	10	10

For wet gluten in paper packaging, a non-normal distribution was found. Thus, we need to test the values from the paper packaging with a non-parametric correlation - Spearman's rho.

Based on parametric and non-parametric correlation, we found no significant correlation between wet gluten and gluten index at 0.05 level of significance in both types of packaging.

Table 25: Spearman's rho of wet gluten and gluten index in paper packaging

		Wet gluten	Gluten index
Wet gluten	Correlation Coefficient	1.000	
	Sig. (2-tailed)		
	N	10	
Gluten index	Correlation Coefficient	.336	1.000
	Sig. (2-tailed)	.342	
	N	10	10

Figure 9 shows the evolution of the Gluten Index of flours in plastic airtight, and in paper packaging. It can be said that the Gluten Index fluctuated and at the same time it slightly rose unevenly. At the beginning of the measurements, the GI value decreased, and then increased until the 4th measurement for both types of flour. Then it decreased quite strongly for the flour from the plastic wrapping, and then increased and decreased again towards the end. After a significant initial decline, the GI of the flour in the paper wrapper increased and fluctuated around values 94 and 96 %. Peak value was measured on the 8th measuring (out of ten) in the flour from plastic packaging, and on the 7th measuring in the flour from paper packaging.

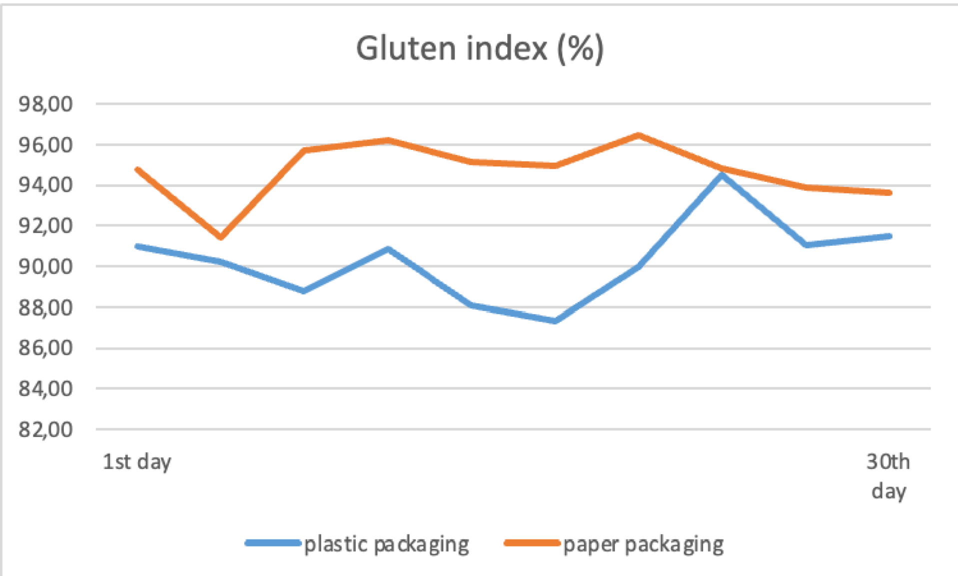

Figure 9: Gluten index changes in time

4.5. Baking experiment

The baking experiment was conducted twice during the measurement period, on the first day of measurement and on the thirtieth day of measurement.
The height and width of the pastry were measured with a sliding scale and are given in centimetres. All the parameters are measured on three representative samples of bakery products and averaged.

Pastry volume was measured by the replacement method. Volume values decreased for both types of flour storage, with a significantly greater change in baking volume measured after one month for flour sealed in plastic packaging, contrary to expectations.

For demonstration of the sensorics evaluation, pictures providing better image are provided (Fig. 10). Sensory evaluation was performed according to the Table 3 and the results were subjectively assessed by one observer.

Sensorics characteristics of the clone made out of flour sample from the first day of measuring, which was packed in a plastic packaging (1^{st} clones from above in Fig. 10) are as follows, the dough was elastic, non-sticky; shape of the clone was evaluated as medium arched; colour of the bread crust was normal, typical pastry; parcelization was good; properties of the pastry crumb were sufficient; porosity of crumb was evaluated as uneven, with fine walls and smaller cavities; and overall taste impression was good.

The flour sample from the 30^{th} day (2^{nd} clones from above in Fig. 10) from plastic packaging had the same features except the shape, which was evaluated as less arched, and the properties of the pastry crumb, which was evaluated as very good, fine.

Sensorics characteristics of the clone made out of flour sample from the first day of measuring, which was packed in a paper packaging (3^{rd} clones from above in Fig. 10) were the same as the clones from the sample from the first day from the plastic packaging - the dough was elastic, non-sticky; shape of the clone was evaluated as medium arched; colour of the bread crust was normal, typical pastry; parcelization was good; properties of the pastry crumb were sufficient; porosity of crumb was evaluated as uneven, with fine walls and smaller cavities; and overall taste impression was good.

The clones made out of sample of flour with age of 30 days stored in paper packaging showed the biggest difference (lower clones from Fig. 10). Clones were evaluated as follows: dough was elastic, non-sticky, shape was well-arched, colour of the bread crust was lighter and glossy, parcelization was good, properties of the pastry crumb were very good and fine, porosity of crumb was uniform with fine walls and medium pores, and the overall taste impression was very good, typical pastry. However, the resulting pastry was rather irregular in shape.

Figure 10: Clones from baking experiment, from the top: Clones made of flour sample from plastic packaging, 1st day; Clones made of flour sample from plastic packaging, 30th day; Clones made of flour sample from paper packaging, 1st day; Clones made of flour sample from paper packaging, 30th day

4.6. Zeleny test

The Zeleny sedimentation test (ST) is a method used to determine the gluten quality of wheat flour. The sedimentation index is a figure that represents the volume of sediment (measured in millilitres) that will develop from a suspension of the flour being tested in a lactic acid solution under particular circumstances. It is one among the factors that determines how well the flour will act during baking. Higher values indicate a higher quantity and/or quality of gluten.

Zeleny test was measured twice from every sample – from sample from plastic packaging as well as from sample from paper packaging. The sedimentation Zeleny test was measured on the first and on the thirtieth day of the experiment.

Table 10 shows the values of ST of flour sample from paper and plastic packaging on the 1st and 30th day. In the sample from plastic packaging, the value of ST did not change, while in the flour sample from paper packaging, the ST value in a month dropped by 2 ml. The decreasing values show the decreasing quality of gluten.

Figure 11: Values of Zeleny sedimentation test (ST) in %

Age of flour	ST (ml) Plastic packaging	ST (ml) Paper packaging
1st day	36	35
1 month	36	33

4.7. Volumetric yield, h/w

Volumetric yield in both cases decreased. In the sample from plastic packaging, it decreased by almost 60 cm^3. Height and width ratio (h/w) stayed in the sample from plastic packaging almost the same after a month. The ideal value of the ratio number is given as 0.65 [88]. According to the evaluation by Skoupil and Tvrznik, the ratio number corresponds to a very good flour quality above 0.7 [89]. Thus, clones from the first baking with flour from the paper wrapper indicate a good flour quality, with an ideal ratio of pastry shape. In Table 26 we can see that the volumetric yield decreased after a month for about 59 cm^3 per 100 g of pastry. The width of the clones made very small changes as vell as the height of the products, and so the ration of hight and width.

Table 26: Volumetric yield, height / width ratio of sample from plastic packaging

Age of flour	Volumetric yield (cm^3/100 g of pastry)	(w) Mean width of product (cm)	(h) Mean height of product (cm)	h/w
1st day	335.31	8.23	5.83	0.71
30th day	275.76	8.2	5.9	0.72

In Table 27 we can see that the volumetric yield of flour from paper packaging decreased, but "only" for about 31 cm^3 per 100 g of pastry, which is almost half the volume loss of flour clones sealed in plastic packaging. The change in height and width was significant after one month. There has been a significant increase in the resulting pastry height, and at the same time a relatively significant reduction in width. The change in the height/width ratio corresponds to 0.12. The dough has therefore narrowed and increased significantly after one month of flour maturation. According to Skoupil and Tvrznik, we can evaluate the value 0.66 from the first day of examination the plastic-packed flour as good. The value measured on this type of flour after a month corresponds to evaluation "very good"[89].

Table 27: Mean values of volumetric yield, and height / width ratio of sample from paper packaging

Age of flour	Volumetric yield (cm^3/100 g of pastry)	Width of product (cm)	Height of product (cm)	h/w
1st day	366.41	9.2	6.1	0.66
30th day	334.77	8.5	6.67	0.78

5. Discussion

The maturation time of the flour influenced significantly some of the measured rheological properties of the flour, and hence the dough. The tested working hypothesis was confirmed.

As can be seen from the results, the differences in rheological parameters were due, firstly, to the maturation time of the flour and, secondly, to the way the flour was stored - in a paper or plastic airtight bag.

The moisture in plastic packaging did not change much while in the flour sample packed in paper packaging it was decreasing. In a month, the moisture of flour in paper packaging decreased by 1.6%. The correlation coefficient between the changes in moisture of flour packed in paper and plastic packaging is 0.66, it indicates a relatively positive linear relationship between two variables. The flour changed in terms of moisture the same way as in the study from Hrušková and Machová (2002) which investigates properties of flour stored in jute sacks – with access of oxygen The change in flour moisture was probably due to the lower humidity and temperature of the storage environment [90]. In view of the greater breathability of the paper bag, there were more changes in it. There are two reasons why the flour's moisture content matters. First, there are fewer dry particles in the flour the greater the moisture content. Typically, flour requirements restrict the moisture content to no more than 14%. The miller has an incentive to maintain the moisture content as near to 14% as feasible, because water plays a role in the weight. Second, flour that has higher moisture than 14% will not remain stable at room temperature. At high moisture levels, naturally occurring organisms in the flour will begin to develop and release tastes and aromas [91]. Flour with higher natural moisture will tend to absorb more water during dough mixing compared to flour with lower natural moisture content. It is because the moisture content of the flour affects its ability to hydrate and form gluten during mixing. This can affect the consistency of the dough. It is also associated with water absorption, which is higher the lower the moisture content of the flour. Measured moisture values for flour in plastic packaging, except for one, show a decreasing trend, as in the study by Ahmad et al. which also investigates the effect of maturation time on the properties of flour stored in plastic packaging. Ahmad et al. also state that the environmental humidity is the determining parameter for moisture status [60].

Binding capacity did not show a linear increase in values. As expected from the study by Fitz (1910), binding capacity values should increase [64]. In neither case of flour packaging could the development of values be described as linear, but the values increased and more markedly for the sample of flour sealed in paper packaging. It can be assumed that the increase in flour binding capacity was influenced by decreasing moisture content. The values of flour binding capacity were within the expected range of 53 to 57.3%.

Although the same type of flour, liquid and mixing method were always used in the measurements, the DDT values varied and do not provide a complete picture of how DDT does or does not evolve over time. The DDT may have been influenced by the temperature of the Mixolab apparatus, which was heated after repeated measurements and thus may have shortened the DDT by any higher temperature, while lower temperatures may have lengthened the DDT. It is to be expected that lower DDT levels should be observed with longer storage, as the development of sticky gluten proteins – glutenin and gliadin, in longer-ripened flour continues. These sticky proteins are responsible for the elasticity and strength of the dough and if they are developed, the development time of the dough should be reduced.

During the maturation of the flour, the amplitude, i.e., the extent of development and change of the dough during the kneading and fermentation process, should gradually increase and stabilise, as well as the stability. Initially, when the flour is fresh, the amplitude and stability may be lower because the sticky proteins in the flour are not yet fully activated and developed and cannot form a stable network. It is therefore to be expected that with longer maturation the amplitude and stability would increase. According to our measurements, the peak of the amplitude values in flour from plastic packaging were in 10 days. Our results of amplitude values in plastic packaging are consistent with the results of the study by Ahmad et al. confirming increasing amplitude values for the first 10 days, when the flour reaches its highest amplitude, and then decreasing values in subsequent measurements [60]. Based on this, we can say that the ideal storage time for flour in plastic packaging is approximately 10 days in terms of its amplitude. Peak values for amplitude were achieved for the paper packaging flour on days 6 and 15. Between these two values, the amplitude was also high. This indicates that the ideal time to use the flour in terms of amplitude is at this long maturation period.

The stability values for the flour sealed in plastic packaging were fairly balanced overall, while the stability values for the flour sealed in paper packaging showed two significantly different peaks in values.

The falling number values in both cases increased unevenly. In general, as the flour matures, the fall number should be expected to be rather stable or increasing. This is due to the fact that during the maturation of the flour, further development of sticky proteins occurs, especially gluten proteins, which are responsible for the strength and elasticity of the dough.

It can be assumed that the gluten index and wet gluten content increase as the gluten proteins develop and harden during flour maturation. All measured values of the gluten index of the flour correspond to the best gluten quality or are close to its range between 92 and 82%.

It turned out that the best sensory evaluation was given to a sample of clones made from flour that had been aged for 30 days in a paper wrapper. There was a change for the better in crumb comparability. All samples produced reasonably good quality, well-rated clones with generally good parameters and taste perception. The question is whether and how the pastry characteristics would change with additional longer flour maturation time.

There was no change in the Zeleny sedimentation test for the flour sample in the plastic container. Whereas the sample sealed in a paper container showed a decrease of two millilitres of sediment. The decrease in the Zeleny sedimentation test value may indicate negative changes in the characteristics of the sticky proteins in the flour. This may be due to ageing of the flour or enzymatic activity which may affect the ability of these proteins to form sediment, although it is surprising that a maturation period of only one month, a relatively short period, should have had such an effect on the sedimentation test value.

The height/width ratio is a useful tool for assessing the appearance, texture, and quality of bakery products. Both flour samples showed a decrease in width with maturation, while the height of the baked clones increased. In the sample enclosed in a paper wrapper, the change was much more marked, suggesting that the flour has gained more strength and that the dough has therefore achieved better proofing and volume development during the baking process. The change in the height/width ratio was 0.01 for the plastic-wrapped sample, while the paper-wrapped sample showed an increase of

0.12. It is also worth noting that the pastry clones produced after the flour had been aged for 30 days in a paper wrapper were highly irregular in shape.

Volumetric yield expresses the volume of pastry produced from a given quantity of raw materials, usually in cm^3. In our case, the raw material was the dough. This metric provides an indication of how efficiently the raw materials are converted into the volumetric yield of the final pastry. For both measurements, the volumetric yield decreased after 30 days. Generally, lower quality or lower gluten content is the cause of reduced volumetric yield. Next cause could be reduced moisture content of the flour. Another reason could be the development of enzymes as the flour ages**.** During the ageing process, enzymes present in the flour may be activated, which may affect the structure and properties of the dough. For example, some enzymes may break down sticky proteins or affect the leavening process, which can result in a lower volume yield of baked goods.

On the basis of the baking experiment we can conclude that the quality of the product of the first day was better in terms of Zelneny test, volumetric yield and volume. On the other hand, with regard to the height/width ratio and sensory evaluation, the clones made from ripened flour were better.

There were changes in the protein status of the flour during ripening, which probably resulted in an undesirable decrease in baking volume after 30 days, an increase in the fall number, and a decrease in the Zeleny sedimentation test value, but also an increase in the height/width ratio.

This work illustrates the effect of time and storage method on the baking properties of flour. It was found that oxygen access has an effect on the development of flour rheological, pasting, and sensory properties. Oxygen is likely to contribute to changes in protein structure. When oxygen interacts with the flour proteins (gluten), it can lead to oxidation. This oxidation can affect the strength and elasticity of the gluten network in the dough. Oxidized gluten tends to form stronger, more elastic networks, which can improve dough stability and handling properties. This is often desirable in bread-making, as it can lead to better volume and texture in the final product. However, over-oxidation can also have negative effects, for example, it can cause the dough to be too stiff or over-mixed, which can lead to a hard final product. Therefore, bakers often control the level of exposure of the flour to oxygen during maturation to achieve the desired rheological properties of the dough. The presence of oxygen during maturation can also influence other factors such as enzymatic activity, which plays a role in the development of the dough. The enzymes present in the flour can be affected by oxidation, which can influence the fermentation and maturation process.

The question is whether it would not be possible to speed up the maturing process so that the flour could be processed immediately and to the best possible quality. Since we have observed a greater variation in the parameters for flour in paper packaging, it can be concluded that oxygen access plays a major role in the maturation of flour. The question therefore arises whether the maturation of the flour could be accelerated by more intensive aeration, for example by pumping and mixing the flour, at the end of the milling process, thereby speeding up the maturation process.

The hypothesis that minimal changes were expected in flour in plastic wrapping, and developing rheological properties of flour in paper wrapping, was fulfilled in most of the measured parameters. The expectation of changing rheological properties of flour that may improve baking properties was also fulfilled. It seems that the changes appearing on the tested flour from the plastic packaging had a more linear progression in more than one characteristic for example stability, moisture, or falling number, which could be due to a slower evolution of the properties.

6. Conclusions

The rheological qualities of dough are directly impacted by the aging process of wheat and flour. The water binding capacity of flour and the viscosity, falling number, increased with the age of wheat and flour due to postharvest maturation.

Statistically significant differences were found for moisture values between flour in paper and plastic packaging. The moisture content decreased in both cases, but the decrease was much more pronounced in the case of flour in paper packaging. The standard deviation was almost eight times higher for the paper-wrapped flour than for the plastic-wrapped flour.

Rheological properties - stability, amplitude, binding capacity, and DDT, were measured on Mixolab. Changes of these parameters of flour stored in plastic packaging were relatively negligible. There were changes, but apart from binding capacity, there was no clear increase or decrease in the measured values. Based on Pearson correlation, statistically significant correlations were found between stability and binding capacity of flour aged in plastic packaging (at 0.05 level of significance). Fluctuating values of binding capacity were found with peaks in the first third of the measurement and at the very end of the measurement time. These parameters were also measured for flour stored in paper packaging. No statistically significant correlation was found for this type of flour.

Torques C1, C2, C3, C4 and C5 were also tested on the Mixolab. For flour wrapped in plastic packaging, statistically significant correlations were found between C2 and C4, C3 and C4, and C4 and C5. For flour sealed in paper packaging, statistically significant correlations were found between C4 and C2 values, and between C3 and C4 values. There were no significant changes in torque values for either of the two flour samples.

Both the maturation time of the flour and the type of packaging had a significant effect on the fall number. The fall number of the flour sample sealed in paper packaging increased almost twice as much as that of the sample from plastic packaging.

There was found no significant correlation between wet gluten and gluten index values at 0.05 level of significance in both types of packaging.

As it occurred a sample of clones prepared from flour that had been aged for 30 days in a paper package had the best sensory evaluation. A positive shift occurred in crumb comparability.

When the Zeleny test was performed, there was no change in the flour in the plastic packaging, while the flour in the paper packaging showed a 2 ml decrease in the Zeleny test sediment value.

As the flour, from which the products of baking, matured, the width of both flour samples decreased but their height grew. Compared to the clones produced of flour from plastic packaging, the ones made of flour from paper packaging increased in height and dropped in length considerably more.

For some of the measured values, the trend for a particular property was clear, while for other properties no trend could be determined. Based on the measured values, the ideal maturation time of the flour cannot be determined with certainty. However, the work maps the evolution of baking properties and confirms the changes in flour parameters depending on the maturation of the flour. On the basis of the baking experiment, a decrease in the volume of the pastry was found, but at the same time an increase in the height/width ratio, which is a relatively important parameter in the production of pastry. Pastry made from flour matured in paper packaging was also better sensory evaluated. We recommend a more frequent repetition of the baking experiment, as the results are very revealing and could provide a more complete picture of the effect of flour maturation on the sensory properties and dimensions of baked goods.

7. References

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