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Faculty of Tropical AgriSciences

Thermo-Mechanical Properties, Solvent Retention Capacity and Sensory Quality of Composite Teff-Wheat Flour

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled: Thermo-mechanical properties, solvent retention capacity and sensory quality of composite teff-wheat flour 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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1. Abstract

Teff is an underutilised cereal crop of local importance grown in the Horn of Africa, especially in Ethiopia, where it is an important staple crop: its seeds form a base of human nutrition. It is often consumed processed into flat bread called *Injera*. Because teff seeds are the smallest of all cereals, the flour is made as wholegrain. Therefore, nutritionally more valuable in terms of protein composition, lipids, fibre and minerals. Therefore, teff flour is an ideal candidate to create a composite flour with regular white wheat flour (with its favourable baking properties) that would have a better nutritional value compared to 100% wheat flour but still retain the baking and organoleptic properties requested and accepted by technologists and consumers. The main goal of the thesis was to verify the popular recommendation of using a 30% mixture of teff flour in baking recipes. Common wheat flour, teff flour and their composites with different ratios of teff (10%, 30% .50% and 70% of teff flour in wheat flour) were analysed by using Solvent Retention Capacity AACC International Method 56-11.01 to assess chemical bonding of gluten, damaged starches, pentosans and β-glucans by different solvents (distilled water, 5% lactic acid, 5% sodium carbonate, 50% sucrose, 1M calcium chloride). Mixolab II was used for analysis of thermos-mechanical properties such as protein weakening, starch gelatinisation, hot gel stability and retrogradation of starches. Additionally, the sensory analysis was performed. Trained panellists evaluated samples of bread produced using wheat, teff and composite wheat-teff flours (10%, 30%, 50%, and 70% of teff flour in wheat flour). Responses were subjected to statistical analysis using Statistika 12 software. The baking test was performed to assess the physical properties of the bread (dimensions, weight, and volume) Water Retention Capacity was increasing with increased ratio of teff flour, while the LASRC was decreasing with increased ratio of teff flour. From Mixolab II Standard Test we concluded that increasing teff ratio decreased retrogradation of starches. From baking experiment, we statistically proven influence of teff flour on decreasing volume of samples. In the sensory evaluation the panellists selected as the best bread made with flour consisting of 30% teff flour in wheat flour.

Key words: Sensory Evaluation, Mixolab II, minor cereal crop, neglected crop, baking

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List of the abbreviations used in the thesis

AACC – American Association of Cereal Chemics

M – Mole

SRC – Solvent Retention Capacity

GI – Glycaemic Index

Fe – Iron

Cu – Copper

Zn – Zinc

A, B2, B5, B6 – Vitamin A, Riboflavin, Pantothenic Acid, Pyridoxin

CO_2 – Carbon Dioxide

pKa – Disociation constant

$C_{12}H_{22}O_{11}$ – Sucrose

H_2O – Water

Na_2CO_3 – Sodium Carbonate

$C_3H_6O_3$ – Lactic Acid

$CaCl_2$ – Calcium Chloride

Nm – Newton meter

p< – significance level

g/mol – molar weight

RPM – Revolutions per Minute

B.u. – Brabender/Farinographic unit

WRC – water retention capacity

SCSRC – Sodium carbonate retention capacity

SuSRC – Sucrose retention capacity

LASRC – Lactic Acid Retention capacity

GPI – Gluten Performance Index

MT – Mixing Time

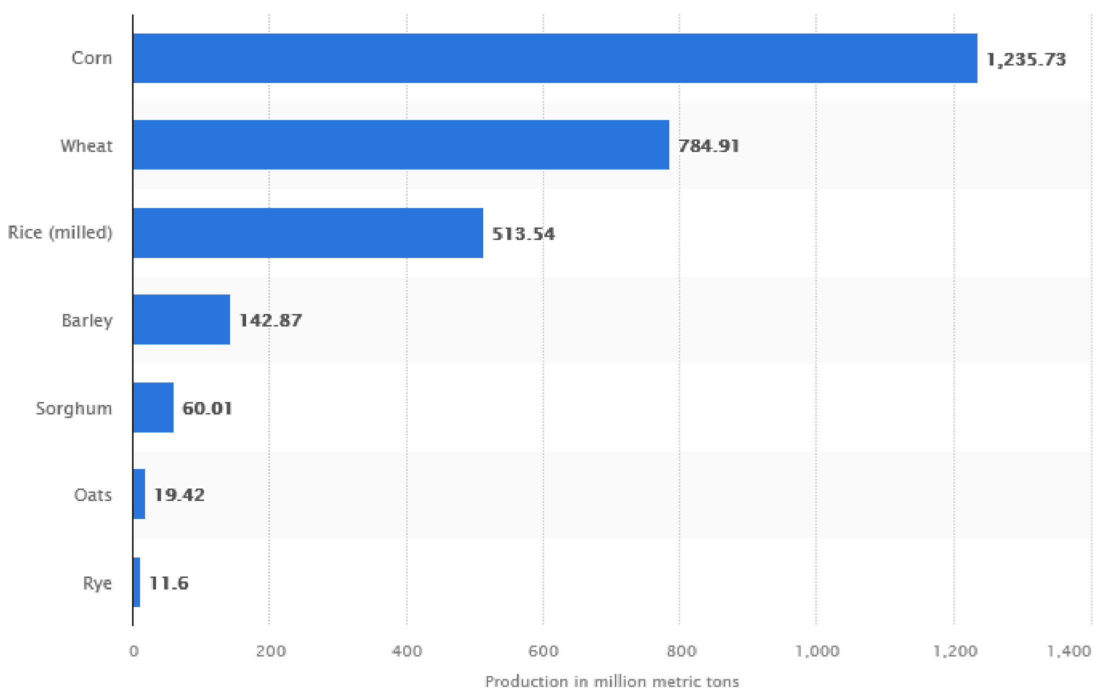
WA – Water Absorption

μ – Arithmetic Mean

2. Introduction and Literature Review

Cereals are the base of calory intake for majority of human population. Cereal calories contribute to over 50 % of human daily caloric intake (Awika 2011). They have been cultivated since human agricultural revolution (Faltermaier et al. 2014). The global agriculture is mainly focused on three species and their cultivars. Namely common wheat (*Triticum aestivum*), maise (*Zea mays*), common rice (*Oryza sativa*) (Awika 2011). In 2022 those three species supplied over 89 % of human cereal consumption and would continue to do so in future as visible in **Graph 1**. Due to their popularity chemical, biological, and organoleptic properties of the common cereals are well known to science.

Graph 1 Forecast of Cereal Production in 2023/2024



source: Statista https://www.statista.com/statistics/263977/world-grain-production-by-type/

However, there are around 10,000 species of *Poaceae* family around the world. Only 35 of them are cultivated for the cereal production. 27 out of them are mostly unknown to the global population (Kellogg 1998). They are grown as main cereal crops of local importance. Such as in case of teff (*Eragrostis tef*). This crop has been traditionally cultivated in Africa, specifically in Ethiopia and Eritrea.

In 2022 Ethiopia produced over 90 % of worldwide teff supply. Teff is eaten daily by people of Ethiopia in form of fermented bread known as *Injera*. Teff is so important staple food that exporting is strictly limited by law. Teff is also important source of animal bedding and fodder. The stems also serve as construction material. Nowadays, it slowly finds its way to global cuisine as healthier, gluten free super food alternative to common white flour (Cheng et al. 2017). Many studies were made in regard of comparison of baked goods from common flour with their teff flour variants.

However, no sensory analysis of teff bread products for Czech consumers had been done, which motivated creation of this thesis. Teff flour is pricier commodity therefore creation of composite flours consisting of teff, and cheaper common wheat white flours were going to be produced and tested using SRC (Solvent Retention Capacity), Mixolab II and sensory analysis. Increased nutritional value is expected in composite flours in comparison with common flour.

2.1. Teff (*Eragrostis tef*)

2.1.1. Basic Morphology of Teff

Teff in Czechia known as *milička habešská* in English is called Eragostis Teff, rarely called Williams Lovegrass. It belongs to the *eragrostis* genus group of C4 annual cereal grass plants. It is considered to be very drought and heat resistant crop as it grows in dry arid environment of Horn of Africa. However, it is well grown in wetlands areas. Teff root system is very shallow with vast rooting system, the stems are very fine up to 2 m tall with many tillers. Leaves of flag type are supported by stems and are sprouting from them. On top of each stem a massive seedbearing crown is developed. The plants are self-pollinated tetraploids (Jifar et al. 2018).

2.1.2. Morphology of Teff Seed

Teff grains are considered to be the smallest grains of all harvested cereals. Average size of seed is less than 1 mm in diameter and is often compared with poppy seeds. Seeds have typical cereal elliptic shape and colour ranges from white, yellow, ivory to dark reddish brown. Grains grow in whip like spikelets with 3 to 17 seeds. Approximate weight of 1000 seeds are estimated about 0.3 g (Jifar et al. 2018). In comparison common wheat has weight of 22–25 g (Lersten 2015). Weight of 150 teff seed is equal to one wheat grain.

Teff seed have huge impact on Ethiopian economy as export of raw grains is banned by government. Local farmers generate about 500 million dollars trading teff grains to local food producing sector. Recent interest in healthier alternatives increase demand for teff products leading to creation of new work opportunities for Ethiopians (Adanech 2019).

2.1.3. Yields and Harvest of Teff

The average yields expected are around 800 kg per hectare in developing countries and between 1000 kg to 1500 kg per hectare in developed countries. Small size of seeds brings up technological challenges to achieve high efficiency in planting, harvesting, transportation, storage, and milling said seeds. Low levels of mechanisation or poor adaptation of machinery to teff is leading to lower yields (Cheng et al. 2017). Teff is milled to whole grain flour, which is more problematic due to shorter shelf life of whole grain products. Production of classic flour is basically impossible due to high loses of mass. Another reason for lower yields and grain quality is lodging of the tall stems of said plants. Especially in condition of European countries, where teff grows taller due to prolonged sun hours. Lodging occurs on fields facing high amounts of winds or heavy rains. Lodged grains are vulnerable to moulds. Ripening is slowed and many grains germinate prematurely (van Delden et al. 2010).

2.2. Teff Flour Description and Composition

As a main benefit of teff flour is it being gluten free, making it a perfect substitution for people with celiac disease or people with distaste for gluten. It also contains high amounts of micronutrients, especially iron. It also comprises balanced mix of essential amino acids to cover human daily intake unlike other common cereals. Teff flour is obtainable in humidity proof bags. The flour itself has appearance of grey–brown dust. Main elements of teff flour are carbohydrates in form of sugars, starches, pentosans (indigestible structural sugars like cellulose and hemicellulose) commonly known as indigestible fibre, proteins, fats, and minerals (Zhu 2018).

2.2.1.1. Teff Carbohydrates

Teff is considered starchy cereal due to high amounts of complex sugars making up to 80 % of grain weight with approximately 73 % of them being starches. Rest are known as structural sugars like cellulose and hemicellulose. The size of starch molecules present in teff is significantly smaller than other comparable cereals. For example, teff starch molecules were measured to be from 2–6 μm, while wheat starch molecules were between 20–35 μm. In other words, teff starches are more comparable to rice starch, which molecules are 2–7 μm.

Smaller size of starch molecules suggested easier accessibility of amylase enzyme, leading to facilitated enzymatic digestion, resulting in higher glycaemic index (GI). However, in vitro digestion tests proved teff starches to be harder digestible than common wheat starches. One of possible explanations is that teff starch molecules are less likely to be damaged during milling, thus less susceptible to enzymatic processes. Meaning teff flour GI (74) is significantly lower than common wheat (100). Teff Flour GI is comparable to other cereals as sorghum (72) or oats (71)(Zhu 2018).

2.2.1.2. Teff Proteins

Crude Proteins in teff take about 8 to 11 % on average. This amount is common with other kinds of cereals. Recent studies proved that most proteins are in form of prolamins. Contradictory in past scientists believed that most proteins inside teff flour are in forms of glutelins and albumins (Zhu 2018).

Teff Amino Acids

In comparison to other cereals teff flour contains higher amounts of amino acids, especially higher concentrations of lysine, which is considered limiting amino acid in most cereals. Fortification of common cereal with teff would lead to increased nutritional value of pastry products by increasing the minimal value of limiting amino acid.

Furthermore, fourteen strands of teff flour were tested with trypsin and pepsin digestion for presence of gluten with no gluten present making teff perfect food for celiac people (Cheng et al. 2017).

Table 1 Comparison of Amino Acid in Teff and Selected Cereals

Amino Acid g /16 g N	Teff	Sorghum	Wheat	Rice
Lysine*	3.7	0.3	2.1	3.7
Methionine*	4.1	0.3	1.5	2.7
Threonine*	4.3	0.5	2.7	3.7
Tryptophan*	1.3	0.2	1.1	1.2
Alanine	10.1	1.6	3.6	5.5
Histidine*	3.2	0.4	2.1	2.3
Leucine*	8.5	2.1	7.0	8.2
Phenylalanine*	5.7	0.9	4.9	5.5
Cystine	2.5	0.3	2.4	1.8
Proline	8.2	1.3	10.2	5.0
Valine*	5.5	0.8	4.1	6.0
Tyrosine	3.8	0.7	2.3	5.2
Glutamine + Glutamic Acid	21.8		29.5	17.0
Arginine	5.2	0.6	3.5	8.5
Asparagine	6.4		5.1	9.0
Serine	4.1	0.8	5.0	5.0
Isoleucine*	4.1	0.7	3.7	4.5
Glysine	3.1	0.5	4.0	4.5

Black rectangle shows amino acids in highest concentration in teff, essential amino acids were marked with star. Data source (Cheng et al. 2017).

2.2.1.3. Teff Lipids

Teff is one of few cereals that keeps high fat acid due to wholegrain milling and low levels of refinement. High levels of oleic acid (32.4 %) and linoleic acid (23.8 %) making teff comparable with legumes like soybean (Zhu 2018).

2.2.1.4. Teff Fibre

Fibers are defined as consumable carbohydrates that are resistant to digestion and absorption inside stomach and small intestine and are partially or completely fermented inside large intestine and serves for physiologic benefits like laxation (faecal bulking) or lowering blood glucose levels.

Teff contains higher levels of crude fibres than most cereals. There are about 3 % of fibres present in teff compared with only about 2 % in common wheat. Dietary fibres reach 4.5 % in teff. Other cereals are almost without them only maize has about 2.6 % (Zhu 2018).

2.2.1.5. Teff Minerals

Teff is considered mineral rich cereal. Especially amounts of iron, copper, zinc and calcium. They are beneficial for blood creation (iron), metabolic processes (copper), metabolism and male health (zinc) and strength of bones and teeth health (calcium).

Iron was a long-time subject of conflicts for scientist. It has been proven that high levels of iron present in teff originates from soil contamination during traditional threshing methods. However, laboratory tests with indoor threshing proved teff is still far superior in term of minerals in comparison with other cereals (Zhu 2018).

2.2.2. Teff Consumption

Teff products are sought-after because of its specific sour taste. Due to increase in demand the price of teff increased in comparison with other staples. In Ethiopian households teff provides over 60 % of caloric intake and over 40 % food expenditure. Teff often serves as animal fodder. However, it is mostly consumed in form of pancake like flat bread called *Injera* (Adanech 2019).

Injera

Traditional method of consumption is form of steam baked bread called *Injera*. Simple preparation of *Injera* starts with mixing teff flour with water. Created dough is inoculated with *ersho* (fermentation starter created by previous fermentation). Usual length of fermentation is 2–3 days. Teff produced *Injera* is well suited for short term storage, better at keeping sauces inside and overall better sensory attributes to other cereals used for *Injera* preparation (de Vos 2011).

2.2.2.1. Composite Flour

By composite flour we understand either combination of wheat flour and non-wheat flours or dry milled matter produced from cereals, legumes, tubers, roots, vegetable and other raw products such as insects or mixture of them (Cecil 1992).

Pure teff flour products consumption is beneficial for overall human health. However, pure teff flour bakery potential is very low (Arslan & Yilmaz 2018). Therefore, usage of teff flour composite had been suggested. The taste of teff composite flours in sensory analysis were reported to be lower than pure wheat flour ones with only average taste score (Oliveira et al. 2020). Therefore, taste improving methods were suggested in case of higher than 10% concentration of teff flour. Shorter fermenting period of only up to 6 hours in comparison to several days for *Injera* might be main reason for the lower sensory acceptability of teff. However, Czech teff flour retail shop ("Bezlepkova.com" n.d.) suggests using 30% teff concentration in bakery products. Therefore, sensory analysis on Czech consumers were performed as part of this thesis.

2.3. Common Wheat (*Triticum aestivum*)

Common wheat (*triticum aestivum*) belongs to P*oaceae* family. It has been source of food for humans since 8,000 to 10,000 BC (Faltermaier et al. 2014). It originates from West Asia. Nowadays it is grown all over the world. It belongs to the top three most produced cereals with rice (*Oryza sativa*) and corn (*Zea mays*). Through selective breeding we now use different types of common wheat for bread production, cookies, pastry and beer brewing (Mehmet 2021).

2.3.1. Basic Morphology of Common Wheat

Common Wheat is annual or biennial plant. Bundled roots can reach depths of up to 150 cm. They support and feed several axillary leaves and culms. They grow from 50 to 130 cm tall. The Stem is smooth and bald with elbows. From elbow long, flag shaped leave propagates. On top of stem inflorescence is located. After pollination it turns into ear with grains. One ear can produce up to 50 grains. The amount of grains is influenced by amount of fertilisation (Lersten 2015).

2.3.2. Morphology of Common Wheat Seed

The grain is covered by plumes and husks. Plumes are with or without awns. Awned cultivars are more resilient to heat and drought. The grain itself ripen into golden yellow or brown colour. Average 1000 seed weight is up to 41 g. The seed consists of several parts or layers: germ, starchy endosperm, aleurone layer, pericarp. Endosperm is nutritionally richest part of the seed and main component of common white flour. It main function is to store energy in form of starches for germination of grain. Aleurone layer and pericarp enrich the flour with protein, minerals, and fiber. Aleurone supports the development of germ. Pericarp protects the grain before germination (Lersten 2015).

2.3.3. Yields and Harvest of Common Wheat

Common wheat is harvested depending on cultivars from summer (winter wheat) to fall (spring wheat). Average yield of common wheat ranges from 2.8 t (India) up to 7.5 t (France) per hectare (Awika 2011). For this disbalance poor mechanisation, poor fertilisers usage knowledge and policy, and weeds management is responsible (Nagarajan 2020).

Nowadays common wheat is harvested by differently sized combine harvesters machines, when the grains reach maturity with low inner moisture of up to 15 % to prolong storage time and prevent grain losses (Patel & Varshney 2014).

2.3.4. Common Wheat Flour Description and Composition

Wheat flour is produced by milling grains. Due to long history of wheat consumption, there are several kinds of flour to satisfy needs of baking industry. They differ in composition and size of particles.

The biggest is called semolina. It is made from unhusked wheat grains. Particle size of semolina ranges from 0.25 to 1 mm. It is used for production of common pastas or couscous. Nowadays enrichment of semolina to improve nutritional value is demanded by consumers (Romano et al. 2021).

Low-milled flour is most common form of milling. Particle size is determined by type numbers. However, the size of particles does not exceed 0.5 mm. The more the flour is milled the higher the type number. Finer the flour the more damaged starches it contains improving the accessibility of sugars for enzymes and microorganisms. However, excessive milling damages the gluten decreasing its bakery quality. This type is great for long term storage and production of sweat pastry. Low-milled pastry has low nutritional value.

High-milled flour is produced by milling whole grains. Particle size does not exceed 0.5 mm. This kind of flour is suitable to production of bread.

Highest level of milling of flour is known as wholegrain flour and it is the most nutritional valuable kind of flour (Elieser & Hibbs 2011).

2.3.4.1. Common Wheat Carbohydrates

Carbohydrates inside grain are stored in Endosperm in form of starch granules. Their function is to be digested by enzymes like α-Amylase into sugars that serve as source of energy for germination. 80 % of Endosperm dried matter consists of starches in form of Amylose and Amylopectin (Shewry et al. 2013).

For baking purposes, damaged starches created by milling of grains are important for quality and usage of the flour as microorganisms consume sugars to produce gases leading to rising of dough (Struyf et al. 2017).

2.3.4.2. Common Wheat Proteins

Proteins contained in grain take up 7 to 22 % of dry grain weight. The most important group is gluten (Shewry et al. 2013). This protein affects the baking properties of dough. Especially rising of dough. High amounts of gluten decrease the ability to rise as the molecule bond is stronger than expanding force of gas. Gluten network gives dough elasticity and shape keep ability important for production of pasta and bread. Low amount of gluten is typical by inability to keep dome shape of bread or ripping of crust (Shewry 2019).

2.3.4.3. Common Wheat Amino Acids

As most cereal the wheat amino acid composition is lacking in essential amino acids such as lysine, methionine and tryptophane. As the human body is unable to store amino acids the nutritional value of wheat produce is decreased by law of limiting amino acid. Low levels of amino acids are well visible in **Table 1**.

2.3.4.4. Common Wheat Lipids

Common wheat flour is composed of 2 to 2.5% of lipids. Even in their low concentration they affect the volume of bread (Pareyt et al. 2011).

2.3.4.5. Common Wheat Fibers

It is recommended to consume fiber rich cereal products such as wholegrain flour. The lighter the flour the less amounts of fiber it contains. The sufficient intake of dietary fiber of at least 30 g per day decreases risk of diabetes and colon cancer by the lowered caloric value and slowing speed of digestion (Cheng et al. 2022).

2.3.4.6. Common Wheat Minerals and Vitamins

Common wheat can serve as source of Fe, Cu, Zn and vitamins: A, B2, B5, B6. Especially for people in developing countries where lack of minerals and vitamins is ongoing issue (Tekin et al. 2018).

2.4. Solvent Retention Capacity

Solvent Retention Capacity (SRC) is an analytical and comparative laboratory method developed to easily compare amounts of components responsible for sorption of liquids in substrates, in this case sorption of different liquids in dough. The calculation for this method is calibrated for flour with 14% moisture basis. Moisture basis had been measured with usage of quick heat evaporation scales. The weigh difference measured would be equal to amount of water evaporated, which is considered the moisture present in flour sample (Kweon et al. 2011).

Basic Principle

Solvent retention capacity is based on fact that liquids create chemical bonds with certain particles in solid matter. The strength of chemical bonds is higher than centrifugal force. Excess liquids are removed from solid matter, while the chemically bound liquids remain. This difference can be described by solid matter increased in weight (Kweon et al. 2011).

There are three main groups of liquid absorbers present in dough: Polysaccharides, mainly starches, non-starchy polysaccharides like cellulose or hemicellulose, also known as pentosans or structural sugars, and proteins, especially glutenin which is main part of gluten protein chains (Banu & Aprodu 2022).

2.4.1.1. 50% Sucrose ($C_{12}H_{22}O_{11}$)

In addition to starch flour contains more non starch polysaccharides. For some of them common designation pentosans (non-starchy polysaccharides present in flour, interchangeable with term hemicellulose or cellulose) is used. Others are arabinoxylans and β-glucans. They affect dough quality by their high-water binding qualities. They can uphold up to 10g of water per g of their own weight (Finnie S.; Atwell A. 2016). Therefore, 50% Sucrose is used to establish percental increase in SRC in contrast with distilled water SRC. Sucrose make pentosans affinity to liquid much higher by changing osmotic potential of pentosans (Banu & Aprodu 2022).

2.4.1.2. 5% Sodium Carbonate (Na_2CO_3)

Sodium Carbonate is used to compare the mass of damaged starches in flour samples.

Damaged starches are product of milling grains into flour. Their amount is one of the watched parameters for establishing quality and utility of selected flour. They are water absorbents. They can absorb up to 10 g of water per g of their own weight.

For baking purposes starches are degraded by enzymes into maltose. Yeast can produce ethanol and gases like CO_2 from starches in bread production to make it fluffier. Baking of starch rich dough without yeast leads to production of sweet pastry without need of sugar addition (Finnie S.; Atwell A. 2016).

Sodium carbonate increases pH to be > 11. This alkaline environment is higher than pKa of hydroxyl groups present in starches. This allows damaged starches to be distinguished from native form of starches or gelatinised starches (Banu & Aprodu 2022).

2.4.1.3. 5% Lactic Acid ($C_3H_6O_3$)

Lactic acid was used to estimate amounts of glutenin in samples. Glutenin is insoluble protein, and it is part of gluten proteins found in common flours. Pure teff flour should not contain any amounts as teff is considered gluten free cereal, while composite flour would have lower amounts than pure white wheat flour. Lactic acid reacts with glutenin in sample. During process known as lactylation glutenin surface charges changes leading to solubility in water thus making it more affiliated to water. Lactylyzed glutenin can binds 2.8 g of water per gram of its own weight. Other protein contribution to retention capacity is negligible (Wang et al. 2022). During SRC we could observe separation of gel like substance consisting of this lactylyzed glutenin.

2.4.1.4. 1 M Calcium Chloride ($CaCl_2$)

This solvent is used to estimate amounts of β-glucans which are water absorber sugars present in flour. β-glucans are part of structural sugars and create dietary fibre, which is described as edible part of plant that is indigestible for human, but fermentable by bacteria inside large intestine. Consumption of dietary fiber has positive effect on human health (Ahmad et al. 2012). Reaction of calcium chloride and β-glucans leads to creation of calcium alginate gel which coats the β-glucans making them more stable and water affinitive (Niu et al. 2017).

2.4.1.5. Water (H_2O)

Water SRC is influenced by all flour constituents mentioned above (Banu & Aprodu 2022). However, not in such a high rate because no change in properties occur. Therefore, we can calculate difference between distilled water and other solvents. This calculation is also important for the next part of experiment to measure flour properties using Chopin Mixolab II.

2.5. Mixolab II

Mixolab II is laboratory machine equipment produced by French company Chopin Technologies since 2006. It is used to analyse thermo-mechanical properties of dough during mixture from different kinds of flour.

Main working part is a dismountable sturdy steel mixing chamber with mixing blades and analytic sensor hole. Flour samples are poured inside working chamber through hole in top side. Preheated distilled water tank is used as source of water for dough creation. The tank is connected with the working chamber by removable elastic pipe, used to plunge hole in the top side of working chamber. Water pump could deliver precise amounts of water into the working chamber through the pipe. Rest of the machine is dedicated for the electromotor, water tank, heater, sensors, computer connection, power supply and cooling system.

Dough properties are analysed and showed on connected computer. Mixolab II can be used for several different tests to collect information about different properties of flour. The samples are hydrated, by distilled water heated to 30 °C. Chamber can be heated or cooled down as needed for test stage. Most used Mixolab Standard test has been used.

Mixolab Standard Test

During this test the sample is subjected to heat and mixing stress. This allows measurements of rheological properties on built in recording dough mixer. The measurement is done by recording torque moment created by dough on mixing blades. To assure constant weight and repeatability of the test samples of 75 g are used. With moisture base of 14% meaning the software can calculate needed water input based on moisture content and absorption rate of sample. Beforehand knowledge of moisture and absorption capacity is helpful, but not needed as it can be calculated after first test on Mixolab II. Usual moisture level of flour sample ranges from 7 % to 14 %. Average absorption rate for fine flour is around 50 % and whole grain flour around 60 %. The test is split up into five stages each for a different aspect of dough. One test cycle takes 45 minutes.

Stage C1

First stage is critical for success of entire test. During this stage the absorption rate, stability and elasticity of dough is measured. During this stage the torque reaches maximum value. In case the torque of dough is not 1.1 Nm with tolerance of 0.05 Nm the test is stopped correct moisture and absorption rate calculated. After washing of the work chamber the test can be repeated using newly acquired values.

Stage C2

In this stage protein weakening is measured. It can be observed as decrease in torque. By protein weakening it is meant weakening of sulfid bonds and non-covalent bonds leading to disaggregation of big protein clusters and creation of smaller clusters of proteins connected by weaker non-covalent bonds. It is created by adding force and heat into the mixture. This process is called mixing. Protein weakening is important for baking purposes as the overmixing of dough is problem resulting in low consistency and poor shape keep of dough. This result in baking failure.

Stage C3

Measurement of starch gelatinisation is realised in this stage. The temperature increases and the torque decreases than rapidly increase as liquid is created. In water and increased heat, the starch granules are broken down creating viscous liquid. This liquid has different properties based on the sources and concentration of starch granules.

Stage C4

This stage is measuring hot gel stability. Consistency of dough is decreasing. This is linked to amylolytic activity. Amylase is an enzyme responsible for degradation of starches into monosaccharides. Amylase is naturally present in grains as it is needed to degrade starch for energy to germinate grain. In case of flour, it degrades starch gel. Amylase activity is hugely increased by high temperature of this stage. Different attributes affect the gel stability. Like the size of the starches or amounts of amylase present.

Stage C5

In final stage retrogradation of starches is measured. It is accompanied by increase in consistency as a gel is created. This is possible due to decrease in temperature as cooling process is performed. Retrogradation is a process in which starches create new crystallin molecules after being heated.

Spider Chart

Spider Chart is visualisation of results measured by Mixolab Standard Test. We can observe absorption, mixing, gluten, viscosity, amylase activity and retrogradation. This chart is useful to compare our flour samples with other flour samples from different measures as well as measures done by other scientists (Chopin Technologies 2012).

2.6. Sensory Analysis

Sensory analysis is semiquantitative method for gathering data about appearance, smell and most importantly taste of food product. It is done by a group of people who rate different aspects of tested blind samples. Main tool is questionnaire with Likert scale-based measurement.

There are three different approaches. First is use of common people. Benefit is that a large amount of data is collected easily, while the results are not so accurate. Second method is use of trained panellists, a group of people taught to perform sensory analysis. Results from this are not as sheer but are more accurate. Lastly a group of professional taste analyst can be used. However, you get very accurate results but on a limited group of people (Murray et al. 2001).

3. Aims of the Thesis

Teff (*Eragrostis tef*) is a cereal plant of local importance for certain tropical countries e.g. Ethiopia. Teff is high in protein and gluten-free which makes it an interesting substitution for people with the gluten-free diet. The main aim was to assess the properties of dough from composite teff-wheat flour using solvent retention capacity and Mixolab II. The secondary objective is to assess the sensory properties of the composite teff-wheat products and their acceptability by consumers on Czech market.

4. Methods

For the assessment of the dough properties, primarily Solvent Retention Capacity (SRC) a comparative laboratory method had been used. Secondary method used had been Mixolab II (Chopin Technologies, France) with precise dough creating analysis and behaviour of dough during baking. The final part had been sensory analysis with aim to compare teff composite breads of different teff contents (10%, 30%, 50%, 70%), with product from commonly used flour bread and pure teff flour bread. Secondary aim of the thesis is to prove whether 30% teff composite flour has best chemical, baking, and sensory properties. All acquired results were statistically tested used corelation analysis on $p < 0.05$ and proven correct in error correction methods as standard deviation.

4.1. Flour Samples

The common wheat for mixing with teff flour were set to be fine white common wheat flour. It was purchased from Mlýn Dubecko ("Mouka Dubecko.cz" n.d.) a milling company established in 1833. According to the producer the flour has high amounts of gluten. It is natural flour without any additives or fortifications.

Table 2 Nutritional Values of Common White Flour from Dubecko. Per 100 g of Flour

Energy Value	**1474 KJ / 384 kcal**
Fats	1.5 g
Saturated Fats from Fats Value	0.3 g
Sacharides	70.0 g
Sugars from Sacharides Value	2.0 g
Fiber	3.0 g
Protein	12.0 g
Salt	0.01 g

Teff flour samples were purchased from ("Bezlepkova.com" n.d.) e-shop specialised in selling gluten free flour from Adveni Medical spol. s.r.o. producer. One type of teff flour from two available kinds had been purchased. It is called fine teff flour light. Used cultivar for production of said flour is unknown to the retail shop and producer have not responded to correspondence.

Table 3 Nutritional Values of Fine Light Teff Flour from Adveni Medical s.r.o., Per 100 g of Flour

Energy Value	**1340 kj / 320 kcal**
Fats	2.0 g
Saturated Fats from Fats Value	0.7 g
Sacharides	62.7 g
Sugars from Sacharides Value	5.4 g
Fiber	Not provided by producer
Protein	11.8 g
Salt	0.02

4.2. SRC Measurement Realisation

4.2.1. Experiment Description

Five solvents were prepared for the experiment: distilled water (H_2O), 50% sucrose ($C_{12}H_{22}O_{11}$), 5% sodium carbonate (Na_2CO_3), 5% lactic acid ($C_3H_6O_3$) and 1 M Calcium Chloride ($CaCl_2$). Combination of results from the different solvents had allowed chemical composition of teff flour, wheat flour and composite flour described and compared with each other. Those properties are useful to predict teff flour baking performance and its suitability for different pastry production. Every solvent selected creates ideal environment for different liquid absorbers in flour to create chemical bonds (Banu & Aprodu 2022).

4.2.1.1. Solvent Preparation

50% Sucrose ($C_{12}H_{22}O_{11}$) Preparation

To prepare 50% sucrose distilled water and sucrose with 99.8 % purity from Penta Labs were used. To prepare 100 ml of said solvent 50.1 g of sucrose needed to be dissolved in 100 ml of distilled water. For better solubility of sucrose distilled water had been heated by using heated water bath. For improved efficiency the sucrose solution can be prepared in advance. It has shelf life of up to 7 days. 100 ml of distilled water was measured in graduated cylinder and 50.1 g of sucrose was weighted on balance scales.

5% Sodium Carbonate (Na_2CO_3) Preparation

Calcium carbonate was purchased with 99 % purity. To prepare 5% solvent 5.05 g of Calcium carbonate was weighted on balance scales dissolved in 100 ml of water measured by graduated cylinder.

5% Lactic Acid ($C_3H_6O_3$) Preparation

To prepare 5% of Lactic acid solvent 80% Lactic acid was purchased. 93.75 ml of distilled water was mixed with 6.25 ml of 80% Lactic acid producing 100 ml of desired solvents. Both liquids were measured using graduated cylinders.

1 M Calcium Chloride ($CaCl_2$) Preparation

To prepare 1M Calcium Chloride solvent 95 % purity was purchased. Calcium chloride molar weight is 110.99 g/mol. To prepare 100 ml of 1 M solvent 11.654 g of Calcium chloride were weighted on balance scales and mixed with 100 ml of distilled water measured by graduated cylinder. 1 M Calcium Chloride reacts with distilled water in exothermic reaction so after mixing the solvent should be cooled down to room temperature. Usage of mortar and pestle to pound calcium chloride into soft dust is recommended, otherwise after addition of distilled water some hard to dissolve lumps of calcium chloride would form.

4.2.2. Samples Preparation

Homogenisation

Homogenisation is process that assures equal mixing of different substances of mixture. For this purpose, ETA Gratus II multipurpose kitchen robot with 1200 W of power had been used. Each sample batch was mixed two times for 5 minutes after each mixing period the mixture was mixed by glass stirring rod.

10% Teff Content

To prepare 200 g of 10% teff content composite flour 20 g of teff flour were mixed with 180 g of wheat flour. This ratio was selected as one of the lowest mixes to compare low difference with common wheat flour.

30% teff Content

To prepare 200 g of 30% teff content composite flour 60 g of teff flour were mixed with 140 g of wheat flour. This ratio was selected to investigate properties of most time recommended ratio of mixture by several different Czech health websites.

50% teff content

To prepare 200 g of 50% teff content composite flour 100 g of teff flour were mixed with 100 g of wheat flour. Selection of this ratio was used to discover whether 1:1 ratio would have 1:1 properties of teff flour and common wheat flour.

70% teff content

To prepare 200 g of 70% teff content composite flour 140 g of teff flour were mixed with 60 g of wheat flour. This ratio was selected to discover properties of almost teff flour mixture.

4.2.2.1. Optimalisation of Solvent Retention Capacity

According to the correct working procedure AACC International Method 56-11.01 by AACC, 5 g of flour is mixed with 25 g of solvent and left for 20 minutes in so called soaking period. During this time chemical reactions take place. The tubes are repeatedly shaked in precise intervals, usually every five minutes. After that tubes are centrifuged for 15 minutes at 1000 RPM. Excess solvent is removed and created gel is turned upside down inside test tubes for ten minutes. Then the tubes are weighted on balance scales (Kweon et al. 2011). The difference of weight is calculated and placed in formula.

$$\%\,SRC = \left[\frac{gel\ weight}{flour\ weight} - 1\right] \times \left[\frac{86}{(100 - \%\ moisture)}\right] \times 100$$

In this formula gel weight is weight of the sample after centrifugation. Flour weight is equal to sample weight, which is usually 5 g. -1 is there to remove the input weight from dividation otherwise the calculation would be over 100%. On the right side the 86 on top is to unify the results of different samples to 14% moisture level. The 100 stands there for maximum attainable level of moisture. The -% moisture is the amount of moisture present in sample. Usually aquired by rapid drying of sample. We used the drying scales. Moisture of grains used for flour production and the milling product should not exceed 14% moisture (Elieser & Hibbs 2011). This limit is set to prevent development of molds and bacteria increasing shelf life and food safety of grain milling products. Finally the x 100 part is to convert final number to percent unit.

Realisation of SRC Test 1

It has been correctly assumed that quantitative placing of gel sample on watch glass is impossible therefore weight of empty test tubes with lids before each measurement had been done. Six samples of 5 g sizes were weighted. Inside the test tubes the 3 samples were mixed with distilled water and left for 5 minutes of soaking. Another 3 samples were left to soak for 20 minutes. First two samples were centrifuged for 15 minutes with 1,000 RPM. Percentual moisture content was measured to be 14.5 %.

Table 4 1000 RPM SRC Test Values

Item	Weight (g)	Item after Centrifuging	Weight (g)
Test Tube 1	13.394	Test Tube 1	22.962
Test Tube 2	13.094	Test Tube 2	22.945
Sample 1	5	Gel 1	9.568
Sample 2	5	Gel 2	9.851

Table 5 1000 RPM SRC Test Results

SRC	Percentage (%)
SRC_1	91.546
SRC_2	97.567

After removing of samples from test tubes even basic observation proved that samples were not centrifuged properly. Samples were moist with excessive water leakage. The tube could not be placed upside down as the contents of it would have spill out. So to proper measurement we had to deviate from standard method by increasing the RPM.

Realisation of SRC Test 2

Samples 3 and 4 were soaked and after 5 minutes for sample 3 and 20 minutes for sample 4 of soaking period were placed into centrifuge for 15 minutes on 3,000 RPM.

Table 6 3,000 RPM SRC Test Values

Item	Weight (g)	Item after Centrifuging	Weight (g)
Test Tube 3	13.190	Test Tube 3	21.305
Test Tube 4	13.220	Test Tube 4	21.344
Sample 3	5	Gel 3	8.115
Sample 4	5	Gel 4	8.124

Table 7 3,000 RPM SRC Test Results

SRC	Percentage (%)
SRC_3	62.66
SRC_4	62.84

Samples 3 and 4 after removing from test tubes were visibly less moist keeping shape with slight leaking of water. Still after turning upside down the content slowly spilled out. The percentual value was closer to expected results.

Realisation of SRC Test 3

Samples 5 and 6 were soaked for 5 and 20 minutes and placed into centrifuge for 15 minutes at 5,000 RPM.

Table 8 5,000 RPM SRC Test Values

Item	Weight (g)	Item after Centrifuging	Weight (g)
Test Tube 5	13.250	Test Tube 5	21.043
Test Tube 6	13.205	Test Tube 6	21.014
Sample 5	5	Gel 5	7.793
Sample 6	5	Gel 6	7.809

Table 9 5,000 RPMG Test Results

SRC	Percentage (%)
SRC_5	56.12
SRC_6	56.51

Usage of 5,000 RPM proved to be within the range to expected results. Samples appeared to be tough, easily keeping the shape without any solvent leaking. In conclusion 5 minutes of soaking is long enough soaking period. However, to keep as close as possible to original method the 20 minutes soaking periods with shaking the contents every five minutes were kept. 5,000 RPM were optimal for getting correct results as for example teff flour in 1,000 RPM still stayed dispersed in distilled water making SRC procedure impossible.

4.2.2.2. SRC Measurement

When all samples and solvents were ready several series of measurements had been done. Results were placed into a table. The most probable results were selected with use by standard deviation calculations. For most solvents the standard deviation can reach 1 % (Kweon et al. 2011). Arithmetic mean of the results was calculated as well.

4.2.3. Mixolab® Standard Test Measurement Preparation

To prepare for measurement the first flour sample moisture content is measured using heated balance scales. Mixolab II, connected computer and cooling system are turned on. Mixolab program on computer is started. The Mixolab Standard Test is selected with the base 14%. Moisture content from the evaporation measurement is placed in.

For water absorption we can use results from SRC of distilled water. However, we need to decrease the resulting SRC with the difference of 14% - current moisture of sample as the SRC operates with the 14% moisture so, the sample can absorb more water than SRC predicted. The SRC works with the 1% variety of error, meaning that SRC results are useful to approximate correct water binding capabilities. It is better to follow Mixolab II Handbook and use 55% absorption for white flour and 60% for wholegrain flour.

Overall weight of the sample is 75 g so depending on the water binding the dry flour weight of sample is about 45 g. This value is calculated from moisture content and expected water biding capability. One test cycle last for 45 minutes.

Table 10 Weight of Flour and Water in Samples for Mixolab Standart Test

Kind of Flour	Weight of Flour 1 (g)	Weight of Water 1 (g)	Weight of Flour 2 (g)	Weight of Water 2 (g)
Wheat Flour	43.2	31.8	43.2	31.8
Teff Flour	29.8	45.2	29.8	45.2
10% Teff	43.2	31.8	43.2	31.8
30% Teff	41.4	33.6	41.5	33.5
50% Teff	39.9	35.1	39.4	35.6
70% Teff	36	39	36	39

4.2.4. Preparation of Samples for Sensory Analysis

4.2.4.1. Baking of Samples

We needed balance scale to weight flour and other ingredients as well as finished dough and bulks. Farinograph to prepare dough with adequate amounts of water. This value was calculated by Mixolab II. Distilled water with 30 °C had been added through burette until optimal consistency of 500–650 B.u. (Brabender/Farinographic unit) is reached. After first drop of consistency on farinograph the dough is mixed for another 5 minutes. After that dough was placed under a bowl into proofer set on 30 °C to be developed for 45 minutes. After this period the dough was divided into several 80 g pieces. Pieces were formed into bulks using curler. Bulks were placed into proofer for another 50 minutes. Industrial baking furnace was preheated to 240 °C was used for the baking. Bulks were baked for 14 minutes. Baked bulks were left on tray to be cooled down for 90 minutes. Three bulks were used to measure their physical properties. Bowls with lid were used to store bulks for sensory analysis.

4.2.4.2. Dough Preparation

For preparation of one set of sample bulks we used 300 g of flour in correct ratio (10%, 30%, 50%, 70% teff content and 100% pure white flour and 100% teff flour). We added 12 g of pulverised yeast, 3 g of butter, 4.5 g of sugar, 5.1 g salt and 1.5 g of Diasta (malt flour) and distilled water in sufficient amounts to create dough with optimal viscosity using farinograph.

4.2.5. Preparation of Questionnaires for Sensory Analysis

Questionnaires were made using Microsoft Forms software. They were printed on paper. For better understanding they were divided into several parts. Three samples were filled in a single column of answers to save paper. Every sample could have been marked from 1 to 7 in each question.

First part consisted of general statistical questions. As the questionnaires were constructed for better understanding of Czech consumer preferences, the general questions consisted of gender, age, nationality and frequence of bread consumption.

Second part was used to describe visual properties of samples. Focus of participants was split between crust and crumb. Shared qualities consisted mainly by colour of samples. The samples were potentially rich or blend in colour. Especially crust colour is influential factor in bread purchase decision. The participants were also questioned about health appearance to provide answer whether Czech consumers believe in myth, that darker the pastry the healthier it is. Question about crust surface is used to describe whether the sample is considered smooth or cracked. Crumb surfaces were described with colour and visual density. Final question for this section is overall visual pleasantness. After each section is small open paragraph for voluntarily notes and thoughts of participants on sample qualities.

Third part was created to describe sound produced by sample during chewing. As crunchy noises are desirable traits for bread. Overall pleasantness was noted as well.

Fourth part was designated to smell properties of samples. This part was tricky as first question was the yeast aroma of bread. For Czech consumers yeast smell relates to good bread aroma as for strangers the yeast smell is not that important. To keep things simple the participants were asked about natural or chemical smell of bread. The natural smell is connected with fresh bread. The chemical smell usually appeared during aging of bread. Thus, it is connected to shelf life of bread. Finally, the overall pleasantness of smell was described.

Fifth part described taste and overall feel from tasting the sample. From physical properties of sample roughness, stickiness to the mouth chamber and absorption of saliva were questioned. Chemical properties in form of common tastes acidic (yeasty), saltiness, sweetness, sourness, and bitterness were asked.

After all samples were questioned, the participants were asked to write down in their opinion the three best performing samples in order of best, second best and third.

4.2.6. Realisation of Sensory Analysis

The trained panellists option was selected. A group of people were educated about realisation of sensory analysis, with help of paper sheets and short verbal presentation. After that panellists were given six blind samples the questionnaires and pencil. The order of the samples was decided by toss of two dices from lowest to highest number. The samples were numbered by random numbers generator in excel from numbers between

100-999. 960 for 70% teff, 662 for 50% teff, 384 for common wheat flour, 850 for pure teff flour, 931 for 30% teff flour and 630 for 10% teff flour. After enough time the questionnaires were collected to undertake statistical analysis.

Results

SRC helps us select baking purpose of examined flour sample. By default, for bread making flour WRC (distilled water SRC) ≤ 57 g/100 g, a SCSRC (5% Sodium Carbonate SRC) ≤ 72 g/100 g, a SuSRC (50% Sucrose) ≤ 96 g/100 g and a LASRC (Lactic Acid SRC) ≥ 100 g/100 g is recommended (Duyvejonck et al. 2012).

Table 11 Suitability of Different Flour Types for Breadmaking

Arithmetic results	WRC (%)	SCSRC (%)	SuSRC (%)	LASRC (%)
Reference Values	< 57	< 72	< 96	≥ 100
Wheat Flour	50.04	85.47	76.76	112.21
10% Teff Flour	47.27	65.74	75.01	74.62
30% Teff Flour	48.8	73.11	69.75	57.4
50% Teff Flour	54.74	63.91	70.25	56.27
70% Teff Flour	62.39	65.15	76.16	64.86
Teff Flour	91.28	97.85	100.64	88.56

Fitting values in green, values too high or too low in red

Clearly pure teff flour is unsuitable for bread production. Common wheat flour is well suitable even though it has higher SCSRC, which corelates with higher amounts of damaged starches therefore, the dough fermenting process would be deviated from norm. To get it into optimal condition for bread making it would have been mixed with rye flour.

10% teff composite flour is most suitable for bread making out of all created composite flours. The low glutenin levels are common problem of teff composite flours.

Same is the case of 30% teff composite flour in which damaged starch content is only by 1.111 % higher from the recommended amount. However, the amount of glutenin is very low. This may predictably lead to problem with creation of bread dome, which would not be dense and strong enough leading to collapse of bread dome during fermentation. The crust would be rough and scarred.

50% teff composite flour faces similar problem with glutenin. Also, clearly some elements of teff inhibits creation of glutenin molecules. We can say that teff is not suitable component for traditional bread baking flour therefore, alternative in baking industry as cookies or other soft pastry should be looked for.

Cookie baking is somewhat more suitable for teff composite as required parameters suit teff composite better and cookie production is more forgiving in not meeting exact requirements. WRC 50 ≤ sample ≤ 70 g/100 g, a SCSRC 60 ≤ sample

≤ 85 g/100 g, a SuSRC 80 $\leq$ sample ≤ 110 g/100 g and a LASRC 80 $\leq$ sample ≤ 100 g/100 g is recommended (Duyvejonck et al. 2012).

Table 12 Suitability of Different Flour Types for Cookiemaking

Arithmetic results	WRC (%)	SCSRC (%)	SuSRC (%)	LASRC (%)
Reference Values	$50 \leq x \leq 70$	$60 \leq x \leq 85$	$80 \leq x \leq 110$	$80 \leq x \leq 100$
Wheat Flour	50.04	85.47	76.76	112.2
10% Teff Flour	47.27	65.74	75.01	74.62
30% Teff Flour	48.8	73.11	69.75	57.4
50% Teff Flour	54.74	63.91	70.25	56.27
70% Teff Flour	62.39	65.15	76.16	64.86
Teff Flour	91.28	97.85	100.64	88.56

Fitting values in green, values too high or too low in red

Common wheat flour is not suitable for cookie production, which was expected as this type of flour is created for breadmaking purposes. 10% and 30% have only up to 2 % less water retaining capacity than required. SuSRC is also only up to 10% lower. Leading to lower amounts of pentosans present. Biggest issue is low amount of glutenin, which may lead to smaller size of cookies and bigger crust ripples. In this regard 50% and 70% composite teff cookies are like 10% and 30%. Pure teff flour would be unsuitable for cookie production as the amount of moisture would be too high leading to unsatisfying crunchiness of cookies, also high amounts of damaged starches may create visually unattractive shape of cookie. Continuous study of teff cookies and other kind of soft pastry is recommended.

Gluten Performance Index (GPI)

GPI serves as SRC parameter predicting behaviour of glutenin in environment filled with other flour properties affecting polymers. It can be described as:

$$\mathbf{LASRC/\ SCSRC + SuSRC}$$

GPI directly corelate to expected volume of loafs of bread. Desired ratio for bakers is at minimum 0.75 (Duyvejonck et al. 2012).

Table 13 GPI Calculation

Arithmetic results	5% Lactic acid	5% Sodium Carbonate	50% Sucrose	GPI
Wheat	112.21 %	85.47 %	76.76 %	0.692
10%	74.62 %	65.74 %	75.01 %	0.53
30%	57.4 %	73.11 %	69.75 %	0.402
50%	56.27 %	63.91 %	70.25 %	0.419
70%	64.86 %	65.15 %	76.16 %	0.459
Teff	88.56 %	97.85 %	100.64 %	0.446

From data available to us we can predict that biggest loaves would be produced from common white flour. With closest of the composite flours being 10% with 0.53 and 70% with 0.459 meaning that in this regard composite teff flour would be underperforming the loafs would be small.

Distilled Water

We discovered that our purchased common wheat flour had binding ability of 50.04 %. Surprisingly pure Teff flour absorbed 91.28 % of distilled water on average. That means 5 g sample absorbed 4.564 g of distilled water on average.

Possible explanation is that whole grain flour like teff contains high amounts of structural sugars from husks. Cellulose and hemicellulose are important water absorbents. Cellulose can absorb from 3.5 to 10 times its own weight. Powdered cellulose also contributes to increasing viscosity further improving its water binding ability.

Predictably with increasing teff content the distilled water binding increased. The water binding improved with only 1.53 % between 10% and 30% composite teff flour. However, it increased by 5.94 % between 30% and 50% composite teff flour. This difference rapidly increased in higher concentration difference between pure teff flour and 70% composite teff flour is 28.9 %. Meaning that there is not that significant difference between common white flour and low amounts of teff flour composites.

Table 14 SRC of Different Types of Flour with Distilled Water

Flour Type	Test 1 (%)	Test 2 (%)	Arithmetic Mean (%)	Standart Deviation (%)
Wheat	49.39	50.7	50.04	0.652
Teff	91.33	91.23	91.28	0.049
10% Teff	47.52	47.02	47.27	0.254
30% Teff	48.86	48.74	48.8	0.058
50% Teff	55.12	54.35	54.74	0.827
70% Teff	62.38	62.4	62.39	0.01

5% Sodium Carbonate Results

Sodium carbonate creates ideal conditions for increased solvent capacity of damaged starches. Predictably teff flour and high amount of teff containing samples (70%, 50%) showed very little increase in sorption in ranges from +2.684 % in 70% teff composite flour to +10.478 % in 50% teff composite flour. In comparison with distilled water meaning there are not many damaged starches present. This may lead to problematic preparation of dough for bread baking purposes as yeast used to produce said dough use starches as main source of energy. Therefore, for baking with high teff content flour prolonged fermentation, which allows yeast to properly digest non–damaged starch.

4.2.7. Mixolab Standard Test Results Interpretation

Results from Mixolab Standard Test are presented in form of spider chart, progress graph and table of values. From mixing properties, we can compare mixing times (MT), which is equal to C1 in the test report. We can compare water absorption, which told us which sample has biggest water absorption (WA) capacity. From protein and starch characteristics we can determine protein weakening and starch gelatinisation (Chopin Technologies 2012). There are not complete collectable data from pure teff flour sample, because pure teff flour dough stuck to the mixing blades separating from each other reducing the torque power to zero. In case of 70% teff one measurement was struck with data corruption.

4.2.7.1. Mixing Time

Mixing Time express time period needed for dough to reach specified torque level. The lower this value is the better development of tested dough could be expected. Flours used for doughs with short mixing times are marked as weak flours, while flours with long mixing times are called strong. This value reaches from 0.99 min to 7.36 min. From the measurements we can say that 30% and 50% teff flour had the shortest MT suggesting best dough development (Chopin Technologies 2012).

Table 15 Mixing Time

Flour		Common Wheat Flour	Pure Teff	10% Teff	30% Teff	50% Teff	70% Teff
MT1 (min)	**(C_1)**	1.55	1.67	1.67	1.05	0.95	1.22
MT2 (min)	**(C_1)**	1.93	1.77	1.75	1.07	1.05	N/A
MTµ (min)	**(C_1)**	1.74	1.72	1.71	1.06	1	1.22

We can see that on average 30% teff and 50% teff flour are weakest flour samples leading to predictably poor baking properties like bad shape keeping and gas retention.

4.2.7.2. Water Absorption

WA is important for workability and consistency of dough. It has influence over texture, elasticity, and handling of dough. In finished product it affects the crumb structure, its formation and overall bread volume. Visibly in **Table 16** The water absorption increases with teff concentration in sample.

Table 16 Rate of Water Absorption

Flour	Common Wheat Flour	Teff Flour	10% Teff	30% Teff	50% Teff	70% Teff
WA1 (%)	53.6	71.3	53.6	55.7	57.8	63
WA2 (%)	53.6	71.9	53.6	55.7	58.4	63
WAµ (%)	53.6	71.6	53.6	55.7	58.1	63

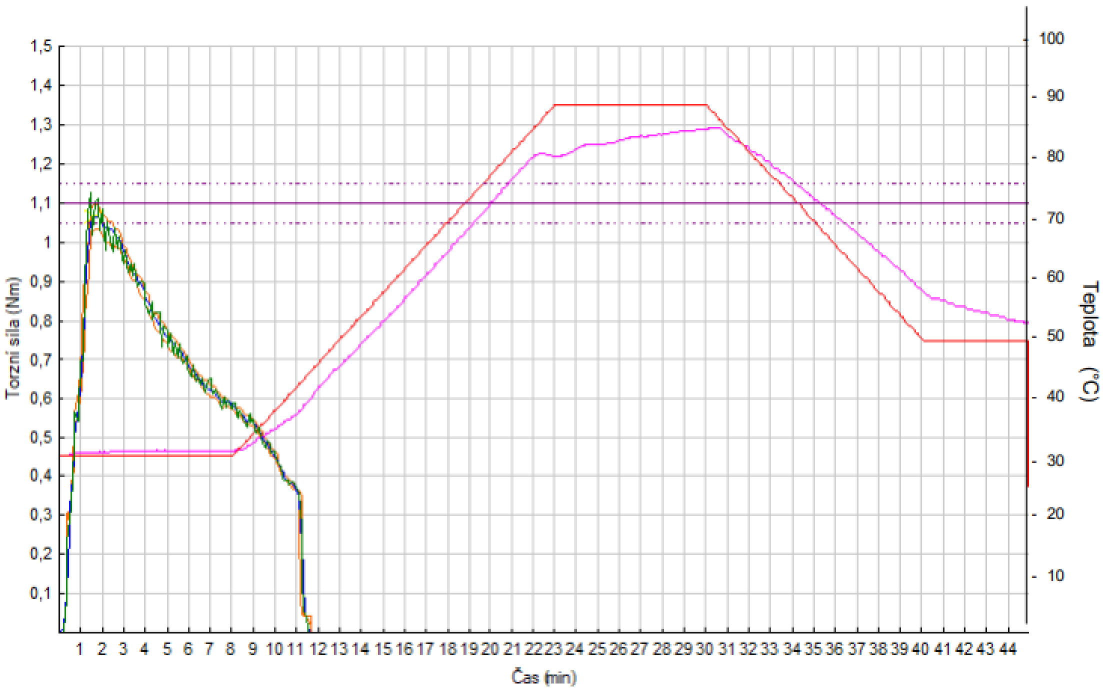
4.2.7.3. Protein Weakening

This value indicated speed of degradation of gluten during temperature increase. It is marked as Slope α. It is curve between 30 °C and C2 part. Protein weakening affects elasticity, resistance to deformation and extensibility. Weaker gluten is related to softer dough reducing resistance to shaping. It also affects gluten ability to trap gas bubbles influencing volume, texture, and crumb structure. Long weakening of dough may lead to poor shape keeping, rising and weak crumb structure. We should be able to witness faster drop between samples as amounts of gluten decreased gradually. We can see in **Graf 2** that pure teff without any gluten have such a fast drop in torque that the test had to be stopped as no measurable torque could be recorded.

Table 17 Rate of Protein Weakening

Flour	Common Wheat Flour	Teff Flour	10% Teff	30% Teff	50% Teff	70% Teff
Slope α_1 (Nm/min)	-0.106	N/A	-0.108	-0.098	-0.110	-0.072
Slope α_2 (Nm/min)	-0.112	N/A	-0.096	-0.104	-0.106	N/A
Slope α_μ (Nm/min)	-0.109	N/A	-0.102	-0.101	-0.108	-0.072

Graph 2 Teff Mixolab Standart Test Run with Pure Teff Flour



4.2.7.4. Starch Gelatinization

This value represents the speed of gelatinization of starch. It is marked as slope β Starch Gelatinization is important to capture moisture and gases. It helps swelling and volume of dough during fermentation. It helps to develop common texture, volume, and tenderness in crumb. It can also improve the taste of product by entrapping the flavour, which is gradually released. In **Table 18** we can see that until 30% teff sample rate of gelatinization swiftly increases than drops again probably as the ratio of different starches from both flour shifts.

Table 18 Rate of Starch Gelatinization

Flour	Common Wheat Flour	Teff Flour	10% Teff	30% Teff	50% Teff	70% Teff
Slope β_1 (Nm/min)	0.356	N/A	0.394	0.612	0.488	0.512
Slope β_2 (Nm/min)	0.388	N/A	0.512	0.760	0.398	N/A
Slope β_μ (Nm/min)	0.372	N/A	0.453	0.686	0.443	0.512

4.2.7.5. Enzyme Degradation

Enzyme degradation speed is used to analyse rate of degradation of starches by α-amylase. Water absorption, mixing tolerance and dough stability are affected by high enzymatic activity affecting baking performance. From **Table 19** is visible inconsistency in results as the composition of enzymes differs inconsistently.

Table 19 Rate of Enzyme Degradation

Flour	Common Wheat Flour	Teff Flour	10% Teff	30% Teff	50% Teff	70% Teff
Slope γ_1 (Nm/min)	-0.042	N/A	-0.08	-0.066	-0.078	-0.048
Slope γ_2 (Nm/min)	-0.052	N/A	-0.082	-0.012	-0.048	N/A
Slope γ_μ (Nm/min)	-0.047	N/A	-0.081	-0.039	-0.063	-0.048

Table 20 Rheological Parameters of Dough with Addition of Teff Flour from Mixolab II

	WA (%)	Dough Development time (min)	Dough Stability (min)	Amplitude/Elasticity (Nm)
(Common Wheat Flour	53.6	3.70	6.58	0.059
Teff Flour	71.3	2.10	3.18	0.064
10% Teff	53.6	9.30	6.78	0.059
30% Teff	55.7	7.10	6.32	0.087
50% Teff	57.8	5.30	5.67	0.083
70% Teff	63	N/A	5.12	N/A

Table 21 Rheological Parameters of Dough with Addition of Teff Flour from Mixolab II

	WA (%)	Dough Development Time (min)	Dough Stability (min)	Amplitude/Elasticity (Nm)
Common Wheat Flour	53.6	3.40	6.57	0.061
Teff Flour	71.9	2.00	2.7	0.066
10% Teff	53.6	8.50	6.73	0.052
30% Teff	55.7	7.40	6.37	0.084
50% Teff	58.4	5.40	5.68	0.097
70% Teff	63	3.40	5.03	0.092

Table 22 Corelation Analysis of Influence of Increasing Teff Content on Rheological Parameters

	% teff	**WA (%)**	**DoughDevelopment Time (min)**	**Dough Stability (min)**
% teff	1.000000	-0.081537	0.101788	0.616095
WA (%)	-0.081537	1.000000	-0.291245	-0.228186
DoughDevelopment Time (min)	0.101788	-0.291245	1.000000	0.168895
Dough Stability (min)	0.616095	-0.228186	0.168895	1.000000

According to **Table 22** No significant correlation on $p < 0.05$ was found.

Table 23 Rhaeological Characteristics of Dough with Addition of Teff

Kind of Flour	**C1 (Nm)**	**C2 (Nm)**	**C3 (Nm)**	**C4 (Nm)**	**C5 (Nm)**
Common wheat Flour	1.134	0.412	1.991	1.599	2.604
Teff Flour	1.066	N/A	N/A	N/A	N/A
10% Teff	1.065	0.402	1.987	1.398	2.124
30% Teff	1.081	0.355	1.950	1.318	2.028
50% Teff	1.127	0.302	1.881	1.292	1.839
70% Teff	N/A	N/A	N/A	N/A	N/A

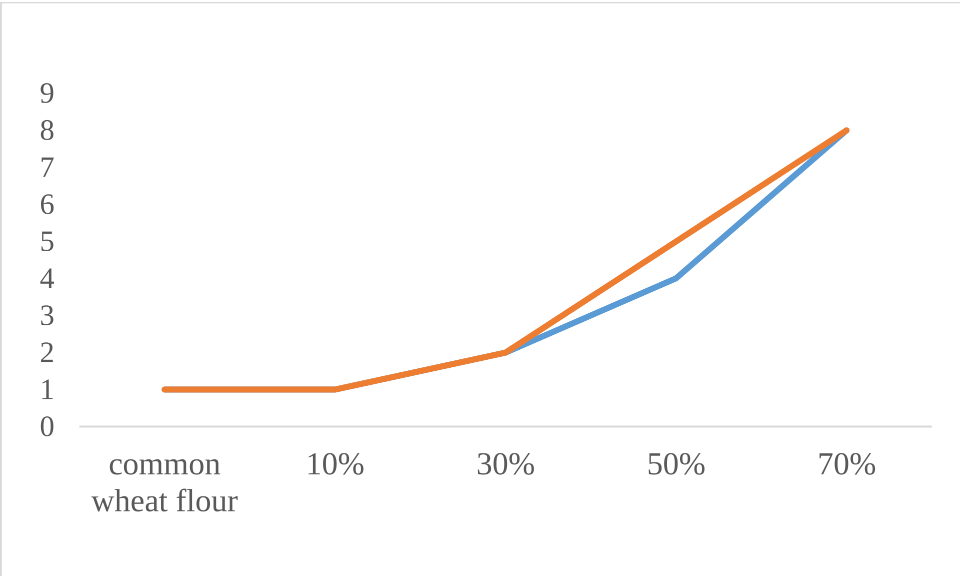
Table 24 Rhaeological Characteristics of Dough with Addition of Teff

Kind of Flour	C1 (Nm)	C2 (Nm)	C3 (Nm)	C4 (Nm)	C5 (Nm)
Common wheat Flour	1.109	0.400	1.973	1.512	2.511
Teff Flour	1.105	N/A	N/A	N/A	N/A
10% Teff	1.066	0.386	1.942	1.341	2.045
30% Teff	1.069	0.356	1.905	1.324	2.002
50% Teff	1.130	0.306	1.853	1.244	1.831
70% Teff	1.119	0.243	1.614	1.545	1.552

4.2.8. Spider Charts Interpretation

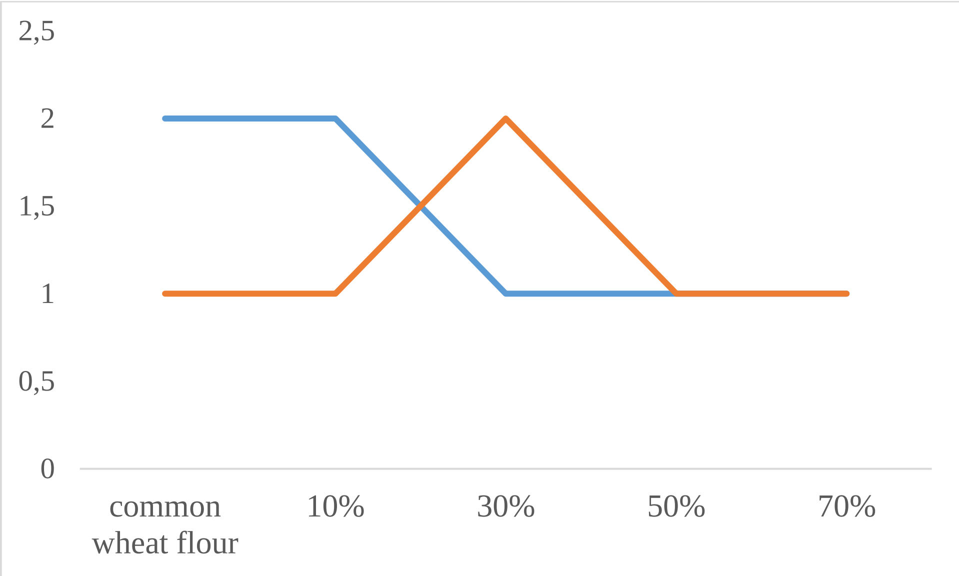
Another way to compare samples is to analyse the spider charts and transform them to form of graphs.

Graph 3 Index of Absorption



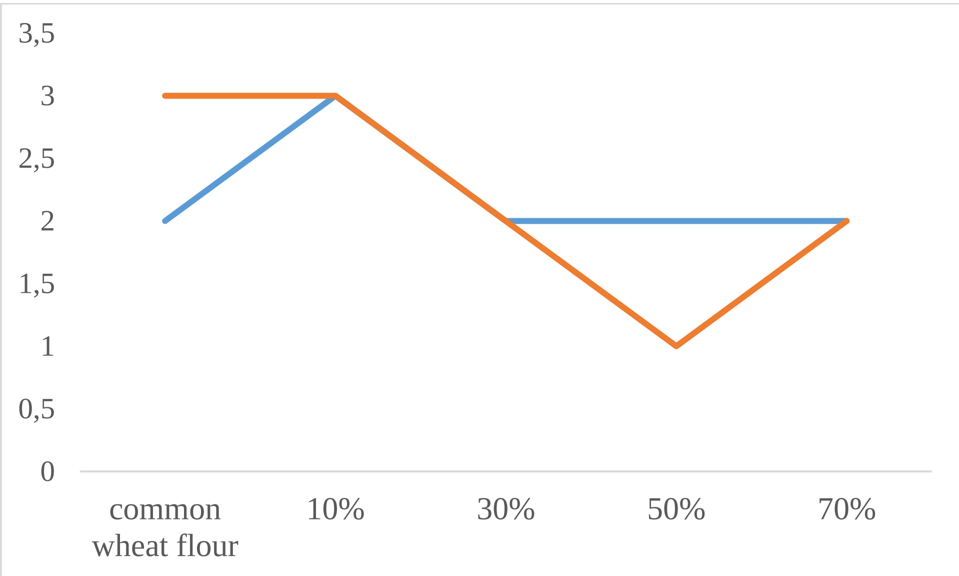
From **Graph 3** we can see that increasing amount of teff flour increases water absorption.

Graph 4 Index of Mixture



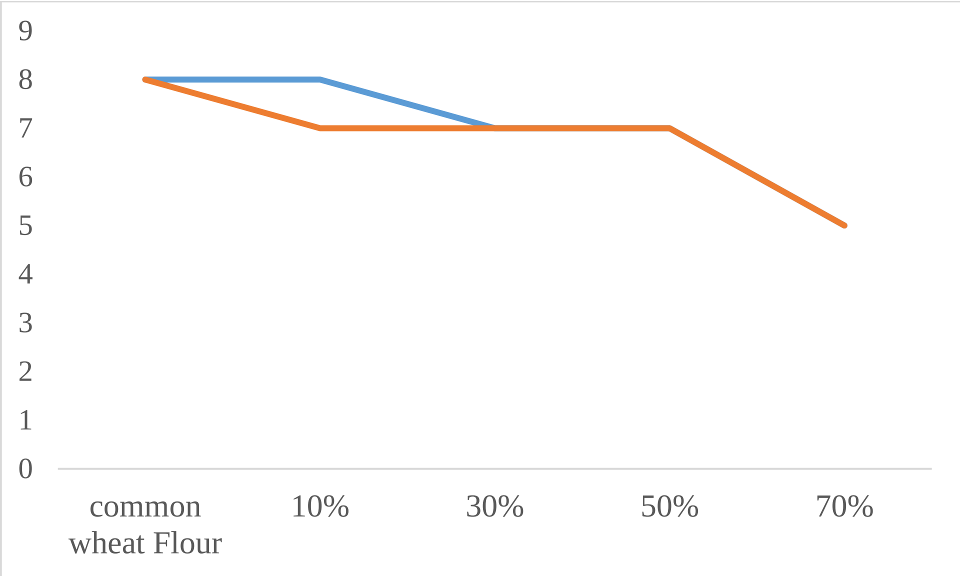
From **Graph 4** we can deduce that teff flour content does not affect mixture.

Graph 5 Index of Gluten +



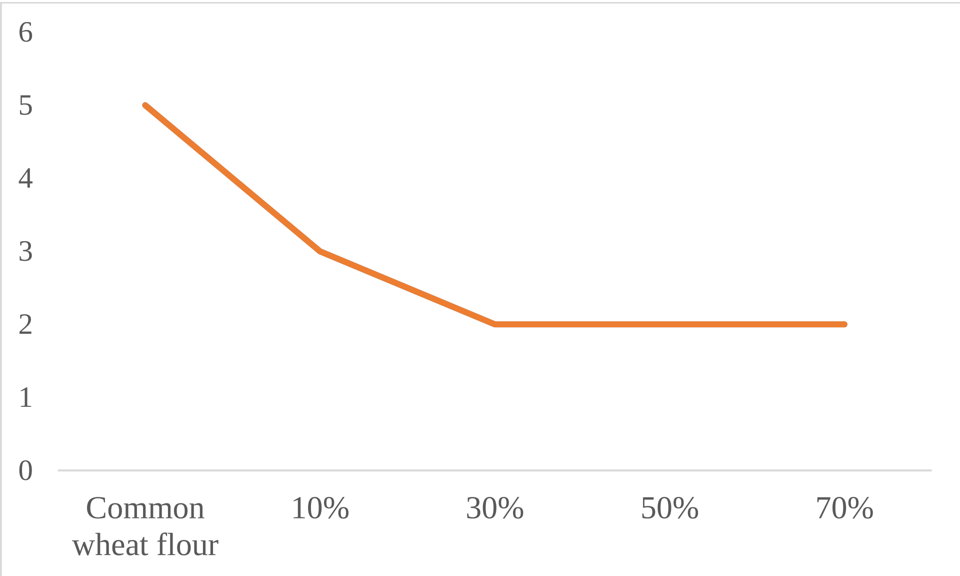
From **Graph 5** we can see some sort of mistake as gluten levels should decrease with increasing amounts of teff flour present as suggested by SRC.

Graph 6 Index of Viscosity



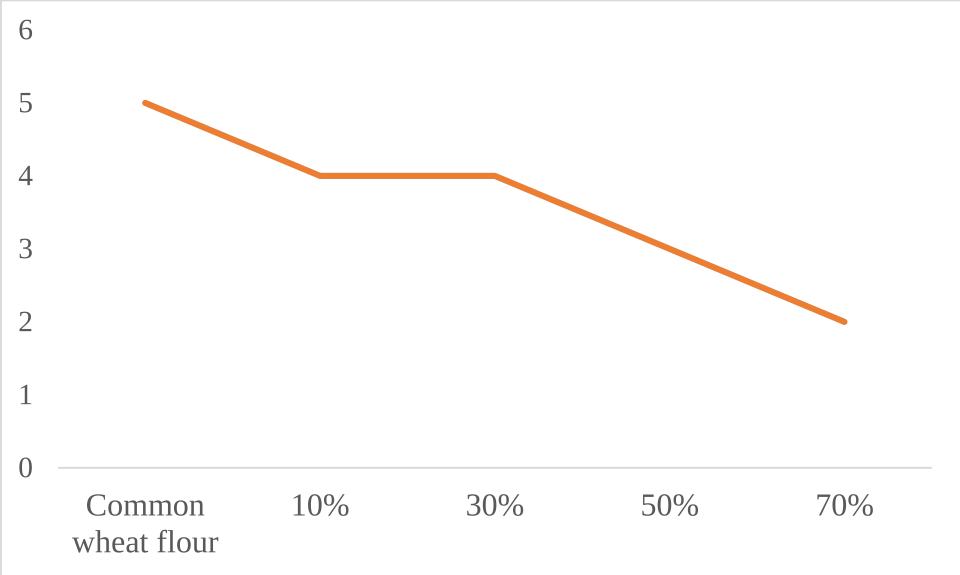
From **Graph 6** we can see that increasing amounts of teff slightly decrease viscosity.

Graph 7 Index of Amylase



From **Graph 7** we can see that increase of teff flour decreases amylase activity.

Graph 8 Index of Retrogradation



From **Graph 8** we can see that increasing amounts of teff decreases retrogradation of starches.

4.2.9. Interpretation of Results of Sensory Analysis

Sensory analysis was participated by 32 people. 19 of them were females and 13 males. Females were 59.38 % of people questioned. while male took only 40.62 %. Youngest participant was 16-year-old. Oldest one was 29-year-old. So. the analysis reflects only young adult spectrum of Czech market consumers. Difference in preference of older adult is expected and should be subject of further study. Most of the participants came from Czechia: 27. which is 84.38 % of all participants. Rest of the participants: 5 (15.62%) came from other European countries such as Slovakia, Croatia and Bosnia and Herzegovina.

4.2.9.1. Best Sample Selection

Three overall best samples were selected by each participant. The best was given three points. second two points and one point was given for third place. 30% teff flour was favourite with 26 voters 81.25 % and total sum of 54 points. Second place was taken by common white flour with 21 votes 65.63 % and 51 points. In the third place ended 10% teff flour bread with 28 votes 87.5 % and 49 points.

Interestingly the 30% teff bread gained more votes than any other sample. However. most of the votes were for second place. The common white flour ended second. but most of the times was selected as best by voters. The 10% teff ended on third place as most of the voters rated it as third best option.

Unsurprisingly pure teff flour was not selected by anyone as it was overall badly accepted. Teff flour is not suitable for bread production. It is not also well accepted by consumers. For 10 people 31.25 % of panellists the 50% teff flour bread was also acceptable. Three panellists 9.38 % also liked the 70% teff bread variant two of them as second best and one even as the best.

Table 25 Overall Rate of Vote for Selected Samples

Flour	Sum	Final Order	No of votes	Mode	Mean
70% Teff	7	5	3	2	2.3
50% Teff	18	4	10	1	1.8
Common white flour	51	2	21	3	2.43
Teff	0	6	0		
30% Teff	54	1	26	2	2.08
10% Teff	49	3	28	1	1.75

4.2.9.2. Visual Properties of Samples

Visual properties were divided into five questions. Each question could have been answered on Likert scale from 0 to 7.

Crust and Crumb Colour

In case of colour low score is dedicated to blend colour while high score represented rich colour. On average all crust colour was precepted somewhere in middle between blend and rich. with 10% teff considered the richest colour. By modus the richest colour with most vote on six was common wheat sample. Pure teff was considered the most blend colour with score of 2.

Crumb colour was considered somewhere between blend and rich as well. Richest colours were marked the common wheat and 10% teff flour. With score of one the blend colour was decided to be the teff flour sample.

Health Appearance Crust and Crumb

As the healthiest appearing crust was selected 70% teff sample with average score of 5.03. As least health appearing was rated the common white and 10% teff flour samples with score 4.3. 3.8 respectively. Pure teff was not selected as healthiest looking crust. even though it had the darkest colour.

70% teff flour sample had the healthiest appearing crumb of all samples with average score of 4.8. As unhealthiest the 10% teff was selected. Pure teff flour sample was considered one of the healthiest crumbs. This suggested that in pair with darker colour the presence of differently coloured particles had influence over increase of the health appeal of sample.

Crust and Crumb Surface

Smoothest crust surfaces were given to common flour with average score of 2.6 and pure teff flour with 2.9. As most rigged crust was selected 50% teff with average score of 4.6.

Visual factor for visual rating of crumb surface was the size of the gas bubbles inside the crumb also describable as density. Lower score on Likert scale suggested higher density. As the densest sample with average score of 1.3 was the pure teff. closely followed by 70% teff flour with 2.5 points.

On the other hand. airiest sample was the common wheat flour with score of 5.3. Expected result as the common wheat flour sample had the best precondition to rise properly.

Overall Visual Appearance

Most visually appealing was the 10% teff sample with average rating of 5.5 and common wheat flour with 5.4. 30% teff flour sample with average score of 5 could be considered visually appealing as well. Pure teff samples with their small size. dark colour and dense crumb came out as most visually unappealing with average score of 2.2. From point of visual appearance. it was concluded that for a bread to have slightly dark colour with visible particles is important to visual appearance.

Picture 1 Cut Through the Bulks from Left Common Wheat Flour, Pure Teff Flour, 10% Teff, 30% Teff, 50% Teff, 70% Teff

Source: Author

4.2.9.3. Sound Properties

To analyse sound properties the crunchiness of samples during chewing were asked to evaluate in questionnaire. Low score suggested the sample did not crunch at all, while high numbers meant loud crunchy sound. As loudest with 3.4 points was marked the 10% teff flour sample. Followed by 30% teff flour sample with 3.3 and 50% teff flour sample with 3.2. As most silent the pure teff was selected with average score of 1.5.

Overall Sound Enjoyment

As best sounding the 10% teff was selected with score of 4.5 and 30% teff flour sample with 3.8. Pure teff with 2.1 overall score ended last.

4.2.9.4. Smell Properties

Professional testers can recognise different scents present in bread like nuts. but for need of this analysis only yeast presence and natural bread aroma is tested (Callejo 2011). This part was difficult for Czech testers as Czechs are considering yeasty aroma of bread as the natural bread aroma as several of them stated in optional comment section.

Yeast Aroma

Strongest yeast aroma was smelled from pure teff flour sample with average score of 4. Second strongest yeast smell was selected to 70% teff with 3.8 points. Possibly because smaller size of bulks the aroma was more concentrated in comparison to other samples. Lowest score of 3.2 shared common white flour. 10% and 30% teff flour samples. As they raised the best with airy crumbs the yeast dispersed more lowering the typical aroma.

Bread Aroma

Natural bread aroma is connected to the fresh bread. As the bread grow stale chemical smell like acetone can be developed by microbial activity inside bread. With 3.5 average score pure teff sits in the middle. As most natural the 50%, 70%. and 30% teff flour samples were selected with score with scores of 2.3 for 50% teff flour and 2.5 for 30% and 70% teff flour. Low score was expected as the bread were freshly made before analysis.

Overall Smell of Samples

Overall smell pleasantness was highest in 30% teff flour sample with 5.2 average score. Followed by 10% flour sample with 5.1 score. Lowest score was selected to pure teff with 3.2 meaning the smell was average. Rest of the samples were marked as rather pleasant.

4.2.9.5. Taste and Feel Properties

Taste of the product is main factor in buying decision. However. taste have highest impact on whether the product would be purchased repeatedly. Therefore, good taste and feeling during consumption are important part of analysis.

Roughness of Sample

By roughness is understood the feeling during chewing as some food can potentially be unpleasant to consume as it scratches the oral cavity.

Only the pure teff sample with average score of 2.6 was considered rather coarse. Rest of the samples had average score around 3 meaning it is not coarse nor soft. With score of 4.4 the common wheat flour could be considered the softest sample.

Stickiness of Sample

As stickiness the difficulty to create morsels were asked. Some samples tend to stick to the oral cavity, teeth, tongue, or oesophagus, leading to unpleasant feeling. With average score of 4.5 the pure teff flour sample can be classified as rather sticky. This behaviour was well expected as even the teff flour dough is very sticky and hard to remove from mixing blades. As least sticky with score of 2.9 the 30% teff flour sample was selected.

Saliva absorption

Saliva absorption is personal feeling of how much saliva is needed to comfortably swallow a morsel. As least saliva absorber the pure teff flour sample was selected with only 2.9 points. Most saliva is needed to swallow common wheat flour sample with average score of 4.1. This value correlated with the fact that least amount of water was needed to produce common wheat flour dough. Therefore, it might taste as the driest requiring increased amount of saliva.

Acidic Taste

The acidic taste is obtained from presence of yeast. It should be the typical yeasty taste of bread for Czech consumers. As the most acidic was selected pure teff flour sample with average score of 3.7 Rest of the samples kept the score under three, meaning they were little acidic.

Saltiness

As every sample set was prepared using same amount of salt (5.1 g) the difference in perception of salt is in native saltiness of flour used. Surprisingly, pure white flour scored 2.0 and pure teff flour 2.2 meaning they were perceived as less salty. 30% scored average of 2.8 still under average saltiness. With increasing amount of teff perception of saltiness declined to 2.5 average score in 70% teff flour.

Sweetness

As in case with salt the samples were prepared using same amount of sugar (4.5 g). The pure teff flour sample scored 1.8 meaning almost not sweet, while pure common wheat 3.6 point making it sweeter than average bread.

Sourness

In terms of sourness, all samples achieved under average value. Pure common wheat sample got lowest of 1.6, while the pure teff considered sourest reached 2.9 points.

Bitterness

Common white flour bread had lowest average value of 1.8 making it least bitter sample. Pure teff flour sample reached the value of 3.7 which is over standard bread bitterness level. High level of bitterness may be the decisive factor for such a poor performance of pure teff flour sample.

Overall Taste Performance

In overall taste performance the common white flour sample reached score of 5.5 making it best tasting sample. Closely followed by 30% teff flour with 5.4. It can be said that this sample is sufficient substitute for basic bread retaining most of the taste, while providing health benefits in better composition in comparison to common white flour. Lowest ranked ended the pure teff flour with average score of 1.7.

4.2.10. Evaluation of Physical Attributes of Produced Bulks

Picture 2 From Left: Common Wheat Bulk, 100% Teff Flour Bulk, 10% Teff Bulk, 30% Teff Bulk, 50% Teff Bulk, 70% Teff Teff Bulk

source: Author

4.2.10.1. Visual Appearance of the Bulks

There are visible differences between produced bulks. Common wheat flour bulks were visibly biggest of the batch. They could have been mistaken only with the 10% teff flour bulks. With increased amounts of teff the colour of bulks darkened, and their size reduced. Their crust changed from smooth to rigged. 50% and 70% bulks reminded American style circular cookies.

Crumbs of the bulks also darkened with more teff present. The density of crumb also increased. while the common white flour bread reminded French bread. the 100% teff flour was dark and dense.

4.2.10.2. Dimensions of the Bulks

To evaluate how well the bulks developed during proofing and baking calliper had been used to determine their size. Control white bulks were the biggest. With increasing amount of teff flour present in bulks the size of bulks decreased, with pure teff flour bulks being the smallest. Lack of gluten and low amounts of damaged starches. which serve as energy source for yeast. As yeast metabolize the sugar from starches. CO_2 is released expanding the dough. As there is not enough gluten the expanded bulks are unable to keep shape and go down in form.

Table 26 Dimensions of 3 Bulks

Kind of Flour	Height (cm)			Average (cm)	Width (cm)			Average (cm)
Common	5.7	5.6	5.7	5.7	8.7	8.6	8.8	8.7
10%	5.5	5.3	5.1	5.3	8.4	9	8.9	8.8
30%	4.5	4.8	4.4	4.6	8.6	8.3	8.8	8.6
50%	3.5	3.5	3.4	3.5	8.1	7.6	8	7.9
70%	2.9	2.9	2.8	2.9	7.1	7.2	7.6	7.3
Teff	3.7	4	3.9	3.9	6.3	5.5	5.7	5.8

4.2.10.3. Weight of the Bulks

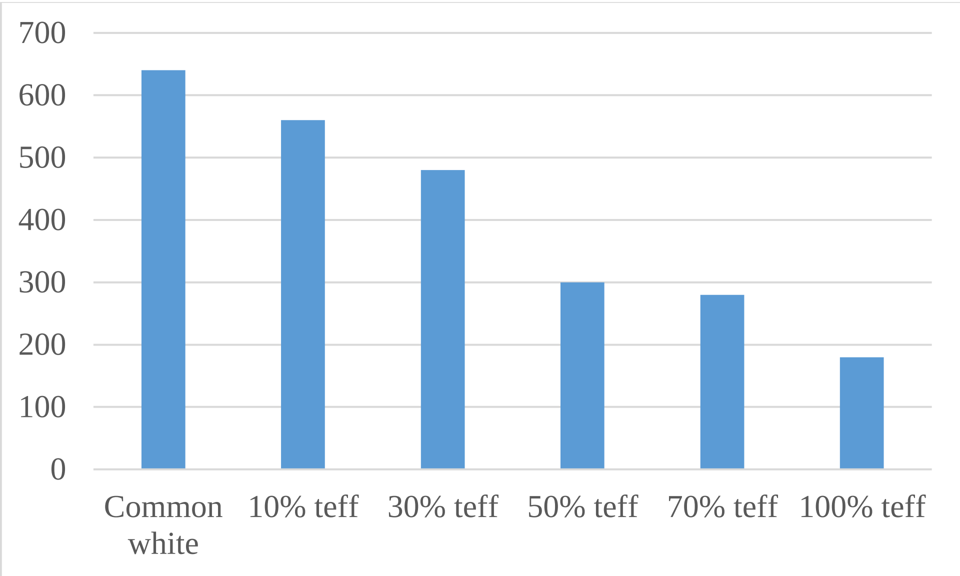
The weight of the dough was measured to determine specific volume of breads produced. Dough was weighted using balance scale with one decimal point. The weight of dough increased from common white flour to 100% teff as the teff flour is able to bind more water.

The weight of three bulks is needed to calculate the specific volume. We selected three best representative bulks from the bunch of each type to weight them using balance scale with one decimal point. The weight of the breads is decreasing with the amount of teff present.

4.2.10.4. Volume of the Bulks

To measure volume of three bulks rape seeds were used. Seeds were poured in container. Their volume was flattened with the edges of the container. Excess seeds were removed. About 2/3 of the container was emptied to a bowl. Three average bulks were placed in container. The rape seed from the bowl were poured back. Excess seeds, after the surface of container was flattened were poured into graduated cylinder to measure the volume of three bulks.

Graph 9 Volume of 3 Breads (ml)



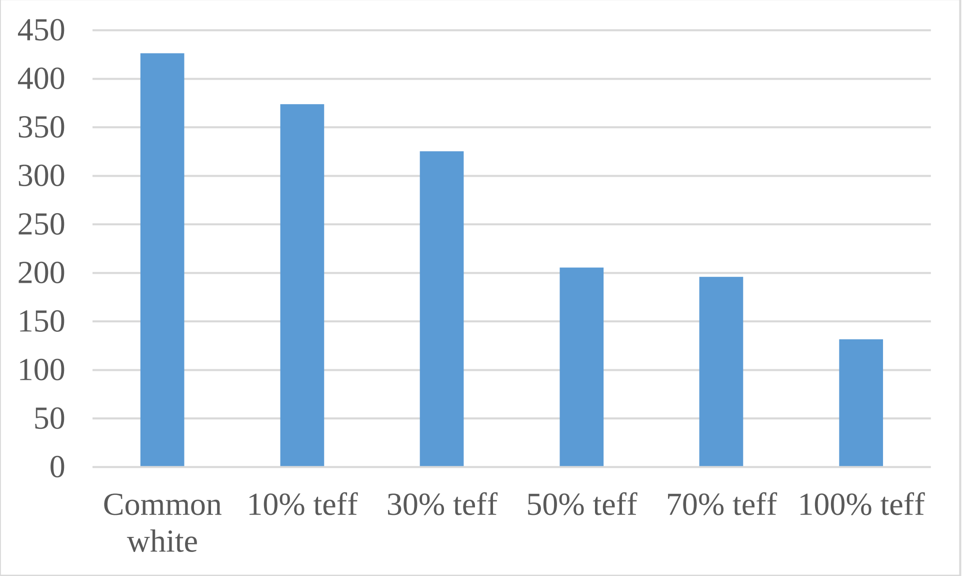
4.2.10.5. Specific Volume

Specific volume is measure that tell us the volume of bulks per 100 g of flour. We need to calculate the weight of flour for three bulks from formula: **(240 x 300) / weight of dough**.

Table 27 Weight of Flour for Three Bulks and Weight of 3 Bulks

Kind of Flour	m of flour for 3 Bulks (g)	m of 3 bulks (g)
Common white	150.156	204.1
10% teff	149.750	201.3
30% teff	147.571	198.6
50% teff	145.956	203.7
70% teff	142.999	202.5
100% teff	136.934	209.8

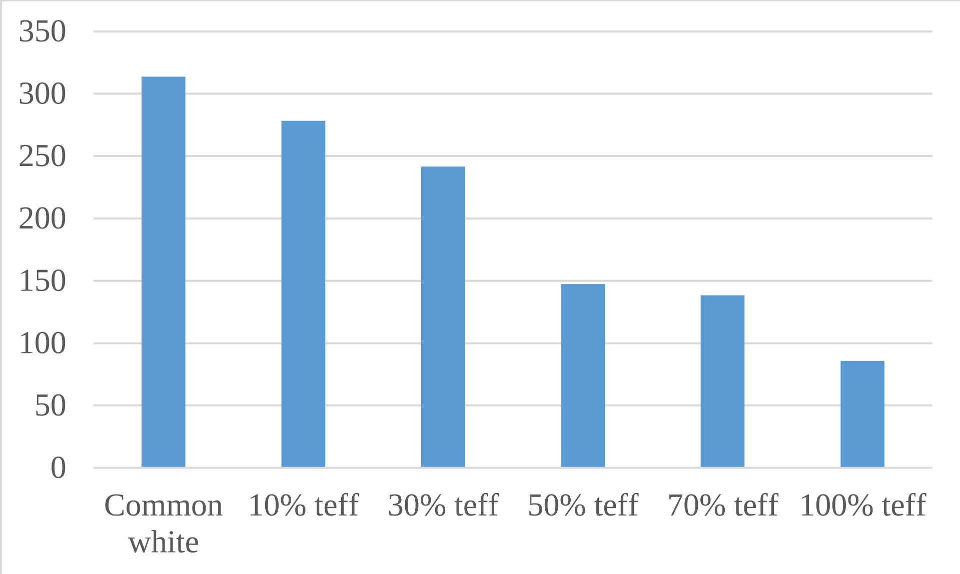
Then we can use formula to calculate the specific volume per 100 g of flour using formula: **(Measured Volume of 3 breads / m of flour for 3 bulks) x 100**



4.2.10.6. Volumetric Yields

Volumetric yields is another form of evaluation of baking product performance it is value of measured volume and weight per 100 g of pastry. It is calculated as: **(volume of bread / weight of bread) x 100**

Graph 10 Volumetric Yield (cm3/100 g bread



From **Graph 10** we can see that biggest difference occurs between 30% and 50% Teff.

Table 28 Correlation Analysis of Influence of Increasing Amount of Teff on Volumetric Yields

	% Teff	Volumetric Yield (cm^3/100 g Bread
	1,000000	**0,990610**
Volumetric Yield (cm^3/100 g Bread	**0,990610**	1,000000

From **Table 28** We can confirm that there is correlation between decreasing volume of bread and increasing amount of teff flour in sample.

4.2.10.7. Ratio of Height and Width

Ratio of height and width is simply calculated from: **height average / width average.**

Table 29 Ratio of Height/Width

Kind of Flour	Ratio Height/Width
Common white	0.651
10% teff	0.605
30% teff	0.533
50% teff	0.439
70% teff	0.393
100% teff	0.663

4.2.10.8. Final Classification

Classification of bread samples is done by using table of quality indicators. The values are: very good. good. weak and very weak.

Table 30 Parameters for Final classification

Quality indicator / bakery quality	Very good	Good	Weak	Very weak
Specific Volume (cm^3 / 100 g flour)	> 550	451 – 550	351 – 450	0 – 350
Volumetric yield (cm^3 / 100 g bread)	> 380	311 – 380	211 – 310	0 – 210
Ratio (H / W)	> 0.7	0.6 – 0.7	0.5 – 0.6	0 – 0.5

Best performance was shown by common wheat flour with average values. The 30%. 50% and 70% teff on the weak side of spectrum with 30% teff being slightly better than 50% and 70%. Pure teff failed in all aspects except ratio of height and width, which was expected as the rising of teff flour without any gluten and low amounts of damaged starches is low.

Table 31 Results of Final Classification

Kind of Flour	Specific Volume (cm^3 / 100 g flour)	Volumetric yield (cm^3 / 100 g bread)	Ratio (H / W)
Common Wheat	Weak	Good	Good
Teff	Very weak	Very weak	Good
10% Teff	Weak	Weak	Good
30% Teff	Very weak	Weak	Weak
50% Teff	Very weak	Very weak	Very weak
70% Teff	Very weak	Very weak	Very weak

5. Discussion

In bread products with addition of teff flour the rheological and sensory properties were changed. In contrast to (Ronda et al. 2015) there was measurable difference in volume of bread from low teff composite flour (10 % and 30 %). There also was visible difference in curst and crumb colouring of low teff concentration (10 %, 30 %) in our case unlike in (Ronda et al. 2015).

However, they added 15 % of wheat bran to mixture, which affected the colouring and other properties such as water absorption and retention of gases. However, we agreed on the decrease in volume of high teff composite (50 % and more). We can also agree on increased hardness of crust in high teff composite breads as our evaluators commented they remind them rocks.

In terms of sensory analysis, the 30% teff was rated as the best or comparable to common wheat bread. In overall acceptance it was 30 % that was selected as the best in contrast to (Ronda et al. 2015) in their case the acceptability decreased with increasing teff concentration even for the 30 % of teff.

However, their group of sample testers was almost two times bigger than ours so it was less affected by personal preference of small amounts of people. Another possibility is that overall age of the respondents was higher than our group as their group consisted of laboratory workers, while ours were mostly students from CZU. Older people tend to be more conservative in every aspect even a marginal thing as the taste of bread.

From SRC perspective we concluded that low teff concentrations (10 %, 30 %) are suitable for bread production in all aspects except for lacking in gluten. Pure common wheat had LASRC 112.21 %, which decreased by addition of 10 % teff flour to 74.62 % and only 57.4 % in 30 % teff.

However, (Hrušková et al. 2012) stated that LASRC increased from 97.6 % to up to 151.6 % in 10 % teff composite flour. Their results are not statistically significant. In sensory analysis they stated the 20 % teff composite had intolerable hay like taste. No such taste was present in our test the 10 % teff was comparable to pure common wheat bread, and 30 % was even more enjoyable than the rest of samples.

After finishing and interpreting results of SRC the though to switch from bread to cookies occurred as teff had more favourable SRC properties for production of cookies, where lack of gluten is not such a problem like in case of bread. Just as seen in **Table 11** and **Table 12** Same conclusion came from (Coleman et al. 2013).

However, they did not find statistically significant decrease in volume of bread with increasing amount of teff but agree it happens in high concentration of teff flour as they only commented on small size of pure teff flour bread. They confirm our own findings that darker crust and crumb is desirable as it is seen as healthier.

However, in pure teff the colour is deemed too much for consumer to enjoy. This dark coloured trait is undesirable in cakes but is not as problematic in cookies and biscuits. Our findings were again against (Coleman et al. 2013) as the stated teff flour has low water absorbing capacity, while we proved that the water absorbing is increasing with teff content as seen in **Graph 3**.

Second time the possibility of producing teff based cookies come during sensory analysis when several respondents pointed out that 50% and 70% teff look like cookies. Even when we measure the height to width ratio, which is similar as width to thickness ratio which is measured in cookies with similar method as height to width ratio in bread. We concluded that the spread is similar.

In terms of rheological factors, measured on Mixolab II (Hrušková et al. 2013) used 10 % and 30 % teff flour mixture. Their results from C1 to C5 points were closely comparable with our findings for same teff flour concentrations. However, ours reached about 0.2 Nm higher values.

To address the problem of low volume of bread with high content of teff and keeping the gluten free quality of bread produce, combination of teff flour with rice flour is suggested. Problem of teff dough is not a lack of starches to produce rising gases but to hold gas inside as proven during traditional preparation of *Injera* (de Vos 2011). The dough is ready when bubbles form on the surface. Rice flour even though it is gluten free as well has good gas holding capacity.(Wu et al. 2019) Discovered possibility to obtain rice bread with great rising potential.

However, **Table 1** shows that rice is lacking in some essential amino acids. Also, fortification with fiber, lipids and minerals present in teff would greatly improve nutritional score of such bread. The healthy appearance factor of this combination would be higher as teff would give the dark colouring to crust and crumb.

Better analysis could have been provided by us if we used different mixolab protocol for pure teff flour. This way we can only estimate the behaviour of pure teff dough unlike (Pulivarthi et al. 2022) they did the Chopping 90+ protocol for teff flour.

The values for C1 to C5 are not comparable with even 70% teff flour dough. They come up with usage of hydrocolloids, gum and emulsifiers greatly improved quality of the bread produced. Thus, it could not be even compared to our product.

6. Conclusions

In this diploma thesis was researched influence of composite teff flour on SRC, rheological properties of dough and sensory analysis of baked products. To analysis mixture of different percentual teff flour concentration were produced.

Addition of teff flour influenced SRC, WRC increased significantly, while LASRC decreased. Thus, predicting unsuitability of high teff concentration for bread production, while providing opportunity to research cookie dough as high teff concentrations were deemed suitable for cookie production.

Mixolab standard protocol measurements were done. In spider charts increase in WA were measured and decrease in viscosity, amylase activity and retrogradation of starches were measured. However, no results were statistically significant in $p < 0.05$.

The size of produced bread was decreasing with increasing amounts of teff flour in composite. Produced breads had statistically proven decrease in volumetric yields. The colour of samples visibly changed from white bread to dark one in form of pure teff.

In sensory analysis 30 % teff composite was selected as overall best. The average rating was comparable to common wheat flour or slightly better in 10 to 30 % concentration, gradually decreasing toward pure teff flour variant with low scores.

Aim of the thesis was to prove whether as according to the several healthy lifestyle websites the 30 % teff concentration is the best for baking purposes. This aim was fulfilled as the 30 % teff composite flour had satisfying SRC results, Mixolab II results, sensory analysis and even the properties of finished breads were sufficient. Making bread from 30 % teff composite provides interesting healthier more nutritional valuable substitute to bakery products. As teff is becoming more popular, more studies in this field will be conducted. They should aim to suitability of teff for cookie production or to find substitute additive to improve the rising potential of dough in place of missing gluten. They should also aim on improving yields, harvest methods and adaptability of teff to conditions of Europe.

7. References

Adanech TN. 2019. Morphological and Molecular Characterization of selected tef (Eragrostis tef (Zucc.) Trotter) Accessions from the Gene Bank of Ethiopia **9**:31–40.

Ahmad A, Anjum FM, Zahoor T, Nawaz H, Dilshad SMR. 2012. Beta glucan: A valuable functional ingredient in foods. Critical Reviews in Food Science and Nutrition **52**:201–212.

Arslan M, Yilmaz HO. 2018. Teff: Nutritional Compounds and Effects on Human Health ACTA SCIENTIFIC MEDICAL SCIENCES Teff: Nutritional Compounds and Effects on Human Health **2**:15–18. Available from https://www.researchgate.net/publication/329465897.

Awika JM. 2011. Major cereal grains production and use around the world. ACS Symposium Series **1089**:1–13.

Banu I, Aprodu I. 2022. Investigations on Functional and Thermo-Mechanical Properties of Gluten Free Cereal and Pseudocereal Flours. Foods **11**.

Bezlepkova.com. (n.d.). Available from https://www.bezlepkova.com/.

Callejo MJ. 2011. Present situation on the descriptive sensory analysis of bread.

Cecil JE. 1992. Semiwet milling of red sorghum: a review. Page Utilization of sorghum and millets. Proceedings of a workshop held at Bulawayo, Zimbabwe, on 8-12 February, 1988.

Cheng A, Mayes S, Dalle G, Demissew S, Massawe F. 2017. Diversifying crops for food and nutrition security – a case of teff. Biological Reviews **92**:188–198.

Cheng W, Sun Y, Fan M, Li Y, Wang L, Qian H. 2022. Wheat bran, as the resource of dietary fiber: a review. Critical Reviews in Food Science and Nutrition **62**:7269–7281. Taylor & Francis. Available from https://doi.org/10.1080/10408398.2021.1913399.

Chopin Technologies. 2012. Mixolab applications handbook. Chopin Technology:1–161.

Coleman J, Abaye AO, Barbeau W, Thomason W. 2013. The suitability of teff flour in bread, layer cakes, cookies and biscuits. International Journal of Food Sciences and

Nutrition **64**:877–881.

de Vos et al. 2011. Metabolomics of a Model Fruit: Tomato In: Hall, D.R., Ed., Annual Plant Reviews. Biology of Plant Me_tabolomics, Blackwell Publishing Ltd., Hoboken **43**:109–155. Journal of Ethnic Foods.

Duyvejonck AE, Lagrain B, Dornez E, Delcour JA, Courtin CM. 2012. Suitability of solvent retention capacity tests to assess the cookie and bread making quality of European wheat flours. Lwt **47**:56–63. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.lwt.2012.01.002.

Elieser SP, Hibbs NA. 2011. Wheat Flour Milling, 2nd edition. Amer Assn of Cereal Chemists, Year: 2011.

Faltermaier A, Waters D, Becker T, Arendt E, Gastl M. 2014. Common wheat (Triticum aestivum L.) and its use as a brewing cereal - a review. Journal of the Institute of Brewing **120**:1–15.

Finnie S.; Atwell A. W. 2016. Composition of Commercial Flour. Page (Finnie S.; Atwell A. W, editor) Wheat Flour. Woodhead Publishing and AACC International Press.

Hrušková M, Švec I, Jurinová I. 2012. Composite Flours-Characteristics of Wheat/Hemp and Wheat/Teff Models. Food and Nutrition Sciences **03**:1484–1490.

Hrušková M, Švec I, Jurinová I. 2013. Chemometrics of wheat composites with hemp, teff, and chia flour: Comparison of rheological features. International Journal of Food Science **2013**:30–32.

Jifar H, Dagne K, Tesfaye K, Assefa K, Tadele Z. 2018. Agro-morphological traits diversity in tef [Eragrostis tef (Zucc.) Trotter] genotypes from various sources. Ethiop. J. Agric. Sci. **28**:131–148.

Kellogg EA. 1998. Relationships of cereal crops and other grasses. Proceedings of the National Academy of Sciences of the United States of America **95**:2005–2010.

Kweon M, Slade L, Levine H. 2011. Solvent retention capacity (SRC) testing of wheat flour: Principles and value in predicting flour functionality in different wheat-based food processes and in wheat breeding-A review. Cereal Chemistry **88**:537–552.

Lersten NR. 2015. Morphology and anatomy of the wheat plant. Wheat and Wheat Improvement **13**:33–75.

Mehmet A. 2021. Theoretical and Practical New Approaches in Cereal Science and Technology Edited By. Available from www.iksadyayinevi.com.

Mouka Dubecko.cz. (n.d.). Available from https://www.mouka-dubecko.cz/.

Murray JM, Delahunty CM, Baxter IA. 2001. Descriptive sensory analysis: Past, present and future. Food Research International **34**:461–471.

Nagarajan AS. 2020. Can India produce enough wheat even by 2020 ? Published by : Current Science Association Linked references are available on JSTOR for this article : Can India produce enough wheat even by 2020 ? **89**:1467–1471.

Niu Q, Pu Y, Li X, Ma Z, Hu X. 2017. Solvent retention capacities of oat flour. International Journal of Molecular Sciences **18**.

Oliveira V, Haas R, Komeroski M, Homem R, Schmidt H, Rockett F, Farias D, Kist T, Rios A. 2020. Physico-Chemical and Sensory Evaluation of Gluten-Free Cakes Made with Teff (Eragrostis tef). Current Developments in Nutrition **4**:nzaa052_036. American Society for Nutrition. Available from https://doi.org/10.1093/cdn/nzaa052_036.

Pareyt B, Finnie SM, Putseys JA, Delcour JA. 2011. Lipids in bread making: Sources, interactions, and impact on bread quality. Journal of Cereal Science **54**:266–279. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.jcs.2011.08.011.

Patel SK, Varshney BP. 2014. Modeling of wheat crop harvesting losses. Agricultural Engineering International: CIGR Journal **16**:97–102.

Pulivarthi MK, Selladurai M, Nkurikiye E, Li Y, Siliveru K. 2022. Significance of milling methods on brown teff flour, dough, and bread properties. Journal of Texture Studies **53**:478–489.

Romano A, Ferranti P, Gallo V, Masi P. 2021. New ingredients and alternatives to durum wheat semolina for a high quality dried pasta. Current Opinion in Food Science **41**:249–259.

Ronda F, Abebe W, Pérez-Quirce S, Collar C. 2015. Suitability of tef varieties in mixed wheat flour bread matrices: A physico-chemical and nutritional approach. Journal of Cereal Science **64**:139–146.

Shewry P. 2019. What is gluten—Why is it special? Frontiers in Nutrition **6**:1–10.

Shewry PR et al. 2013. Natural variation in grain composition of wheat and related cereals. Journal of Agricultural and Food Chemistry **61**:8295–8303.

Struyf N, Van der Maelen E, Hemdane S, Verspreet J, Verstrepen KJ, Courtin CM. 2017. Bread Dough and Baker's Yeast: An Uplifting Synergy. Comprehensive Reviews in Food Science and Food Safety **16**:850–867.

Tekin M, Cengiz MF, Abbasov M, Aksoy A, Canci H, Akar T. 2018. Comparison of some mineral nutrients and vitamins in advanced hulled wheat lines. Cereal Chemistry **95**:436–444.

van Delden SH, Vos J, Ennos AR, Stomph TJ. 2010. Analysing lodging of the panicle bearing cereal teff (Eragrostis tef). New Phytologist **186**:696–707.

Wang Y, Li Y, Fan M, Wang L, Qian H. 2022. Effect of lactylation on functional and structural properties of gluten.

Wu T, Wang L, Li Y, Qian H, Liu L, Tong L, Zhou X, Wang L, Zhou S. 2019. Effect of milling methods on the properties of rice flour and gluten-free rice bread. Lwt **108**:137–144. Elsevier. Available from https://doi.org/10.1016/j.lwt.2019.03.050.

Zhu F. 2018. Chemical composition and food uses of teff (Eragrostis tef). Food Chemistry **239**:402–415. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.foodchem.2017.06.101.