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IMPACT OF ACIDITY, HARDNESS AND IRON CONTENT OF COOKING WATER ON BULGUR QUALITY

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BY

SADİYE MICHEL

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Supervisor

Prof. Dr. Mustafa BAYRAM

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Sadiye MICHEL

ABSTRACT

IMPACT OF ACIDITY, HARDNESS AND IRON CONTENT OF COOKING WATER ON BULGUR QUALITY

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The two main raw materials used in making bulgur are wheat and water. In bulgur factories, different water sources are used as water source and the chemical constituents of water affect various properties of bulgur produced. The aim of this study is to use cooking water in bulgur production after adjusting its chemical properties and to examine the quality parameters after cooking (cooked wheat) and drying, tempering, bran separation, grinding operations (bulgur) and to contribute to the production of better quality bulgur. In order to achieve this, pH (3, 5, 7, 9 and 11), hardness (~53 (soft), 129 (hard) and 269 (very hard) mg/L $CaCO_3$) and iron contents (0, 1 and 2 ppm) of the wheat cooking water were adjusted and used in the bulgur production. In the study, some properties of water and wheat were examined during cooking. Wheat, cooked wheat and bulgur samples underwent analyses for pH, moisture, ash, protein, fat, starch, colour, phenolic compounds, antioxidant activity, mineral content and texture profile. Furthermore, FTIR and DSC analyses were performed on wheat and bulgur samples and additional sensory analysis was performed on bulgur samples. As a result of the study, it was determined that the colour of bulgur darkened in bulgur produced with cooking water with a pH ≥11 and that cooking with very hard water negatively affected the colour of bulgur, but the amount of iron did not have a negative effect on the colour. The results of the study showed that the textural properties of bulgur were not statistically significantly affected by the acidity, hardness and iron level (P>0.05) of cooking water.

Key Words: Bulgur, Cooking water, Acidity, Hardness, Iron content.

ÖZET

PİŞİRME SUYUNUN ASİTLİK, SERTLİK VE DEMİR İÇERİĞİNİN BULGUR KALİTESİNE OLAN ETKİSİ

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124 sayfa

Bulgur yapımında kullanılan 2 temel hammadde buğday ve sudur. Bulgur fabrikalarında su kaynağı olarak farklı su kaynakları kullanılmakta ve kullanılan suyun kimyasal içeriği, üretilen bulgurun çeşitli özelliklerini etkilemektedir. Bu çalışmanın amacı, bulgur üretiminde pişirme suyunun kimyasal özelliklerinin ayarlandıktan sonra bulgur üretiminde kullanılması ve pişirme (pişmiş buğday) ve kurutma, tavlama, kepek ayırma, öğütme sonrası (bulgur) kalite parametrelerinin incelenmesi ve daha kaliteli bulgur üretimine katkı sağlamaktır. Bu amaçla, buğday pişirme suyunun pH (3, 5, 7, 9 ve 11), sertlik (~53 (yumuşak), 129 (sert) ve 269 (çok sert) mg/L $CaCO_3$) ve demir içerikleri (0, 1 ve 2 ppm) ayarlanarak bulgur üretiminde kullanılmıştır. Çalışmada, hem suyun hem de buğdayın bazı özellikleri pişirme süresince incelenmiştir. Buğday, pişmiş buğday ve bulgur örneklerinde pH, nem, kül, protein, yağ, nişasta, renk, fenolik madde, antioksidan aktivite, mineral madde miktarı ve tekstür profil analizi gerçekleştirilmiştir. Ayrıca buğday ve bulgur örneklerinde FTIR ve DSC analizleri, bulgur örneklerinde ise ek olarak duyusal analiz de gerçekleştirilmiştir. Yapılan çalışma sonucunda, pH değeri ≥11 olan pişirme sularıyla üretilen bulgurlarda rengin koyulaştığı, çok sert suyla pişirmenin de bulgur rengini olumsuz etkilediği, ancak demir miktarının ise renk üzerine olumsuz bir etkisinin olmadığı belirlenmiştir. Çalışmada, pişirme suyunun asitlik, sertlik ve demir içeriğinin bulgurun yapı özellikleri üzerine istatistiksel olarak anlamlı bir etkisi olmadığı (P>0.05) belirlenmiştir.

Anahtar Kelimeler: Bulgur, Pişirme suyu, Asitlik, Sertlik, Demir miktarı.

To my large and lovely family

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LIST OF SYMBOLS

Ca	Calcium
$CaCI_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate
Fe	Iron
$FeCI_3$	Iron (III) Chloride, Ferric Chloride
HCl	Hydrochloric Acid
Mn	Manganese
Na_2CO_3	Sodium Carbonate
NH_3	Ammonia
NH_4Cl	Ammonium Chloride
Na	Sodium
UV	Ultraviolet
YI	Yellowness Index
w/v	Weight/Volume
v/v	Volume/Volume

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
AOAC	Association of Official Agricultural Chemists
CIE	Commission Internationale de l’Eclairage (International Commission on Illumination)
CW	Cooking Water
d.b.	Dry Basis
DPPH	2,2-diphenyl-1-picrylhydrazyl
DSC	Differential Scanning Calorimeter
ER	Electrical Resistivity
FTIR	Fourier Transform Infrared Spectroscopy
GAE	Gallic Acid Equivalents
LOD	Limit of Detection
LOQ	Limit of Quantification
USGS	United States Geological Survey
WHO	World Health Organization

CHAPTER 1
INTRODUCTION

1.1 Wheat

Cereals and their products are indispensable parts of a healthy and balanced diet as they contain major (carbohydrate, fat, protein and dietary fibre, etc.) and minor (minerals, vitamins and phenolic compounds, etc.) nutrients simultaneously. The composition and amount of components in wheat grain vary depending on the species, the soil in which it grows and other environmental conditions (Ciudad-Mulero et al., 2021; Liyana-Pathirana & Shadidi, 2007). *Triticum aestivum* and *Triticum durum* are two wheat species that are commercially important due to their application in the manufacturing of numerous foodstuffs (Arendt & Zannini, 2013). Accordingly, *T. aestivum* species are used in making bread. In contrast, *T. durum* is used in making pasta, couscous, bulgur and noodles because it contains high amounts of protein and can create a harder texture (Arendt & Zannini, 2013; Lachman et al., 2017). At present, approximately 95% of wheat cultivated worldwide is accounted for by bread wheat (Tadesse et al., 2016). Durum wheat is a significant food crop, with an annual production of approximately 36 million tons in the world. Türkiye and Canada are the top two producing nations. Nowadays, durum wheat costs 10 to 20% more than bread wheat when purchased by the pasta, bulgur and couscous industries (Sall et al., 2019). The protein contents and compositions of these wheat are different.

The most important physical features of the wheat grain are its elliptical shape, the embryo at one end, the hairs forming the brush at the other end and the crease extending from one head to the other. Wheat grain mainly consists of bran, endosperm and germ. Each of these parts is rich in different components and has different importance during wheat processing. The exterior layer of the wheat kernel (bran) is rich in proteins (soluble in water), dietary fibre, minerals, phenolic compounds and B-group vitamins such as thiamin, riboflavin and niacin. Proteins and starch are intensified in the endosperm. Lastly, the germ is located close to the bottom of the kernel. This portion is lipid-rich and noteworthy for having proteins, vitamins including vitamin E and B-group vitamins (Arendt & Zannini, 2013; Liyana-Pathirana & Shadidi, 2007).

Gelatinization of starch, the most important process for bulgur production, occurs when the wheat grains are heated with water. During this process, starch particles absorb water and expand when heated to the gelatinization temperature (Arendt & Zannini, 2013). Apart from the major components of wheat, minor components that play a role in both the visual quality and functional properties of the final product have also gained importance recently. In addition to forming colour-giving compounds of bulgur, the phenolic substances in wheat help lower oxidative stress by defending the body against free radicals in the body. Wheat contains phenolic acids, anthocyanins and flavonoids as phenolic compounds. The main phenolic acid in the wheat is ferulic acid and it is accounting for approximately 50% of total phenolic acids which is generally positively correlated with total phenolic content. The colours of wheat mainly originate from anthocyanins and carotenoids. Carotenoids are responsible for yellow and anthocyanins are responsible for the blue, red and purple colours of wheat. The main carotenoid in wheat is lutein, a xanthophyll, which also contributes to the antioxidant properties of wheat (Ficco et al., 2014; Lachman et al., 2017; Liyana-Pathirana & Shadidi, 2007; Piironen et al., 2009; Vaher et al., 2010).

1.2 Bulgur

Wheat and whole wheat products are known as sources of dietary fibre, minerals and antioxidants, which have a lower glycaemic index. Therefore, these foods are suggested to be taken for a health-enhancing diet (Jenkins et al., 1986; Ragaee et al., 2006). On the other hand, they must be processed before consumption to transform them into more pleasant easier to prepare and digest foods (Narwal et al., 2020). Nevertheless, the separation of some parts during wheat processing causes a decrement in the nutritional value of the product (Piironen et al., 2009). Bulgur is a whole wheat product obtained by cleaning, cooking, drying, tempering, debranning (separation of the bran), grinding and classifying wheat. Bulgur is the most wheat-like product in appearance and chemical composition, as various components of the bran part pass into wheat during cooking and thus debranning has less influence than other wheat products (Hayta et al., 2003). Because of its superior yellow colour and protein amount to other wheat types, Durum wheat is preferred in bulgur production (Bayram & Öner, 2006).

Bulgur is a more durable product (longer shelf life) than wheat, as the enzymes and microorganisms in wheat are damaged during cooking and the water activity is reduced by subsequent drying (Elgün et al., 1990; Singh & Dodda, 1979). Although there is no global method in bulgur production, there are two main methods used in the industry, Antep and Mut (Karaman) type production. Hereby, the Antep method is used in the processing of 70% of the bulgur manufactured globally (Bayram & Öner, 2005).

1.2.1 Production and consumption in the world

Nowadays, the interest of people in foods that have functional properties as well as natural and nutritional properties is increasing. Bulgur aroused attention and its consumption is ascending because it is an ethnic food that is tasty, easy to prepare, cheap, less processed food and has various functional properties (Bayram & Öner, 2005; Giambanelli et al., 2020). Coarse bulgur is generally cooked like rice and used to make pilaf in Middle Eastern countries and is often consumed with dishes such as meat or chicken (Elgün et al., 1990; Elias, 1995). Fine bulgur is used in making dishes such as “köfte” (Bayram & Öner, 2005; Deethardt, 1976; Elias, 1995). A traditional famous dish in the Middle East, Kibbeh is a blend of meat and bulgur that can be prepared in a variety of ways. Falafel, a food prepared by mixing chickpea, fava beans and bulgur, is popular and consumed with pleasure in the Middle East. Fine bulgur is also used to make salads like Tabbouleh (Elias, 1995; Hayta, 2001).

Bulgur can be used in making various soups, main dishes, baked products, accompaniments, stuffings, salads and desserts. Although bulgur was consumed mostly in Türkiye, the Balkans and Middle Eastern countries, various recipes have been developed in which bulgur can be used, especially in American sources (Bayram & Öner, 2006; Deethardt, 1976; Hayta, 2001; USDA, 1961). Türkiye has historically provided the majority production of bulgur and the European Union is now among the biggest bulgur importers due to rising bulgur consumption (Giambanelli et al., 2020; USDA, 2021). Additionally, Russia is a new bulgur consumer in parallel to grecha. In the post-colonial period, as North Africans settled in France and Europeans travelled more, Western European countries became more cosmopolitan and as a result of intercultural interaction, their food cultures also altered. Bulgur has also taken its place in the markets because it is used in making Tabbouleh, especially in France. Because it is easy to prepare, can be prepared with different vegetables and is a nutritious food that can be consumed by vegetarians, Tabbouleh has also entered modern French cuisine and is also consumed in places where there are no immigrants (Maxwell, 2019; Maxwell & DeSoucey, 2016).

1.2.2 Bulgur manufacturing process

Bulgur is produced by cleaning (removing foreign substances), washing (removing dust and substances stuck to the grains), cooking, drying, debranning, grinding and classifying. Durum wheat is superior to other wheat types in bulgur production as it is richer in protein and colour substances (Ercan, 1986; Özkaya et al., 1993). A large number of colour components in Durum wheat contribute to the more appealing, brilliant yellow colour of bulgur, while the high quantity of nitrogenous compounds enables the starch to react with proteins to constitute a firmer and tighter texture (Anıl, 1994; Ercan, 1986). The wheat species and cooking and drying techniques used are the principal parameters influencing the quality of bulgur (Bayram et al., 2004a; Evlice & Özkaya, 2020; Kadakal et al., 2007).

The cleaning operation of wheat is applied by passing stones, soil, stalks, straw and crushed grains through aspirator sieves. Subsequent to cleaning, it is washed in machines. The cooking operation is exerted either under atmospheric conditions (traditional cooking) or under pressure. Traditional cooking is realised by boiling the wheat in 1.5-2 times water (Certel & Ertugay, 1992; Hayta, 2001). The cooking operation is the production stage that affects both the nutritional and sensory properties of bulgur production and causes the most changes in the wheat. Therefore, the changes that take place during this process will be covered in greater detail in the following section.

The drying operation is performed by employing divergent drying methods to remove water from the product with high moisture content after cooking. With the drying operation, the texture of bulgur hardens and it becomes more resistant to external conditions, therefore can be stored for an extended period. The volatile compound formation which contributes aroma-active substances, vitamins and bioactive components of bulgur is influenced by the methods used for drying (Kadakal et al., 2007; Yılmaz, 2019; Yousif et al., 2018). Hence, assorted drying methods have been tried by researchers in order to facilitate the drying operation in bulgur production. Various drying methods (sun, tray, solar, microwave, tower, fluidized bed, ventilated oven, infrared, superheated steam and sprouted bed) were investigated to convert the drying operations into new green technologies that are energy-efficient as well as to ascertain the effects of this step on various bulgur attributes (Dueck et al., 2020; Erçetin & Uralcan, 2009; Evlice & Özkaya, 2019; Kahyaoğlu et al., 2010; Kamışlı, 2003; Savas & Basman, 2016).

Following drying, a tempering operation is applied by adjusting the moisture content of wheat to about 17% to soften the bran and help with debranning treatment which involves peeling off the exterior layers of wheat (Kemahlıoğlu & Demirağ, 2010; Terras et al., 2019). The bran part contains a large portion of the minerals and phenolic compounds in wheat. During the cooking operation, some of the minerals and water-soluble phenolic compounds transfer into the water, but still, through the bran separation operation, some of these components are lost (Ercan, 1986; Giambanelli et al., 2020; Özkaya et al., 1993, Terras et al., 2019). Even though stone mills are utilized to crush bulgur in conventional production, roller and hammer mills are more commonly used in industrial production. Lastly, they are classified according to their size through sieves (Ercan, 1986). As can be understood from the bulgur production operation, every stage of bulgur manufacturing should be carefully evaluated and incorporate novel technologies.

1.2.3 Impact of the cooking process on bulgur production

The cooking treatment stands as the most significant stage of bulgur production, as most of the alterations for the wheat to transform into bulgur occur during this process. By virtue of the cooking process, the raw odour of wheat disappears, the unique taste and aroma of bulgur develop and a new product, bulgur, basically emerges after this process. Grain experiences several changes during the process of turning wheat into bulgur, including physical, chemical and sensory changes (Certel & Ertugay, 1992; Ercan, 1986). Starch, being the main ingredient in cereals, is assumed to be the principal source of energy in foodstuffs universally. It needs to be hydrated and heated to gelatinize it before it can be completely digested (Stapley et al., 1998). Cooking of grains primarily refers to the gelatinizing of starch. Owing to the cooking of wheat during bulgur production, the cooking time of bulgur for preparing meals is shortened (Abecassis et al., 2012; Bayram, 2005).

The process of cooking of wheat involves adding water and applying heat treatment, which inactivates enzymes and destroys the microflora of the kernel. Foremostly, the cooking operations cause the starch to expand by imbibing water, go through physicochemical alterations and finally gelatinize and denature the proteins. As a result of all these changes, the floury or glassy grain structure acquires a glassy and very hard structure because of the coalescing of protein and starch gel. Owing to cooking treatment, the nutritional quality of proteins increases (Bayram et al., 2004a; Certel & Ertugay, 1992; Koca & Anıl, 1996).

Because cooking increases the risk of the grain dispersing, it is one of the most crucial processes in bulgur manufacturing. Variations in grain dimensions, colour and quality are brought on by dispersed wheat grains, along with yield loss and gumminess (leakage of starch) (Bayram et al., 2004b; Ercan, 1986). The wheat kernel expands in diameter and its crease opens throughout the cooking process. As a result of the grain absorbing more water during soaking and cooking, its size increases. When the grain is cooking, its longitude and density decline while other dimensions—the y- and z-dimensions—ascend. The extra heating process and leaching of gelatinized starch might cause the crease of the wheat grain to become scattered (Bayram et al., 2004b; Ercan, 1986). As wheat cooks, the starch granules in its structure swell, thus amylose and amylopectin fractions leak out. While amylose leaks more, the leakage rate of amylopectin is slower than amylose. Leakage of starch causes the cooked wheat to become sticky (Hirashima et al., 2005). Several issues (such as stickiness and dimension distortion) arise for the following processes (drying, transferring, debranning and deterioration of the final product) as a result of disruption of the wheat kernel and starch leaching during the cooking operation (Bayram et al., 2004a; Bayram et al., 2004b; Ercan, 1986).

There are two common methods for cooking of wheat for bulgur production: traditional (atmospheric) cooking and pressurized (autoclave) cooking. Although the cooking procedure is different in atmospheric and pressure cooking, the main purpose is to absorb enough water into the wheat grain at the appropriate temperature and time interval by adjusting the temperature and time simultaneously. The absence of white spots, clumping, sticking and darkening in colour in the cooked wheat and complete gelatinization are indicators that the cooking has been done properly (Ercan, 1986). Conventionally, bulgur is often made by atmospheric cooking at 95 to 100°C. On the other hand, in the industry wheat is cooked by using an autoclave after soaking the grains for a couple of hours for it to achieve around 40% moisture (Anıl, 1994; Ercan, 1986). Both cooking methods used in bulgur production have advantages and disadvantages. The bright yellow colour that consumers prefer is achieved through atmospheric cooking, although this method also causes greater damage and dispersion to bulgur grains. On the contrary, autoclave cooking prevents the grains from disintegrating, but it causes the bulgur to darken due to the high temperature and pressure applied (Bayram et al., 2004a; Evlice & Özkaya, 2019; Evlice & Özkaya, 2020).

The significance of the cooking treatment lies not only in its impact on quality but also in its power use. Due to these factors, numerous cooking methods (such as atmospheric, pressurised, steam, microwave and ultrasound-aided atmospheric) (Dueck et al., 2020; Erçetin & Uralcan, 2009; Evlice & Özkaya, 2019; Kahyaoğlu et al., 2010; Kamışlı, 2003; Savas & Basman, 2016) were investigated in an effort to decrease energy consumption and therefore make cooking process a low-polluting process as well as to ascertain the influences of this process on various bulgur characteristics.

1.3 The role of water in food production

Water has a crucial role in the food manufacturing industry since it serves a variety of functions such as cleaning, using as an ingredient, processing aid and other purposes. Herewith, the properties of food are influenced directly by the soluble ions and other chemicals in the water (Krosnijs & Kuka, 2003; Wujie et al., 2011). Water is essential for effective functioning in any place, hence efforts should be made to guarantee that the quality of the water is constantly drinkable, particularly in sectors where water is utilized to prepare food (Jacob, 1988). As water is the principal constituent of most foods, high amounts of water of varied quality are needed and used for the processing and manufacture of food (Kirby et al., 2003). Water is used in the food industry for a variety of reasons, but its main applications are usage in the ingredient list and recipe for processing. The largest volume of water is utilised by the dairy, meat and poultry sectors. The other leading water-consuming industries are starchy foods, soft drinks and processed products (fruits and vegetables). Among the food industry, the low-water-use sectors are cereal milling and baking (Jacob, 1988; Kasaai, 2014).

In the food processing industry, water is added to food as either an auxiliary processing agent or used in formulation (Bowser, 2017). As an auxiliary component, water can be used in transportation, clearance, heating, refrigeration, dissolution, dilution, separation and steam production (Bowser, 2017; Wujie et al., 2011). Water is utilised extensively in the food production sector for a variety of tasks, including soaking, boiling, cooking, fermenting, formulating food, baking and brewing (extraction of some food components) (Haring & Van Delft, 1981; Kasaai, 2014; Krosnijs & Kuka, 2003; Navarini & Rivetti, 2010; Nawaz et al., 2018; Sinani et al., 2014).

Water is a component of the foods such as grains, meat, milk, vegetables and fruits and it is the main ingredient in assorted foods. Some of the basic nutritional components in foods, such as carbohydrates, minerals and vitamins, are soluble in water. Most carbohydrate derivatives gel and gain elastic structure with proteins through water. Water provides an excellent cooking environment for food (Kasaai, 2014). When used as an ingredient, water can influence the rheological characteristics of dough and, therefore the bakery products by influencing the structure of the gluten; the aromatic sensorial characteristics of tea and coffee because of variations in its extraction ability; the chemical, textural and sensorial characteristics of grain products after heating (Murugesan et al., 2016; Navarini & Rivetti, 2010; Nawaz et al., 2018; Sinani et al., 2014).

In food production, water not only creates an environment for reactions to occur but also is an important parameter used to control and regulate the texture, colour and physical, chemical and biological properties of the food (Bowser, 2017). Water is utilized as a reaction medium to prepare the dough, as well as a cooking environment for vegetables and grains and for the diluting or formulating of soft and alcoholic beverages and food products. For example, the formation of the gluten occurs subsequent to the flour and water combination. In addition to this, water is also employed to alter the physical characteristics, reactions and rates, flavour and texture of food (He & Lu, 2014; Huang & Miskelley, 2016; Navarini & Rivetti, 2010; Sinani et al., 2014; Sozer & Kaya, 2008). Consequently, various aspects of food features, such as appearance, colour, flavour, clarity, taste, textural and functional properties, chemical constitution, crystallisation characteristics, anti-nutritional factors and aroma-forming substances are significantly influenced by the composition of the water (Brandt et al., 1984; Wujie et al., 2011).

In the food factories, the water is supplied from the municipality or mains. Therefore, the processes to be applied to water vary depending on the source from which the water is obtained and the properties of the water. Water to be used for any purpose in food processing must be of drinking water quality not contain undesirable taste, odour and colour substances and should be of sufficient clarity (Kirby et al., 2003; Wujie et al., 2011).

1.4 Influence of chemical content of water on the production of various foods

Water interacts strongly with various other compounds and can receive and give protons to create hydrogen linkages, which makes it a solvent for a wide range of compounds. Therefore, it is a great solvent for many polar components (Kasaai, 2014; Wellinger et al., 2017). The minerals in water are considered to be the most important parameter that affects the quality of the liquid foods it is used in production (Kasaai, 2014; Murugesan et al., 2016; Navarini & Rivetti, 2010). The pH and mineral composition and their concentrations are the foremost chemical factors in terms of food quality (Dvorak et al., 2014; Franks et al., 2019; McFarland & Dozier, 2004). Well and tap water are widely utilised in the food production industry for multiple functions, including food processing; however, their pH and mineral content vary depending on the region and period. Even if the quality of tap water satisfies the safety standards for drinkable water, it may not be proper for use in food processing and may need to be regulated prior to usage (Bowser, 2017; Sinani et al., 2014; Wellinger, 2017).

The pH is one of the leading parameters that influences many quality characteristics of the foods prepared by using water. Based on its pH level, water can be classified as acidic, neutral or alkaline (Wellinger, 2017). A previous study (Bayram et al., 2004c) showed that cooking water pH significantly affects the textural traits and pigment and moisture levels of bulgur. The gelatinization of starch and, consequently, the viscosity and textural characteristics of cereal products are significantly influenced by pH (Nawaz et al., 2018). Furthermore, the pH of the water utilized during manufacturing affects not only the textural and organoleptic features of food items but also the solubility, extractability, functionality and denaturation of proteins and the stability of phenolic substances (Deleu et al., 2019; Friedman & Jürgens, 2000; Hirashima et al., 2005).

A study conducted by Brandt et al. (1984) highlighted the influence of cooking water pH on some vegetables and pulses. For this purpose, potatoes, beans, peas, cauliflower and corn were cooked with water in the pH range of 2-10. According to the research, the textural properties of the investigated foods changed depending on the pH level. At pH 4, cooked vegetables and pulses were the firmest, while at pH 10, they were the softest.

He & Lu (2014) investigated the influence of water pH on the quality traits of steamed bread and figured out that the specific volume, whiteness and sensory acceptability of steamed bread ascended as the water pH climbed between 3 and 6, but they declined as the water pH value increased (in the range of 6 to 9).

Sinani et al. (2014) concluded that alkaline water impacts gluten structure and negatively affects the dough's plasticity and shaping the dough, therefore suggested utilising slightly acidified water.

Calcium and other divalent cations, which partially come from magnesium and manganese, are associated with the existence and quantity of hardness in water. Water hardness can be divided into two groups: temporary and permanent hardness. The ions of sulphate, chloride and nitrates in the water provide permanent hardness, whereas the carbonates and bicarbonates of divalent cations are the source of temporary hardness. However, total hardness -defined as the sum of the calcium and magnesium concentrations and given as mg of $CaCO_3$ per litre or in multiple hardness degrees- is the most common way to specify water hardness (Diggs & Parker, 2009; Haring & Van Delft, 1981). Nevertheless, there are several scales for categorisation of water hardness, water hardness has been defined by the World Health Organisation (WHO) and the United States Geological Survey (USGS) into four categories: soft (<60 mg/L of $CaCO_3$), moderately hard (60–120 mg/L of $CaCO_3$), hard (120–180 mg/L of $CaCO_3$) and very hard (>180 mg/L of $CaCO_3$) (Sumalapao et al., 2017; World Health Organization, 2011).

In a study examining the effect of water hardness on the quality of steamed bread, it was stated that calcium ions modified the structure of gluten in steamed bread produced with water containing 0.1% $CaCO_3$, thus enabling the production of higher volume, whiter bread (He & Lu, 2014).

Haring & Van Delft (1981) studied the effect of cooking with water of different hardness on the mineral content of potatoes, cauliflower, carrots and endive. As a result of the study, it was determined that more minerals passed into the water from vegetables cooked in soft water than in hard water.

Navarini & Rivetti (2010) made Espresso coffees from the same coffee lots using water of divergent hardness and compared their effects on the foam volume, stability and texture of the resulting coffees. The study stated that coffees made with hard water form more foam and there is a directly proportional relationship between water hardness and foam volume, but the foams of coffees made with hard water had lower stability than others and had an unacceptable foam texture.

Murugesan et al. (2016) examined the effects of water hardness on tea quality and reported that the minerals in the hard water used for brewing interacted with the polyphenols in the tea, resulting in the colour of the tea to darkening, thus negatively affecting the quality.

Franks et al. (2019) examined the effects of water hardness on turbidity, colour, flavonols and sensory quality of teas brewed using distilled, bottled and tap water to examine the effects of water hardness on green and black tea making. The results obtained from the study showed that the water used in brewing tea has vital effects on the examined properties of both green and black tea. Additionally, tap water was observed to darken the colour of black tea, similar to the study conducted by Murugesan et al. (2016). It has been stated that both types of tea brewed with tap water are cloudier than the others.

In a study where cowpeas were cooked with water of different hardness, it was determined that hard water decreased water absorption and augmented the cooking time, hardness of the product and the amount of minerals retained in the product (Uzogara et al.,1992).

Iron is an element that does not have a negative effect on health, but can cause problems in the water supply. Iron-containing compounds can be dissolved and maintained in solution by water seeping through rocks and soil. Another important source of iron in water is the dissolution of iron in the pipes used to transport water and its transfer into the water. There are two types of iron found in water: ferrous iron and ferric iron. In the low oxygen level, iron exits its water-soluble ferric form, which transforms into non-water-soluble ferrous iron when it reacts with oxygen. This results in colour changes in the drinking water and food products treated with that type of water, with the white colour gradually turning yellow and finally reddish (Dvorak et al., 2014; World Health Organization, 2003).

The insoluble form of iron gives rise to some problems, such as red colour formation in the water and therefore in the colour of the foods used in its production. Due to its high reactivity, iron can react with food ingredients and cause negative effects on colour when added to the foods it is used in, either through water or for enrichment purposes (Dvorak et al., 2014; Habeych et al., 2016; Pascu et al., 2016). Iron can interact with anthocyanins in plant foods and cause the formation of blue colour (Enaru et al., 2021). In addition, it may interact with phenolic substances in tea, coffee and certain alcoholic beverages and lead to the formation of undesired appearance, flavour, odour and off-colour issues (Dvorak et al., 2014; Mellican et al., 2003).

1.5 Studies on bulgur processing

Research on the processing and production of bulgur was carried out on the production of bulgur from different raw materials and the application of different soaking, cooking, drying, tempering and milling methods. Studies in the literature have focused on converting various raw materials into bulgur to facilitate cooking, thus boosting their consumption and enhancing the nutritional value and technological characteristics of bulgur in manufacturing processes. Previous studies on bulgur have been examined under the following subheadings in an attempt to demonstrate that there is a gap in the literature on this topic and that the cooking water used in bulgur manufacturing has not been studied.

1.5.1 Studies on producing bulgur from different raw materials

Giambanelli et al. (2020) produced bulgur from both hulled and dehulled einkorn wheat, cooked for different time and examined their effects on the phenolic substances of bulgur. The study revealed that increasing the cooking time did not have a significant effect on the amount of phenolic substances in bulgur, but caused a more carotenoid loss in bulgur produced from dehulled einkorn wheat.

Yılmaz (2019; 2020) produced bulgur from emmer wheat with different cooking (conventional, pressure, microwave) and drying (hot air, microwave) techniques and studied their impacts on chemical composition, phenolic substances, texture parameters and sensory characteristics. As a result of the study, it was determined that cooking reduced the amount of phenolics in all bulgur samples, microwave cooking had a positive effect on phenolic substances and reduced the cooking time, while microwave drying had a negative effect on phenolics, the colour of bulgur produced by pressure cooking was negatively affected and received lower scores in sensory evaluation.

Candal-Uslu et al. (2021) produced gluten-free bulgur by boiling and steaming methods from brown rice. They reported that cooking time and phytic acid diminished while resistant starch increased in the produced bulgur compared to brown rice.

Köksel et al. (1999) produced bulgur from barley using traditional and autoclave methods and its properties such as phytic acid, riboflavin, thiamine and protein content were monitored. It was noted that there were significant losses in the vitamins examined after the bulgur production process, there were no significant alterations in the amount of protein and there was a reduction in the amount of phytic acid.

The impact of different drying methods (hot air, microwave and superheated steam) on the chemical composition of bulgur produced from high-amylose and waxy hull-less barley was determined by Dueck et al. (2020) and compared to waxy barley bulgur, high-amylose barley bulgur had higher levels of ash, arabinoxylans, resistant starch, dietary fibre and β-tocotrienols but lower levels of proteins.

In their research, Ertaş & Türker (2012) produced bulgur from common beans using varying soaking water pH (4, 6 and 8) and soaking hours (2, 8 and 12). As the result of the study, they identified the ideal soaking process parameters needed to achieve the best nutritional qualities, which were pH 8 and 12 h of soaking time.

In a study comparing the phytic acid, essential amino acid constitution and organoleptic parameters of bulgur produced from sweet and bitter lupine seeds, it was found that bulgur produced from sweet lupine seeds was richer in essential amino acids and contained less phytic acid. Its organoleptic features were more acceptable than those produced from bitter lupine seeds (Yorgancılar & Bilgiçli, 2014).

Bayram (2003) produced bulgur from rye and soybean using pressurized, traditional and microwave cooking. Pressure cooking was superior to other methods because it required shorter cooking time and less energy, the optimum cooking time was detected as 6 min for soybeans and 9 min for rye at 15 psig in pressure cooking.

Bilgiçli (2009) produced bulgur from the common bean and chickpea with 3 different cooking methods (traditional, autoclave and microwave) and 2 different drying methods (microwave and oven) and scrutinized its effects on colour, sensory properties and phytic acid content. The results showed that pressure cooking increased the yield and was more effective than other cooking methods in reducing the amount of phytic acid, but caused a decrease in the L value of common bean bulgur. Consequently, it has been highlighted that as the temperature increases in oven drying and power applied in microwave drying increases, the L values of bulgur are negatively affected and the most sensorially pleasing bulgur is the bulgur cooked in an autoclave and dried in the oven at 80 ^{o}C.

1.5.2 Research related to the cooking of bulgur

In their study to determine the effect of bulgur type and cooking methods on the nutritional content of bulgur; Evlice & Özkaya (2020) stated that cooking with a steam cooker is superior to pressure cooking. It has been reported that the nutritive properties of bulgur (vitamins, dietary fibre, yellow colour substances, etc.) are adversely affected by heat treatment and pressure during pressure cooking and that these values are higher when bulgur is cooked in a steam cooker. This is explained by the fact that wheat grains cooked in a steamer cooker are more fragile, therefore the debranning process removes less bran and the relevant nutrients remain in the structure of bulgur.

In another study (Evlice & Özkaya, 2019) examining the effects on colour and yield with the same cooking methods, it was stated that the yield of bulgur produced by pressurised cooking was lower and the colour became darker due to the removal of more bran. Additionally, it has been observed that Durum wheat is superior to bread wheat in terms of colour due to its higher L (lightness) and b (yellowness) values and lower a (redness) values.

Yilmaz & Koca (2017) probed the phenolic compound amount and antioxidant activities of bulgur produced by two different wheat varieties (einkorn, Durum), three different cooking methods (atmospheric, pressure and microwave) and two different drying methods (hot and microwave). It was noted that, although einkorn wheat contained more phenolic substances than Durum wheat, it was influenced more adversely during the bulgur manufacturing process. Microwave cooking was suggested as the best option to ensure greater preservation of phenolic substances, while pressure cooking was detected to cause the most negative effects and hot air drying was indicated to be superior to other methods as a drying method.

Kadakal et al. (2007) evaluated the influence of cooking (atmospheric at 90 and 100 $^{\circ}$C and pressure cooking) and drying methods (sun and hot air) on the water-soluble vitamins of Durum bulgur. As a result of the study, it was determined that the vitamins in question were less in bulgur cooked under pressure than in bulgur cooked under atmospheric pressure. The study also showed that vitamin loss deepened as temperature increased in atmospheric cooking and that drying with hot air was more effective than sun drying in reducing vitamin loss.

1.5.3 Investigations about drying and tempering of bulgur

In the study conducted by Savas & Basman (2016) where they examined the effect of infrared drying on the properties of bulgur such as colour and dietary fibre, it was stated that infrared drying showed similar results to the sun and hot air drying in bulgur drying. In addition, it has been pointed out that infrared drying is a method that shortens the drying time without having a negative effect on the quality of bulgur, but application at high power induces water to evaporate in the grains in a very short time, making the grains more sensitive and less resistant to the debranning process and therefore causes the formation of smaller-sized bulgur.

Hayta (2001) assessed the effect of different drying methods (tray, sun, microwave and solar) on the yield for pilaf bulgur, colour and sensory traits of bulgur. It was stated that the highest yield of pilaf bulgur was achieved by solar drying and the highest L value was also seen in bulgur dried with this method. It was observed that the fastest drying was attained via microwave drying and that the drying methods did not have a significant impact on sensory acceptability.

Balci & Bayram (2015) applied two diverse tempering techniques prior to sun and UV-light polishing and examined their influences on total carotenoid amount and colour values. The results disclosed that UV light was more effective on L* and b* values than sunlight. It has been reported that both tempering processes significantly increase L*, b* and YI values and the highest amount of carotenoids can be achieved by spray tempering and UV-light application.

1.5.4 Research concerning milling of bulgur

Milling is a crucial process in the manufacturing of bulgur, which is distinct from the milling used to make other granular foods. The purpose of milling wheat to make semolina and flour is to separate the bran from the endosperm. Conversely, in bulgur production, cooked wheat is dried, then moistened and its bran is separated, so the milling process is used only to obtain and classify grains of the desired size (Bayram & Öner, 2005).

Unal & Sacılık (2011) milled einkorn and emmer wheat types using fixed top stone and fixed bottom stone. The results of the study revealed that bulgur with smaller particles could be obtained by grinding with the fixed bottom stone compared to grinding with the fixed top stone mill and that the bulgur milled with the fixed top stone was lighter in colour due to constant friction and high heat generation.

Bayram & Öner (2005) used a stone, disc and hammer mill to grind bulgur and examined its effects on parameters such as appearance, surface structure and dimensions of bulgur. Disc and stone mills produced bulgur particles with a smooth and uniform shape. Particles of bulgur ground by stone mill were opaque rather than being fractured or glassy. Besides, it was stated that the stone mill was superior to others in terms of coarse bulgur fraction yield. Even though the hammer mill provides higher grinding efficiency than others, it is not recommended to be used in bulgur production because it negatively affects the surface properties and appearance of the grains.

1.6 The importance of study and the contribution to the literature

Bulgur with a bright yellow colour is demanded by consumers. Therefore, the bulgur industry is trying to regulate all production parameters for this purpose. The impacts of various wheat species, cooking, drying, tempering and milling methods have all been thoroughly studied for this purpose in the bulgur industry. On the other hand, the effect of the properties of water, which is the principal raw material along with wheat and the primary ingredient in bulgur production in quantity, on the quality of bulgur has not been examined.

The water used in the bulgur industry is microbiologically safe well water. Whereas the water used in the food industry must be microbiologically safe, the effects of the chemical properties of the water used on the quality of the food produced have been disregarded. Chemical properties of water, such as pH, hardness and iron content, are considered secondary parameters since they do not have direct negative effects on health. Therefore, while the microbiological properties of the water used are generally controlled, chemical parameters are neglected.

In the food and beverage industry, although it is thought that the hardness value of the water used in production affects parameters such as foam formation and colour in some beverages such as coffee, the effects of water on the quality of foods and beverages have not been adequately examined in the literature. Nevertheless, in recent years, the effects of the chemical parameters of the water used on foods have been investigated. The interest and therefore the studies in this subject have increased.

In the bulgur industry, it is thought that undesirable colour occurs in some bulgur produced and that this is related to the water composition, but the effects of chemical parameters on quality are unknown. Accordingly, this study was established considering the production problems and requirements of the bulgur industry and the gap in the literature on this subject. This study was designed considering that the pH value of the cooking water used in the bulgur industry will affect the solubility of substances in wheat; the hardness value may cause hardening and whitening due to calcium; and iron may have a negative effect on the colour of bulgur by interacting with some compounds or causing oxidation.

1.7 Objectives of the research

The three main aims of this thesis study are; (i) disclosing the effect of cooking water pH, hardness and iron content on the parameters and kinetics of wheat and cooking water during cooking operation, (ii) determining the pH, hardness and iron values of water for better quality bulgur production, (iii) revealing the effects of cooking water pH, hardness and iron amount on both cooked wheat and bulgur. In the study, the effects of cooking water pH, hardness and iron content on the chemical properties, bioactive and mineral substance contents and colour and texture properties of cooked wheat and bulgur were examined, thus the effects of both the chemical parameters of water and the processes in bulgur production on the examined properties were determined. Therefore, this study provides an important source of information for both the bulgur production industry, producers in industries producing similar grain products and researchers studying the effects of chemical parameters of water on food products. The overall experimental set-up is shown in Figure 1.1.

The aims of this research are:

- To assess the influence of cooking water pH in a wide range (3, 5, 7, 9 and 11), hardness (soft (53 mg/L of $CaCO_3$), hard (129 mg/L of $CaCO_3$) and very hard (269 mg/L of $CaCO_3$)) and iron content (0, 1 and 2 mg/L) on the gelatinization degree of wheat during cooking operation and on the cooking water physicochemical properties,
- To monitor the colour, pH, Brix, turbidity, water hardness and conductivity of cooking water during the water 10 min intervals,
- To find out the recommendable values of pH, hardness and iron content of cooking water in terms of bulgur quality,
- To examine the influence of cooking water pH, hardness and iron content on the pH and proximate composition (moisture, ash, fat, starch and protein content) of cooked what and bulgur samples,
- To reveal the impact of cooking water pH, hardness and iron content on the mineral (Fe, Zn, Ca, Na, Mn) and bioactive contents (total phenolic compounds

and antioxidant activity) and colour (L*, a*, b* and Yellowness Index (YI)), textural and sensory properties of cooked what and bulgur samples,

- To determine the effect of cooking water pH, hardness and iron content on the thermal (DSC) and structural (FTIR) characteristics of bulgur samples.

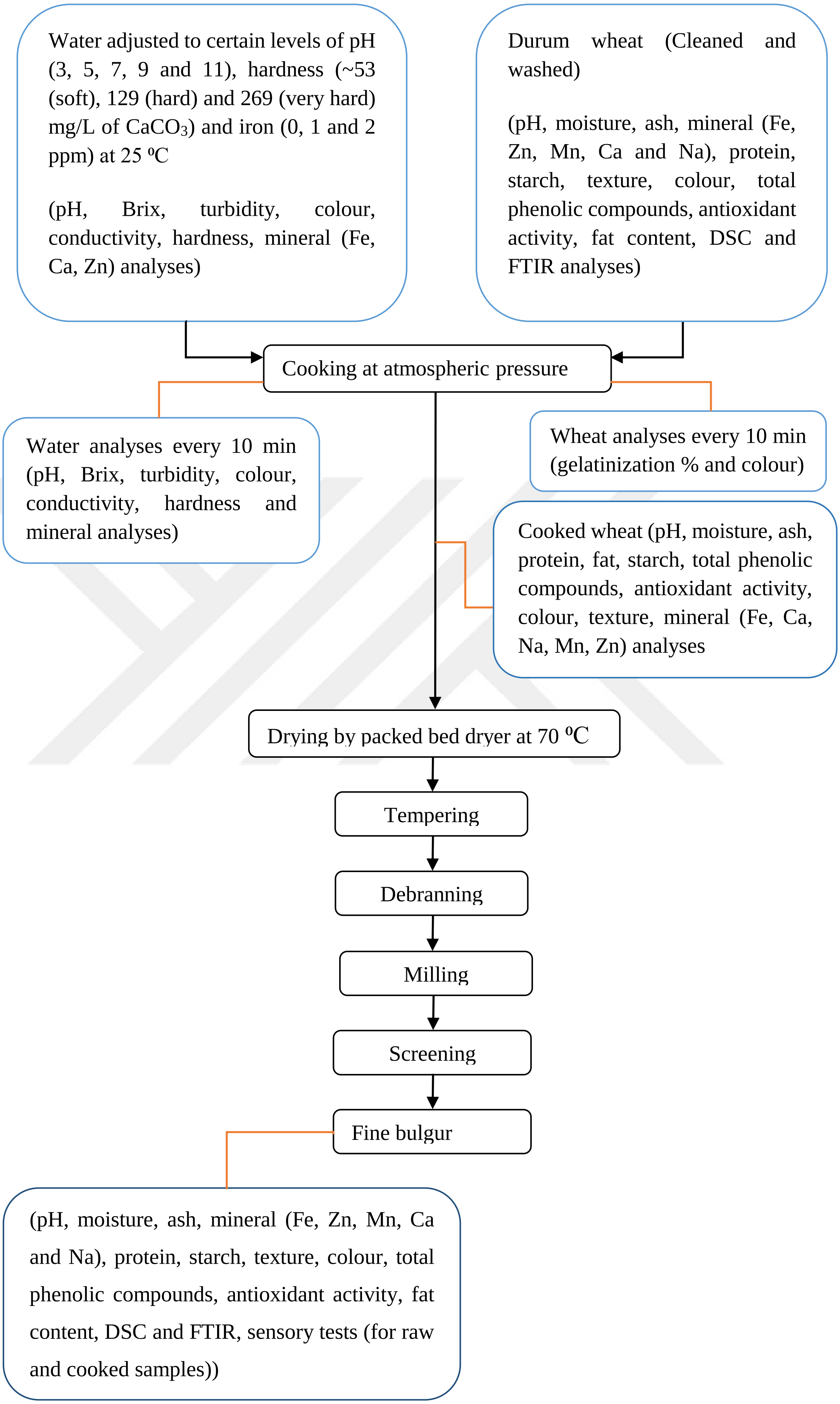

Figure 1.1 Experimental setup of the thesis

CHAPTER 2
ALTERATIONS IN THE CHEMICAL AND COLOUR VALUES OF WHEAT AND COOKING WATER COOKED WITH WATER OF DIFFERENT ACIDITY, HARDNESS AND IRON CONTENT

Summary

Colour variations in wheat and cooking water have a significant impact on wastewater and bulgur quality. To produce brilliant yellow bulgur and ascertain the potential adverse influence that cooking water may have on nature and ecology, it is important to figure out the effects of cooking water acidity, hardness and iron content. Thus, the degree of gelatinization and colour (Lightness (L*), redness (a*), yellowness (b*) and yellowness index (YI)) values of wheat cooked in water varying in a wide range of pH (3, 5, 7, 9 and 11), hardness (~53 (soft), 129 (hard) and 269 (very hard) mg/L of $CaCO_3$) and iron concentration (0, 1 and 2 ppm) were measured at 10-minute intervals. Furthermore, the pH, Brix, conductivity, hardness, turbidity and significant colour parameters for bulgur (L* and b*) of cooking waters were measured every 10 min and examined kinetically. After cooking, it was discovered that whereas pH 11 induced darkening, cooking with water at pH 3 had a positive impact on the colour of the cooked wheat. The gelatinization rate of wheat was reduced and cooking time was prolonged while using very hard water. Due to their pH levels at the end of cooking, pH 3 and 11 were shown to be more environmentally hazardous.

2.1 Introduction

Due to its versatility, the ease of preparation and taste with a wide range of meats and vegetables, bulgur is becoming more and more popular worldwide, especially in Europe (Maxwell, 2019; Maxwell & DeSoucey, 2016). Furthermore, bulgur is a common ingredient in tabbouleh salad, which is popularly consumed. The main producer and supplier of bulgur throughout history has been Türkiye. One of the biggest importers of bulgur is the European Union, which grew in popularity due to rising consumption (USDA, 2021). Moreover, studies reveal that bulgur is not just a food for immigrants to Europe; it is also a component of contemporary French cuisine, which is well-known worldwide (Maxwell, 2019).As the primary and crucial stage in the production of bulgur, cooking affects the final quality of bulgur since it allows the starch in the wheat to gelatinize and absorb water into the kernel (Balcı & Bayram, 2020). Because it is needed in roughly twice the quantity of wheat, water is the primary ingredient utilised in the production of bulgur. Bulgur quality is influenced by the characteristics of the water used during cooking, which is a mass transfer process between wheat and water. It is also crucial to consider the pH and mineral content of the water since it permeates into the wheat and changes its chemical, physical, textural and sensory properties (Kasaai, 2014). There is a mass transfer between water and wheat during cooking and vice versa, which causes components in the wheat to enter the water (Geankoplis, 2012) and the characteristics of the water affect how much a substance leaches (Kasaai, 2014).

When wheat is placed into water at boiling temperature for cooking operation, the heat damages the cell wall, allowing water-soluble substances to migrate from the wheat to the cooking medium. During cooking, the complex transition between wheat and water continues. Nitrogenous matter, starch, minerals, vitamins, hydrophilic phenolic substances and pigments have a tendency to seep into water (Bayram et al., 2004c). The dissolubility and reaction of compounds can be altered by the chemical characteristics of water, such as its pH, hardness and iron concentration, which can impact the mass transfer rate and direction between wheat and water (Kasaai, 2014). Because complete starch gelatinization and a bright yellow resulting bulgur are required for the finished product, monitoring the colour and degree of gelatinization of the wheat is important because they can serve as indicators of the final quality of the bulgur. To further shed light on the mass transition to water and the ultimate composition of wastewater during the cooking operation, monitoring the characteristics of water is also essential (Balcı & Bayram, 2020).

There are environmental issues since the last bit of water left over after the wheat is cooked for the manufacturing of bulgur is discharged into the surrounding untreated. As a result, monitoring the water used to cook wheat is crucial for identifying the qualities of the wastewater that is produced after cooking and outlining the options for cleaning, using or valorising this water (Balcı & Bayram, 2020; Hassan et al., 2021;

Islam et al., 2020). In order to understand the impact of cooking water at varying pH (3, 5, 7, 9 and 11), hardness (~53 (soft), 129 (hard) and 269 (very hard) mg/L of $CaCO_3$) and iron content (0, 1 and 2 ppm) on the colour and gelatinization characteristics of wheat, as well as the chemical and colour characteristics of cooking water at 10-minute intervals throughout the cooking process, this study was conducted. According to published reports, the hardness of the water used in food industries varies by location and its iron level can reach up to 2 mg/L. Since the chemical composition of water varies throughout districts, it is more appropriate to artificially vary the parameters under study to ascertain the true impact of each parameter (Boguniewicz-Zablocka et al., 2019). In this research, the kinetic characteristics of cooking water, including pH, Brix, conductivity, turbidity, hardness and colour, that are associated with compounds leaching were ascertained in this investigation. Furthermore, the mineral composition of the cooking waters was ascertained at the start and finish of the cooking process in order to forecast the mineral transitions.

2.2 Materials and methods

2.2.1 Raw materials

The bulgur samples were made from durum wheat (*Triticum durum* cv. Güneyyıldızı) that was supplied by a local bulgur company (Tiryaki Agro Food Co., Gaziantep, Türkiye). The cooking water was standardised to the required pH, hardness and iron content using deionized water from Milli-Q Advantage A 10 (Millipore, France). Iron chloride ($FeCI_3$) was obtained from Sigma Co. (St. Louis, MO, USA), while food-grade sodium carbonate (Na_2CO_3), citric acid (E330) for pH adjustment and food-grade $CaCI_2$ for hardness adjustment were acquired from Kimbiotek Kimyevi Mad. San. ve Tic. Co. (İstanbul/Türkiye).

2.2.2 Reagents

The hydrochloric acid (HCl), calcium carbonate ($CaCO_3$), ammonium chloride (NH_4CI) and pH standards (4, 7 and 10) were acquired from Merck Co. (Merck KGaA, Germany) and the conductivity standard (1413 µS/cm) was bought from Mettler-Toledo Co. (Mettler-Toledo AG, Switzerland). Ammonia solution (25%) and ethylenediaminetetraacetic acid (EDTA) were obtained from Carlo Erba Co. (Carlo Erba Reagents, Italy), Eriochrome Black T was purchased from Riedel-de Haën

(Seelze, Germany) and lastly, the standards of minerals (Fe, Ca and Zn) were supplied by Perkin Elmer (PerkinElmer Inc., USA).

2.2.3 Analysis of pH, conductivity, Brix and hardness of cooking waters

The pH was detected by taking 100 ml of cooking water at 25 ºC through a pH meter (AZ 86505, AZ Instrument Corporation, Taiwan) calibrated by using standardized buffer solutions at pH 4, 7 and 10, prior to each measurement. The amount of soluble solids, or brix (g/g, %) content, was determined at 25 °C using a refractometer (PTR 46 X, Index Instruments, England). The conductivity detections were accomplished at 25 ºC by using the conductometer (AZ 86505, AZ Instrument Corporation, Taiwan) standardized by using the 1413 µS/cm conductivity standard. The water hardness experiment was actualised according to the method of Harris (2003). In order to analyse the hardness of the water, 25 mL of water was placed into a conical flask, 1 mL of buffer solution (which contained 6.8 g of NH_4CI and 57 mL of 25% NH_3) and 4–5 drops of Eriochrome Black T indicator were added and the mixture was then titrated with EDTA (standardised by $CaCO_3$) solution until the colour turned blue.

2.2.4 Cooking operation and sampling of wheat and cooking waters

Wet and dry cleaning was applied to wheat before it was cooked. The pH levels of 3, 5, 7, 9 and 11 were achieved by adjusting the water with solutions of 1 and 5% Na_2CO_3 (w/v) and 1 and 10% (w/v) citric acid. The pH metre was utilized to continuously measure the pH at 25°C in order to modify it. Cooking water hardness levels were controlled by adding 1000 mg/L of $CaCI_2$ solution to deionized water and measuring the continuous hardness value using the EDTA method (Harris, 2003). To achieve the appropriate iron concentration, 100 ppm of $FeCI_3$ solution was added to the cooking water.

Following a 3.6 and 1.6 mm sieve for dry cleaning, the wheat was treated with distilled water (wheat to water ratio: 1/1.8) for 3 min in order to remove any remaining dust or foreign materials. Initially, in order to ascertain the impact of water acidity on the wheat and cooking water throughout the cooking process, the cooking water used to produce bulgur was individually changed to pH levels of 3, 5, 7, 9 and 11 and the wheat was cooked twice using each water. Secondly, the cooking water of wheat was separately set to hardness at 53 (soft), 129 (hard) and 269 mg/L (very hard) of $CaCO_3$

levels and wheat was cooked with each water twice to reveal the impact of the water hardness on the wheat and cooking water of wheat during the cooking operation. Finally, water for cooking wheat was independently adjusted to 0, 1 and 2 ppm and wheat was cooked with each water twice in order to disclose the effect of water iron concentration on the wheat and cooking water of wheat throughout the cooking operation. The cooking was applied by pouring 1 kg of wheat into 1.8 L of boiling water and simmering it until the complete gelatinization of starch was achieved. During cooking, samples were taken from both the cooking water and the cooked wheat at 10-minute intervals. The gathered samples were subjected to measurements of pH, Brix, turbidity, conductivity, hardness and colour of the cooking water. The gathered samples were subjected to measurements of pH, Brix, turbidity, conductivity, hardness and colour of the cooking water. Furthermore, measurements were made of the Fe, Ca and Zn concentrations in each cooking water both before and after the cooking process. Colour parameters and gelatinization degree analyses were conducted on wheat samples gathered at 10-minute intervals during cooking.

2.2.5 Measurement of colour parameters of wheat and cooking water

The colour of the collected wheat and cooking water samples was evaluated using a colourimeter (HunterLab ColorFlex, Model EZ 45-2, Reston, VA). The standardization of the apparatus was accomplished by utilising the manufacturer's recommended standard black and white tiles. The L*, a*, b* and YI values were used to measure colour changes. L* stands for lightness; a* indicates greenness (-a*)/redness (+a*), b* indicates blueness (-b*)/yellowness (+b*) and YI (yellowness index) indicates the degree of clarity. To minimise the impact of the external light, the sample was only partially placed into the standardised sample container (up to a height of 25 mm) of the device and then the lid made from an opaque material was covered. Each sample has a mean value calculated by averaging four observations from different points.

2.2.6 Assessment of the level of gelatinization in wheat during cooking

According to the suggested cutting procedure of Bayram (2006), 100 cooked grains were sliced using a convenient cutter knife and the endosperms were examined for opaque white cores. According to this assessment, the grains were considered gelatinized if their core colour was consistently glassy (transparent) and devoid of any whiteness or opaque.

2.2.7 Evaluation of mineral composition of cooking waters

The cooking water samples were acidified with 3 mol/L HCl and filtered through a 0.45 μm syringe filter before being subjected to Atomic Absorption Spectroscopy (AAS). An AAS equipped with a flame atomizer (Perkin Elmer AAnalyst 800, Shelton, USA) was used to spray the solution into the flame and determine the minerals (Fe, Ca and Zn) by adjusting the apparatus to the suggested parameters for each mineral. Quantification was accomplished using the calibration curve drawn from a minimum of five external standards at various concentrations of each element. The oxidant gas used to create a flame in this process was air (17 L/min) and the fuel used was acetylene (2 L/min). The minerals were analysed at the following wavelengths: 422.7 nm for Ca, 248.3 nm for Zn and 213.9 nm for Fe. Blank measurement was used to calculate the limit of quantification (LOQ) and limit of detection (LOD) of the Fe. The following formula (Shrivastava & Gupta, 2011) was used to determine the LOD and LOQ values. In this formula, X_b stands for the mean value of blank concentration and S_b for the standard deviation of blank concentration. Blank measurements were made a minimum of 20 times.

$$LOD = X_b + 3\ S_b$$

$$LOQ = X_b + 10\ S_b$$

2.2.8 Kinetic models for the chemical and colour characteristics of cooking waters and wheat

In order to plan and control the cooking conditions, it is important to determine the order of reactions and their rate constants of the chemical and colour attributes of the cooking water and wheat. The mechanisms underlying the changes in attributes over time are displayed by reaction kinetic parameters, such as reaction order and rate. For the variations in food qualities, the generalized model provided in Equation (1) can be applied. The parameters of the Equation Model are P, the studied feature of food; t, time (s); k, rate constant and lastly n, the order of the reaction (Kumar et al., 2006; Lau et al., 2000; Yao et al., 2023).

$$\pm \frac{dP}{dt} = kP^n \quad (1)$$

Zeroth and first-order reactions are indicated to be the models that most effectively explain variations in food characteristics over time (Kumar et al., 2006). Since n is equal to zero for zero-order reactions, food properties change in direct proportion to time. For the zero-order model, Equation (1) may be rearranged by substituting n=0 and Equation (2) can be found as follows:

$$\pm \frac{dP}{dt} = k \quad (2)$$

Equation (3) can be obtained after integration,

$$P = P_0 \pm kt \quad (3)$$

Since n=1 for first-order processes, the food characteristic changes exponentially over time.

The first-order model can be constructed by rearranging Equation (1) by substituting n=1. This will yield Equation (4).

$$\pm \frac{dP}{dt} = kP \quad (4)$$

Equation (5) can be obtained by integration.

$$\text{In}\,\frac{P}{P_0} = \pm kt \quad (5)$$

The models previously described were compared and the reaction order was determined by selecting the model with the highest correlation coefficient constant (Lau et al., 2000).

2.2.9 Statistical evaluation

The findings of mineral analysis of cooking water samples were presented as the mean and standard deviation of at least four analysis results (two analyses of double production in each sample group, n = 2x2). Using the statistical program SPSS 25.0 (IBM Corp., New York, USA), significant differences at α = 0.05 level were determined using a one-way ANOVA and their levels were determined using Duncan's multiple-range tests. The software OriginPro 2024 (OriginLab Corporation, Northampton, MA) was used to display the graphs, calculate the regression coefficients (R^2) and determine the reaction order and rate (k).

2.3 Results and discussion

Production techniques are being researched in the bulgur industry in order to produce bright yellow bulgur. Even though the effects of wheat quality on bulgur have been extensively researched, little is known about the effects of pH, hardness and iron concentration of water that are thought to be particularly significant in bulgur quality. This research aims to fill this gap in the literature and the findings will help scientists and producers better understand the kinetics of changes that occur during cooking when studying bulgur and other grain products produced using comparable techniques.

2.3.1 Variation in the mineral composition of wheat cooking water during the cooking process

The bran layer of wheat contains the majority of the minerals, which include iron, zinc and calcium. As micro minerals, iron and zinc contribute to the structure of enzymes and aid in the regulation of numerous bodily processes, whilst calcium aids in the production of bone structure. Thus, in order to enhance the nutritional qualities of bulgur during production, it is preferred to keep these minerals within the grain structure. The differences in the iron, calcium and zinc concentrations of bulgur cooking water with different levels of acidity, hardness and iron content are shown in Table 2.1. Since there was no iron in the deionized water used to adjust the pH and hardness parameters, iron could not be detected in the water at 0^{th} min. Likewise, since no external iron was added to water containing 0 ppm iron, iron could not be detected in the water at 0^{th} min. In the adjustment of water containing 1 and 2 ppm iron, since the water sufficient for 2 repeated productions was adjusted at once, the averages were the same and no standard deviation occurred, since the same results were found in the analysis of the water samples (4 repetitions). In the waters where the pH parameter was adjusted, the standard deviation could not be determined since the initial Ca values (0.20 ± 0.00) of all waters were the same and the analysis results (absorbance) were all the same. Similarly, since zinc was not added externally to deionized water, the initial zinc values of all waters were found to be equal and therefore no standard deviation was detected between the results. Based on the results of the iron and calcium content analysis, it was found that acidity significantly ($P \leq 0.05$) influences the leaching of these two elements and that increasing the acidity of cooking water facilitates the transition of iron and calcium into the water. Ertaş and Türker (2014) suggest that an increase in acidity leads to the solubility of most minerals, which causes them to dissolve into water. Nevertheless, it has been found that zinc leaches water less slowly at neutral pH levels and dissolves much easier in water with increasing acidity and alkalinity. The iron concentration of cooking water was not significantly affected by water hardness ($P>0.05$). However, the transition of calcium and zinc from wheat to water is enhanced when cooking with soft water and the amount of calcium passed into water decreases proportionately with increasing water hardness. According to findings from past research, cooking with hard water increases the amount of minerals in food, which means fewer minerals are leaching into the water (Uzogara et al., 1992). The findings from the cooking water with different iron contents after the cooking process showed that the quantity of iron augmented in all samples when iron was passed to the water during cooking and that the amount of iron was proportionate to the initial amount of iron. Additionally, it was observed that the cooking water initially adjusted to 2 mg/L iron contained more calcium and zinc at the end of the cooking process.

2.3.2 Changes in the pH of cooking water throughout the cooking process

Figure 2.1 illustrates the pH values of wheat cooking water that have been corrected for variations in pH, hardness and iron content. With the exception of the cooking water, which has been set to pH 11, it is evident that, by the time cooking is complete, the pH of every other water approaches pH 6, which is close to the pH of wheat. The wheat utilised in the cooking process was found to have a pH of 6.32. As a consequence of the transfer of phenolic and phytic acids from wheat into the water, the results show that cooking water with a pH of 9 shows a steady decrease during cooking, whereas cooking water with a pH of 3 shows a steady increase during cooking (due to the migration of alkaline materials into the water, such as amino acids of wheat). In addition, during cooking, it is noted that the pH values of water with pH values 5, 7 and 11 vary.

Regarding the various hardness levels of the cooking waters, the pH increases during the first 10 min of cooking and subsequently decreases when using soft or very hard water. Though all cooking waters eventually approach the pH of the wheat, hard water cooking produces the reverse acidic balance between the water and the wheat. The results of measuring the pH of the cooking water with varying iron amounts show that, after cooking, the pH values of all the cooking waters converged towards the pH of wheat and that the amount of iron had no significant impact (P>0.05) on the pH values of the water. According to a prior study, wastes from cereal processing plants have a pH between 3.5 and 8.5; for these wastes to be released into the environment, their pH needs to be between 6 and 9 (Hassan et al., 2021). In this regard, it was found that the water obtained from the cooking process, which used water that had been adjusted to pH 3 and 11, as well as hard and very hard water, needed to be filtrated before it could be released back into the environment.

Table 2.1 Changes in mineral content of cooking water of wheat with different acidity, hardness and iron content during the cooking process

Parameter of cooking water	Levels of each parameter	Iron content (mg/L)		Calcium content (mg/L)		Zinc content (mg/L)	
		0^{th} min	End of cooking	0^{th} min	End of cooking	0^{th} min	End of cooking
pH	3	ND	2.28 ± 0.07a	0.20 ± 0.00a	46.02 ± 0.57a	0.02 ± 0.00a	15.40 ± 0.01a
	5	ND	1.00 ± 0.06b	0.20 ± 0.00a	29.43 ± 0.77b	0.02 ± 0.00a	8.36 ± 0.06c
	7	ND	0.97 ± 0.00b	0.20 ± 0.00a	27.03 ± 0.77c	0.02 ± 0.00a	4.83 ± 0.06e
	9	ND	0.77 ± 0.06c	0.20 ± 0.00a	19.71 ± 0.30d	0.02 ± 0.00a	5.65 ± 0.06d
	11	ND	0.23 ± 0.07d	0.20 ± 0.00a	16.72 ± 1.85e	0.02 ± 0.00a	10.48 ± 1.04b
Hardness	Soft	ND	1.03 ± 0.23A	31.76 ± 5.01C	61.48 ± 0.03B	0.02 ± 0.00A	7.58 ± 0.41A
	Hard	ND	1.03 ± 0.23A	49.55 ± 3.45B	61.48 ± 3.38B	0.02 ± 0.00A	5.81 ± 0.29B
	Very hard	ND	1.14 ± 0.02A	110.56 ± 1.36A	143.42 ± 1.20A	0.02 ± 0.00A	5.81 ± 0.29B
Iron content	0 ppm	ND	1.03 ± 0.02z	0.42 ± 0.03x	25.66 ± 1.15y	0.03 ± 0.00x	8.40 ± 0.13y
	1 ppm	1.03 ± 0.00y	1.71 ± 0.20y	0.35 ± 0.03x	26.85 ± 1.15y	0.03 ± 0.00x	8.46 ± 0.15y
	2 ppm	2.14 ± 0.00x	2.74 ± 0.26x	0.36 ± 0.02x	31.04 ± 0.60x	0.04 ± 0.01x	10.67 ± 0.13x

*Soft, hard and very hard: water hardness with ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively. ND: Not detected (Limit of detection: 0.0284 mg/L; Limit of quantification: 0.0399 mg/L for iron content).

a-d: Different small letters in the same column denote significant changes between the cooking water samples with different pH (α = 0.05 level).

A-D: Different upper case letters in the same column denote significant changes between the cooking water samples with different water hardness (α = 0.05 level).

x-z: Different letters in the same column denote significant changes between the cooking water samples with different water iron content (α = 0.05 level)

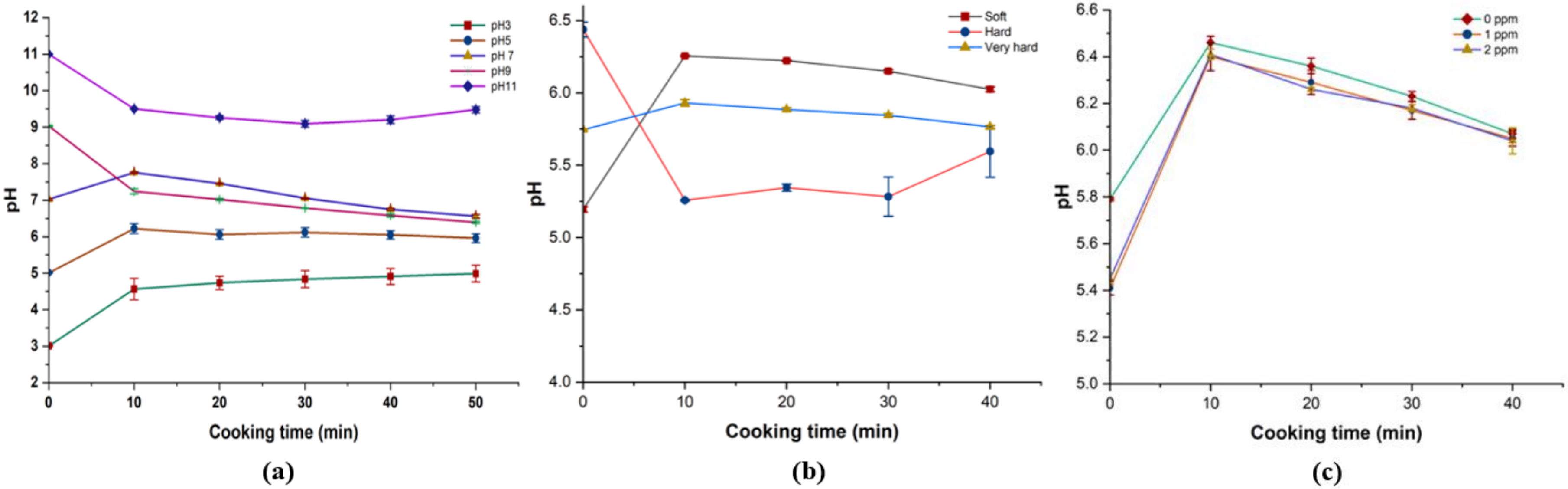

Figure 2.1 Alteration of pH of cooking water of wheat with different acidity (a), hardness (b) and iron content (c).

Soft, hard and very hard: cooking water with a calculated hardness of ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively. 0, 1 and 2 ppm: cooking water containing 0, 1 and 2 ppm of iron, respectively. pH results are given as the average of two independent experiments of twice produced samples ± standard deviation. Error bars display standard deviations.

2.3.3 Results of modelling the chemical and colour properties of cooking water

Analysis of the acidity, hardness and iron content of the wheat cooking water was done to determine the kinetics of chemical and colour changes. Prior research has demonstrated that when wheat grains are cooked, nutrients (protein, carbohydrates, minerals, vitamins, phytic acid and pigments) are transferred from the grains to the water (Balcı & Bayram, 2020). Based on the experimental results, zero-order kinetic model was fitted to determine the change in Brix, conductivity, hardness, turbidity and colour features (L* and b* values). Table 2.2 shows the predicted regression outcomes for these features. All examined characteristics of cooking waters with different properties could be sufficiently explained by the zero-order kinetic model. The transition of organic and inorganic compounds into the water during cooking raises the Brix value, suggesting that bacteria may use them and produce environmental problems (Balcı & Bayram, 2020). Nonetheless, the rate of this transfer varies depending on the acidity, hardness and iron content of the water. It was found that the rate at which soluble solids were transferred to water was pH 11>pH 3>pH 7>pH 9>pH 5. Because of a greater dissolve ability, it was found that the transfer occurred most quickly at the most alkaline pH. The water hardness-dependent variation in water soluble matter was examined and the results showed that the transfer rate was soft>very hard>hard. Cooking with hard water reduced the amount of soluble compounds that transferred to the water. The transfer of soluble compounds to water was enhanced by iron content up to 1 ppm, after which it was slowed down. This effect was dose-dependent.

Measurement of conductivity yields an estimate of the minerals and ionic compounds present because it describes the capacity of a solution to conduct electricity (Bayram et al., 2004c; Islam et al., 2020). Transitions of minerals and ions into water occur more quickly at pH 3 and pH 7 than those other pH's. The transition is also accelerated by very alkaline (pH 11) boiling water, although it decelerates at pH 5 and pH 9. When the effect of water hardness on the conductivity reaction rate was studied, soft and very hard water demonstrated a faster transition than hard water. There is a direct correlation between the impact on Brix and the conductivity rate caused by the iron content in water. In general, the presence of calcium and magnesium ions in water is linked to its hardness. In comparison to waters adjusted to various pH values, the rate of hardness in very acidic waters (pH 3) was around 2-3 times faster. Most alkaline water (pH 11) had the lowest hardness rate, although water adjusted to pH 5, 7 and 9 were shown to generate similar effects. The samples analysed to assess the influence of water hardness showed dose-dependent variations in the hardness rate, which led to the conclusion that very hard>soft>hard. The rise in iron concentration in the water was inversely correlated with the hardness reaction.

The amount of colloidal materials that seep into water, such as proteins, carbohydrates and other compounds, is measured as turbidity. The study examined the correlation between turbidity and the pH of cooking water and found that, at pH > 7, the rate of reaction increased continuously, while there was no change observed between pH 3 and 5. Notably, the reaction rate of turbidity varies inversely with water hardness; yet, iron-containing water has been observed to have a higher reaction rate than iron-free water. According to Lachman et al. (2017), the colour ingredients of wheat are flavonoids and anthocyanins, which are present in the bran and give the grain its blue, purple and red colour and carotenoids, which are nonpolar and water-insoluble molecules that give the endosperm its yellow colour. Tracking colour during the cooking process may shed light on the total quantity of vitamins and water-soluble colour compounds that have been released into the cooking water of wheat (Bayram et al., 2004c). Previous research has demonstrated that food colour can be affected by pH and mineral concentration, particularly divalent cations like Ca and Fe, which can change the solubility or form complexation (Enaru et al., 2021; Ertaş & Türker, 2014). The correlation between the pH of water and the L* value reaction rate demonstrated that, within the pH range of 3 to 9, the reaction rate was precisely proportional to pH and that, at pH 11, the reaction slowed down significantly (Table 2.3). Furthermore, moderate correlation values ($0.5<R^2<0.69$) (Mukaka, 2012) were found for soft and hard water and 1 ppm iron-containing water and water having pH 11. Nevertheless, the zero-order was the best-fitting kinetic model for the L* value. Reaction rates were found to be similar in the pH range of 3 to 9, but lower at pH 11, when the impact of water pH on the rate of change of b* value was investigated. The results additionally demonstrated an inverse relationship between the water hardness and the rate of change of the L* and b* values. Finally, the rate at which the L* and b* values vary is influenced by the iron concentration of the water.

Table 2.2 Chemical kinetic parameters of cooking water of wheat with various acidity, hardness and iron content

Parameter of cooking water	Levels of each parameter	Brix (g/100g)			Conductivity (µS/cm)			Hardness (mg/L of $CaCO_3$)			Turbidity (Abs)		
		RO	k	R^2	RO	k	R^2	RO	k	R^2	RO	k	R^2
pH	3	Zero	0.0386	0.9470	Zero	56.3950	0.9700	Zero	10.3518	0.9148	Zero	0.0115	0.9587
	5	Zero	0.0312	0.9380	Zero	51.5804	0.9648	Zero	4.7536	0.9493	Zero	0.0113	0.9921
	7	Zero	0.0365	0.9507	Zero	56.3693	0.9596	Zero	5.4701	0.9635	Zero	0.0197	0.9745
	9	Zero	0.0328	0.9518	Zero	52.7579	0.9684	Zero	4.5190	0.9502	Zero	0.0203	0.9817
	11	Zero	0.0396	0.9374	Zero	54.1070	0.9552	Zero	3.2789	0.9380	Zero	0.0215	0.9499
Hardness	Soft	Zero	0.0439	0.9449	Zero	74.2189	0.9752	Zero	5.7191	0.9818	Zero	0.0214	0.9967
	Hard	Zero	0.0360	0.9720	Zero	64.7925	0.9886	Zero	3.8700	0.9865	Zero	0.0177	0.9988
	Very hard	Zero	0.0388	0.9590	Zero	76.4225	0.9800	Zero	6.2531	0.9858	Zero	0.0145	0.9587
Iron content	0 ppm	Zero	0.0370	0.9474	Zero	61.6880	0.9691	Zero	7.0413	0.9716	Zero	0.0204	0.9910
	1 ppm	Zero	0.0460	0.9389	Zero	73.2143	0.9686	Zero	6.5038	0.9624	Zero	0.0234	0.9941
	2 ppm	Zero	0.0437	0.9318	Zero	69.0428	0.9654	Zero	6.3869	0.9460	Zero	0.0232	0.9915

Soft, hard and very hard: cooking water with a calculated hardness of ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively.

RO: Reaction order. k: reaction rate constant.

Table 2.3 Colour kinetic parameters of cooking water of wheat with various acidity, hardness and iron content

Parameter of cooking water	Levels of each parameter	L*			b*		
		RO	k	R^2	RO	k	R^2
pH	3	Zero	0.2098	0.9128	Zero	0.1912	0.9838
	5	Zero	0.2156	0.8403	Zero	0.1876	0.9897
	7	Zero	0.2986	0.9249	Zero	0.2072	0.9306
	9	Zero	0.3226	0.9197	Zero	0.1932	0.9033
	11	Zero	0.0670	0.6687	Zero	0.1453	0.7110
Hardness	Soft	Zero	0.2487	0.6449	Zero	0.2358	0.9864
	Hard	Zero	0.1978	0.6777	Zero	0.2315	0.9731
	Very hard	Zero	0.1667	0.8762	Zero	0.2017	0.9629
Iron content	0 ppm	Zero	0.2863	0.7580	Zero	0.2405	0.9493
	1 ppm	Zero	0.2693	0.6714	Zero	0.2458	0.9802
	2 ppm	Zero	0.2942	0.7616	Zero	0.2314	0.9606

Soft, hard and very hard: cooking water with a calculated hardness of ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively. RO: Reaction order. k: reaction rate constant.

2.3.4 Modelling the degree of gelatinization of wheat

Gelatinization increased with time and the reaction kinetics followed a zero-order reaction, according to an analysis of the degree of gelatinization of wheat cooked in water with different acidity, hardness and iron concentrations (Table 2.4). Depending on the pH, the gelatinization reaction was accelerated when cooking with neutral or very alkaline (pH 11) water. In contrast to the results, a prior study (Simonin et al., 2011) discovered that the gelatinization rate of waxy maize and rice starch increased as pH declined, but the gelatinization properties differed based on the starch source (Chakraborty et al., 2022). The inverse relationship between water hardness and gelatinization rate means that cooking in soft water accelerates the process and reduces cooking time, which is consistent with previous studies (Uzogara et al., 1992). Wheat cooked in soft, hard and very hard water took 45, 47 and 49 min to cook, respectively. It was discovered, interestingly, that cooking in water containing iron accelerated the rate of gelatinization. This could be connected to the iron and starch complex that forms, which could speed up the gelatinization process (Somsook et al., 2005).

Table 2.4 The kinetics of gelatinization parameters of wheat cooked in various waters

Parameter of cooking water	Levels of each parameter	Order of reaction	k	R^2
pH	3	Zero	1.9310	0.9612
	5	Zero	1.9292	0.9741
	7	Zero	1.9802	0.9288
	9	Zero	1.9373	0.9691
	11	Zero	2.0124	0.9735
Hardness	Soft	Zero	2.3925	0.9493
	Hard	Zero	2.2566	0.9460
	Very hard	Zero	2.2293	0.9475
Iron content	0 ppm	Zero	2.2966	0.9415
	1 ppm	Zero	2.4397	0.9489
	2 ppm	Zero	2.4178	0.9590

Soft, hard and very hard: cooking water with a calculated hardness of ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively. 0, 1 and 2 ppm: cooking water containing 0, 1 and 2 ppm of iron, respectively. k: reaction rate constant.

2.3.5 Alterations of the colour of wheat during cooking operation

Bright-coloured bulgur is chosen by consumers, as colour is the main factor influencing bulgur quality. Therefore, colour is important to consumers. Accordingly, studies are being conducted to determine and regulate the factors affecting bulgur colour in order to get the required colour. Cooking causes the Maillard reaction, colour pigments to dissolve in water and heat-induced denaturation to cause wheat grains to turn darker (Enaru et al., 2021; İbanoğlu, 2002). It is necessary to model the colour kinetics in order to get the system kinetics for process design. The collected colour kinetic characteristics can be used to forecast and regulate colour quality during cooking. Kinetic models, nevertheless, are useful for tracking the colour change of wheat-cooked water; yet, because of the low R^2 values of the colour change of cooked wheat found in zero-order and first-order models, using these models is not appropriate. Consequently, Figures 2.2, 2.3 and 2.4 show the variations in the colour values of the cooked wheat as influenced by the pH, hardness and iron concentration of the cooking water throughout cooking.

2.3.5.1 The relationship between pH and colour changes in wheat during cooking

Within the first 10 min of cooking, there were the most alterations in L*, b* and YI measures. Depending on the pH and chemical transitions between the cooking water and the wheat, the colour values fluctuate throughout the cooking process. The preferred colour of bulgur might be achieved by cooking with water adjusted to pH 3, as confirmed by the high L* and b* readings at the end of cooking. Conversely, the colour of wheat cooked in water at pH 11 darkened towards the end of cooking, with low L* and a* and high YI. Consequently, the colour of the bulgur was adversely affected by cooking in excessively alkaline water (pH 11). This might have to do with improving the solubility and extractability of colour components, as well as variations in anthocyanins based on pH (Enaru et al., 2021; Lee et al., 2018).

2.3.5.2 Changes in the colour values of wheat cooked in water with different levels of hardness

The kinetics of wheat colour change are affected discretely by different amounts of water hardness during cooking. The L*, b* and YI values of all samples increased, but a* values decreased in the first 10 min. In line with earlier research, the sample cooked in very hard water had an increase in L* value (Uzogara et al., 1992), but at the end of cooking, its b* value was lower than that of the other samples. The interaction of calcium ions with anthocyanins to generate a blue colour can be used to explain the reason for this alteration (Enaru et al., 2021). Wheat colour was affected similarly by other samples, except those that were cooked in very hard water. Thus, when making bulgur, it is best to avoid cooking wheat in very hard water.

2.3.5.3 Colour changes in wheat cooked with water having different iron contents

Similar to the impact of water hardness, the L*, b* and YI values increased during the first 10 min of cooking. As anticipated, during the cooking process, the a* values of wheat cooked in water containing iron were higher than those of wheat cooked without iron. Because the samples with iron had higher a* and YI values and lower L* values than the samples without iron, it was determined at the end of cooking that the iron-containing samples had an undesired influence on bulgur colour.

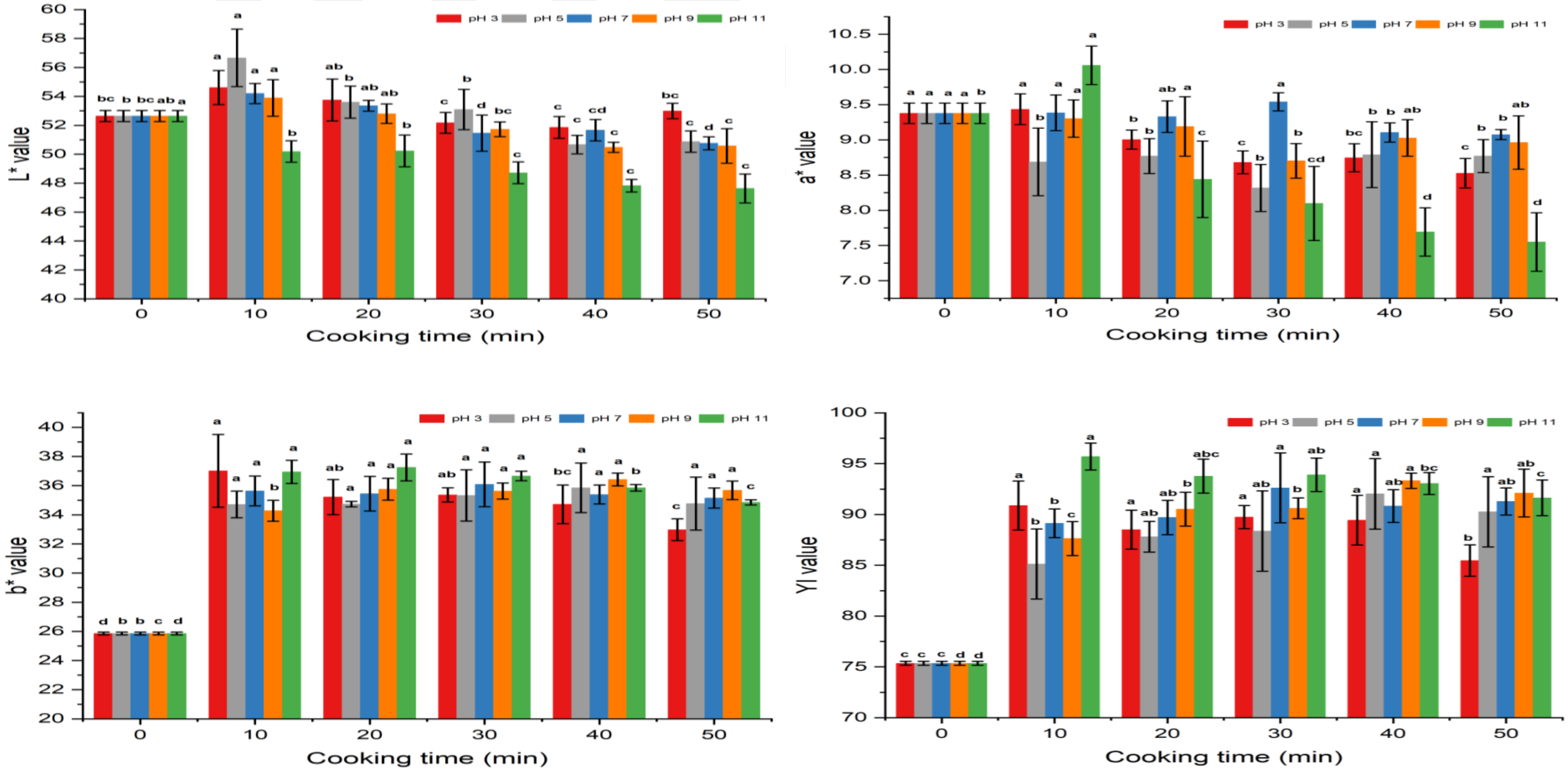

Figure 2.2 Colour values (L*, a*, b* and YI) of wheat samples during cooking with water varying in acidities.

The results are stated as the average of two independent experiments of twice-produced samples ± standard deviation. Mean values with different letters show the significant differences between the values in the wheat samples cooked with the same water over time (α = 0.05).

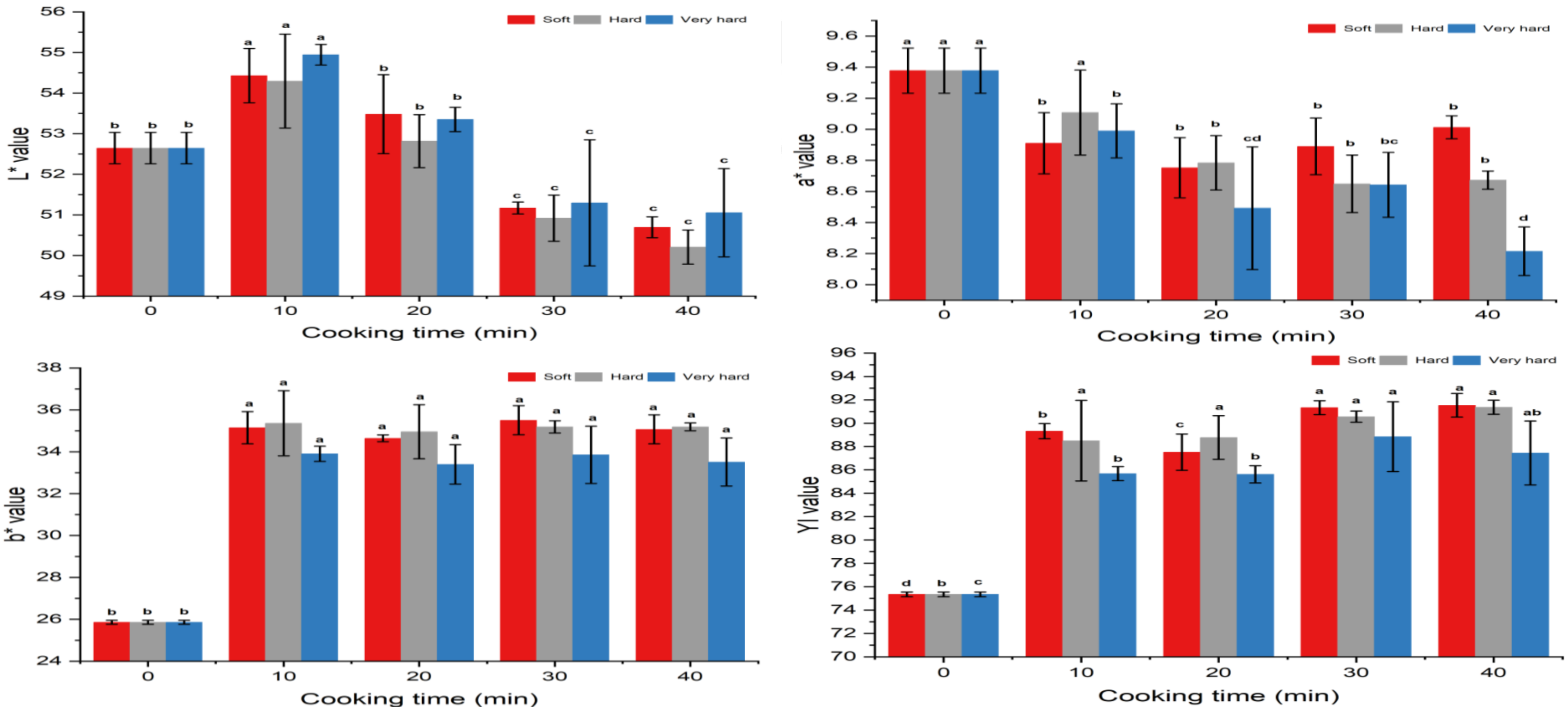

Figure 2.3 Colour values (L*, a*, b* and YI) of wheat samples during cooking with water varying in hardness values.

Soft, hard and very hard: cooking water with a calculated hardness of ~53 mg/L of $CaCO_3$, 129 mg/L of $CaCO_3$ and ~269 mg/L of $CaCO_3$, respectively. The results are stated as the average of two independent experiments of twice-produced samples ± standard deviation. Mean values with different letters show the significant differences between the values in the wheat samples cooked with the same water over time ($\alpha = 0.05$).

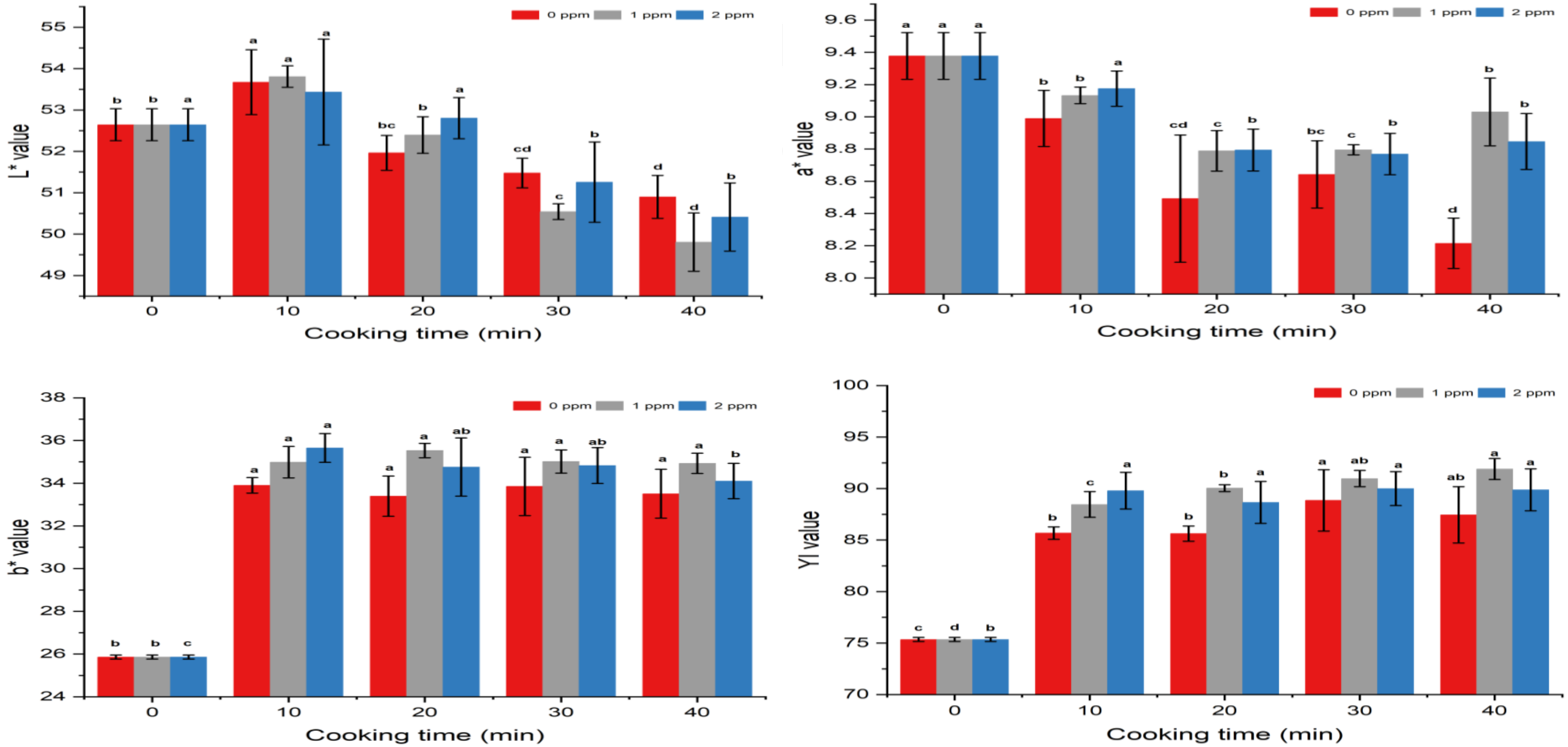

Figure 2.4 Colour values (L*, a*, b* and YI) of wheat samples during cooking with water differing in iron values.

0, 1 and 2 ppm: cooking water containing 0, 1 and 2 ppm of iron, respectively. The results are stated as the average of two independent experiments of twice-produced samples ± standard deviation. Mean values with different letters show the significant differences between the values in the wheat samples cooked with the same water over time ($\alpha = 0.05$).

2.4 Conclusions

According to the findings of this study, wheat can be improved in colour and the chemical properties of excess water after cooking can be controlled by adjusting the acidity, hardness and iron level of the cooking water. The colour of the wheat improved when cooked in extremely acidic water (pH 3), but the colour turned green when cooked in extremely alkaline water (pH 11), which is not acceptable for bulgur. Furthermore, the wastewater created by cooking with extremely alkaline and acidic water is more hazardous to the environment since it allows more chemicals to transfer to the cooking water. The rate at which substances transferred to water was accelerated while using soft water for cooking and the colour of the cooked wheat was better than when using harder water. In addition, cooking wheat in hard water lengthens the cooking time and slows down the rate of gelatinization. Thus, the amount of energy needed for cooking increases along with the hardness of the water. Cooking with water that was high in iron had a negative effect on colour because it increased the redness value of wheat. The findings of this study will be helpful for researching the impact of water qualities on grain products that are processed using comparable methods, enhancing their production and researching the valorisation of wastewater.

CHAPTER 3
THE EFFECT OF WATER pH AND PROCESSING ON THE QUALITY PROPERTIES OF BULGUR

Summary

The impact of cooking water acidity on multiple bulgur quality parameters is examined in this study. Specifically, the effects of a range of analyses (pH, proximate composition, bioactive properties, mineral content, colour parameters, thermal, structural and textural characteristics) on wheat and bulgur samples prepared using cooking waters within the pH interval of 3 and 11 were assessed. While the influence on proximate composition was inconsistent, cooking with high alkaline water (pH 11) improved bioactive characteristics. Due to the separation of bran during the debranning operation, the amount of starch in the dry matter increased in all samples, despite the starch being the most essential component of the wheat grain decreasing when it was transferred to water during cooking. The mineral levels of bulgur samples were lower than those of wheat after the debranning and milling operations, with the exception of Na. Following debranning and milling, the amount of Ca and Mn in bulgur samples reduced inversely with increasing pH. When compared to wheat, the bulgur manufacturing procedure increased L* and b* values while decreasing a* and YI values in all sample groups (L*: 52.64, a*: 9.38, b*: 25.85 and YI: 75.51) due to debranning. The textural properties of bulgur appeared to be unaffected by the pH level of cooking waters. Darkening problems and a negative colour impact were induced by production using cooking water with a pH of 11. The findings of the study are helpful for future research on parboiling cereals and enhancing the quality of bulgur in the marketplace.

3.1 Introduction

Consuming cereals and their products has been advised for a balanced and health-promoting diet since the time of Hippocrates. The protein, carbohydrate, dietary fibre, minerals, B vitamins, phenolic content and antioxidant properties of wheat and whole wheat products make them essential cereals for human nutrition (Solah et al., 2015). To make them easier to cook and digest and more pleasant for customers, processing is necessary before consumption (Narwal et al., 2020). Bulgur is a more palatable and easily prepared form of wheat that can be cooked into a semi-ready or ready-to-eat meal by following a few simple steps: cleaning, cooking, drying, debranning, milling and optional polishing and categorization. Although a variety of wheat species can be used to manufacture bulgur, Durum wheat (*Triticum durum*) is the variety most often used because of its high carotenoid content, superior yellow colour, high protein content and hard texture after processing (Bayram & Öner, 2006; Lachman et al., 2017; Solah et al., 2015).

Bulgur was formerly mostly consumed as an ethnic food in the Middle East, North Africa, the Balkans and Türkiye. However, due to its widespread use in a variety of dishes (such as entrees, breads, soups, salads, meats, cakes, cookies, puddings and desserts), quick cooking time and ability to be used as a meat substitute in vegetarian dishes, it has recently gained attention in Europe, the United States, Australia and other countries (Deethardt, 1976; Giambanelli et al., 2020; Narwal et al., 2020; Singh & Dodda, 1979). The cooking and debranning processes that follow drying are the ones that have the biggest effects on the quality of bulgur. As a result of the grain absorbing water, the starch expands and eventually gelatinizes during cooking. Since most minerals and phenolic compounds are found in the bran portion of wheat, debranning results in their loss even though it helps produce the bright yellow colour that consumers want (Caba et al., 2012; Ciudad-Mulero et al., 2021; Fares et al., 2010; Savas & Basman, 2016).

The second-most important ingredient in the majority of foods is water which, in terms of quantity and chemical properties, is the principal one. In the food industry, water is utilised to alter many food properties during production and processing (Brandt et al., 1984; Kasaai, 2014; Nawaz et al., 2018). This means that the quality of the water used, particularly during cooking, matters greatly to the final quality of the products. Although tap water is widely used for food production and all other purposes, its chemical composition (pH and minerals) varies depending on the location and time of year. Thereby, to produce higher-quality products, the chemical characteristics of the water source may need to be controlled even if it satisfies the microbiological safety requirements (Sinani et al., 2014; Tiefenbacher, 2017). The most notable characteristic of food treated with water during manufacture is the pH of the water. In addition to structural and organoleptic properties, the pH of the water used in manufacturing can change the properties of proteins as well as the solubility of colourants and minerals (Ertaş & Türker, 2012; Navarini & Rivetti, 2010; Sozer & Kaya, 2008).

Scientific research on bulgur has significantly increased recently, coinciding with the rise in its acceptance worldwide (Dueck et al., 2020; Giambanelli et al., 2020; Narwal et al., 2020). Though many studies have been done on bulgur raw materials, the majority of them focus on altering the type of wheat or producing bulgur from various grains and legumes, ignoring the impact of the cooking water (Evlice & Özkaya, 2020; Giambanelli et al., 2020; Yılmaz & Koca, 2020). Wheat and cooking water are the primary constituents in bulgur (Singh & Dodda, 1979). Water has garnered attention lately due to its effect on food quality when utilised as an ingredient in preparation and processing (Wellinger et al., 2017). There is no research in the literature examining the effects of the pH value of cooking water on bulgur quality, even though the pH value of water has a well-known effect on food quality. Therefore, the impact of the pH value of cooking water on the quality parameters of bulgur throughout cooking and the drying, debranning and milling processes was examined in this study.

3.2 Materials and methods

3.2.1 Chemicals

The following materials were acquired from Sigma Co. (St. Louis, MO, USA): sulfuric acid, hydrochloric acid (HCl), tungstophosphoric acid hydrate, hexane, copper sulphate, pH 4, 7 and 10 solutions, calcium (Ca) and iron (Fe) standard solutions for Atomic Absorption Spectroscopy (AAS), methanol and DPPH (2,2-diphenyl-1-picrylhydrazyl) radical and Folin-Ciocalteu's reagent. On the other hand, potassium sulphate was bought from Tekkim Co. (Bursa, Türkiye) and zinc, manganese (Mn) and sodium (Na) standard solutions for AAS were purchased from Perkin Elmer. (PerkinElmer Inc., USA). A MilliQ Advantage A 10 water purification system from Millipore provided deionized water, which was used for cooking and conducting tests (Molsheim, France).

3.2.2 Preparation of bulgur samples and experimental design

Wheat (*Triticum durum* cv. Güneyyıldızı) was obtained from Tiryaki Agro Food Co., Gaziantep, Türkiye. Citric acid (E330) and food-grade sodium carbonate (Na_2CO_3) were purchased from Kimbiotek Kimyevi Mad. San. ve Tic. Co. (İstanbul/Türkiye). Both dry and wet washing techniques were used to remove extraneous contaminants from wheat prior to bulgur manufacturing. Wheat was cooked using deionized water (ER<18.2 MΩ) that had its pH adjusted to the pre-determined levels using solutions of 1 and 10% (w/v) citric acid and 1 and 5% Na_2CO_3 (w/v). The wheat was cooked in a pot over low heat until the starch in it fully gelatinized after water was brought to a boil and wheat was added (wheat to water: 1/1.8). The samples were cooked and then taken for analysis (pH, proximate composition (dry matter, ash, protein, fat and starch), phenolic compounds, antioxidant capacity, mineral content (Fe, Zn, Mn, Ca and Na), colour properties (L*, a*, b* and YI) and textural features (hardness, springiness, cohesiveness, gumminess, chewiness and resilience). These samples were then stored in plastic sample vessels at -18 °C until the analyses were performed. After that, the cooked wheat was allowed to cool before being dried at a constant temperature of 70 °C for about 12% (w.b.) of moisture content in a packed bed drier (MK II, Sherwood Scientific, England) at an airflow rate of 2.3 m/s. After that, the samples were submerged in water to a moisture content of about 17% (w.b.) and left for 25 min. A debranner (Merba Makine, Türkiye) was used to separate the bran from the kernel. The disc mill (Tekpa Laboratory Systems, Ankara, Türkiye) was used for the bulgur milling process. Ultimately, the samples were sorted through the usage of sieves and samples with sizes of 0.5 and 2 mm were utilised for additional analyses. Until they were examined, the samples were kept in plastic containers in the fridge. Along with the tests that were supposed to be carried out on wheat samples following cooking, these samples also underwent DSC, FTIR and sensory assessments. For every pH treatment, the manufacturing of samples was duplicated and the analyses were carried out at least two times independently on each production.

Before being subjected to assays for pH, proximate analysis, total phenolic compounds, antioxidant capacity and mineral content, the samples that were obtained after cooking were ground in a grinder (Bosch, TSM6A014R, Germany). The mill employed for milling was utilised to reduce the size of the wheat and fine bulgur samples. Furthermore, to prepare the samples of fine bulgur and wheat for Fourier transform infrared spectroscopy (FTIR) and differential scanning calorimeter (DSC) examinations, they were ground into flour size (~200 µm) in a mortar.

3.2.3 Methods for chemical content and colour parameters

Wheat, cooked wheat and fine bulgur samples were dried for 4 h at 105°C to determine the total dry matter content of the samples. The samples were ashed at 550°C until white ash at a consistent weight was formed to determine the ash content of wheat and fine bulgur samples. A colourimeter (HunterLab ColorFlex, Model EZ 45-2, Reston, VA, USA) calibrated with black and white tiles prior to measurements was used to obtain the colour values (L*, a*, b* and YI). Protein content analysis was carried out by multiplying the quantity of nitrogen obtained by the Kjeldahl method (using sulfuric acid, hexane, copper sulphate and potassium sulphate for digestion) by a factor (5.7) for cereals using Kjeltec 2200 (Foss, Denmark). With the use of hexane extraction, the fat content of the samples was calculated using the Soxtherm 416 and Manager v2.2 software (Gerhardt, Germany). A polar 3000 model polarimeter (Optical Activity Ltd., England) was used to measure the starch concentration by Ewer's protocol, which involved the use of HCl and tungstophosphoric acid hydrate solutions. The following formula was used to get the starch proportion (Elgün & Certel 1987):

$$\% \text{ Starch (d.b., g/g)} = \frac{V_{TS} \times \alpha_p}{A_D^{20} \times L_p \times W_s} \times 100$$

where V_{TS}, α_p, A_D^{20}, L_p and W_s stands for total sample volume (mL), polarization value, the conversion factor for Ewer’s starch method [182.7/(dm x g/mL)], length of polarization tube in decimetre (dm) and dry matter amount (g) of the sample, respectively. After mixing 25 g of sample with 200 mL of deionized water, a digital pH metre (AZ 86505, AZ Instrument Corporation, Taiwan) was used to measure the pH at 25 °C. The pH metre was calibrated using standard solutions with pH values of 4, 7 and 10 prior to any measurements.

3.2.4 Assessment of functional traits

3.2.4.1 Extraction of phenolic substances

The methodology of Caba et al. (2012) was followed in order to extract the phenolic compounds from the samples. Briefly, 40 mL of 80% (v/v) methanol with 1% (v/v) HCl was added to 4 g of sample and the mixture was then shaken at 25 °C for 2 h at

200 rpm in an orbital shaker (Innova 40R, New Brunswick Scientific, USA). The slurry was transferred into a different flask after centrifugation (Eppendorf Centrifuge 5810 R, Germany) at 2040 × *g* for 15 min. The process was rerun with the residue and prior to the analyses, the extracts were combined and filtered (Whatman No. 42).

3.2.4.2 Quantification of phenolic compounds

The modified Folin-Ciocalteu technique assay developed by Caba et al. (2012) was used to assess the total concentration of phenolic compounds in the samples. An aliquot (125 µL) of the sample extract was combined with 0.5 mL deionized water and 125 µL of Folin-Ciocalteu's reagent (diluted 1:10 with water). Following a 6-minute incubation period, 1.25 mL of Na_2CO_3 (75 g/L) and 1 mL of deionized water were added to the mixture and it was then allowed to stand for 90 min at 25 °C in the dark. The results were represented as gallic acid equivalents (mg GAE/kg sample) and the absorbance was measured at 760 nm in the spectrophotometer (Pharmacia Biotech Novaspec II, Cambridge, England).

3.2.4.3 Evaluation of antioxidant activity

The free radical scavenging activity of the samples was assessed using a modified version of the approach used by Brand-Williams et al. (1995). The sample extract (150 µL) was mixed with 2850 mL of daily prepared DPPH solution (60 µmol/L, dissolved in methanol). The absorbance readings were done at 515 nm using methanol as a blank after the sample was left in the dark for 30 min at 25 °C. Methanol was substituted for the extract in order to prepare the control solution. For the determination of the inhibitory capacity, the formula shown below was utilised. The absorbance values for control and sample are denoted by the terms $Abs_{control}$ and Abs_{sample}.

$$\% \text{ Inhibition} = \frac{Abs_{control} - Abs_{sample}}{Abs_{control}} \text{ x } 100$$

3.2.5 Analysis of mineral content

The samples (wheat, cooked wheat and fine bulgur) were prepared for mineral analysis using the dry ashing method at 550 ºC in a furnace. After dissolving the ash in 10 mL of 3 N HCl, the mixture was filtered through a 0.45 µm membrane filter and diluted to a volume of 100 mL using deionized water. By modifying the parameters particular to each element, the mineral composition was ascertained using an atomic absorption spectrophotometer equipped with a flame atomizer unit (Perkin Elmer AAnalyst 800, Shelton, USA). An external calibration graph drawn with a minimum of five standards for each mineral served as the basis for the quantification. The flame source was a combination of air (17 L/min) and acetylene (2 L/min). The minerals that were analysed were quantified at the following wavelengths: Fe, 248.3 nm; Zn, 213.9 nm; Mn, 279.5 nm; Ca, 422.7 nm; and Na, 589.0 nm.

3.2.6 Method for determination of textural properties

The slightly modified approach published by Li et al. (2016) was used to assess the textural features of wheat, cooked wheat and uncooked fine bulgur samples. For measurements and computations, a TA.XT2i-Plus Texture Analyser (Stable Micro System Ltd., Surrey, UK) with a 36 mm cylindrical aluminium probe was used. A compression test with two cycles was used to examine the samples. The pre-test speed was set at 2 mm/s, while the test and post-test speeds were set at 0.5 mm/s, with a strain of 80% and a trigger force of 5 g. Test curves led to the recording of factors related to hardness, springiness, cohesiveness, gumminess, chewiness and resilience.

3.2.7 Acquisition of Mid-Infrared (FTIR) spectra

FTIR spectroscopy was used to detect the structural changes within the product during the processing. With a universal Attenuated Total Reflectance (ATR) sampling accessory attached, the Perkin Elmer Spectrum 100 FTIR spectrometer (PerkinElmer Inc., Waltham, MA, USA) was used to obtain the transmittance spectra of wheat and fine bulgur samples. By obtaining 4 scans using the Spectrum 10 STD program (PerkinElmer Inc., Waltham, MA, USA), the spectra were obtained at a resolution of 4 cm^{-1} in the range and 4000-650 cm^{-1}. Before observations, the background spectrum of air was obtained. Samples were detected by placing the powdered sample on the ATR machine and measuring the spectra. Two analyses were performed on each sample replicate.

3.2.8 Determination of thermal properties by Differential Scanning Calorimeter

In order to examine the changes in starch, a differential scanning calorimeter (DSC) (Perkin Elmer, Pyris 6 DSC, Netherlands) with an intercooler was used as indicated in the procedure of Savas & Basman (2016). The samples of fine bulgur and wheat were subjected to the DSC examination. Samples that were powdered were weighed and placed into hermetic aluminium pans with a sample-to-water ratio of 1:3. The tightly sealed pans were refrigerated overnight. Using a heating rate of 10 °C per min, pans were heated from 20 to 100 °C to complete the scanning. The purge gas was nitrogen at a flow rate of 20 mL/min.

3.2.9 Sensory evaluation

The sensory properties of bulgur samples (uncooked (raw) and cooked bulgur (pilaf)) were performed by 12 trained panellists for those familiar with eating bulgur and those not. The appraisals of the samples were actualized by 3 Africans (Botswana, via Erasmus + program), 1 Tunisian (via Erasmus + program), 1 Iraqi and 7 Turkish panellists, all of whom were between the ages of 26 and 56. The panellists received training on the qualities of bulgur and the scoring system prior to the evaluation. The uncooked bulgur samples were rated based on odour, yellowness and overall acceptability; the cooked bulgur samples were scored based on odour, taste, yellowness, texture and overall acceptability using a 9-point (1-dislike extremely, 9-like extremely) hedonic scale. Bulgur samples were boiled in water (1:2, w/v) and following complete absorption of the water, allowed to cool to room temperature. A 5-g sample was placed on a plate with a 3-digit code that was assigned at random. All samples were assessed twice by the panellists. White light was used to illuminate individual cabinets during inspections. Water was given to the assessors so they could wash their mouths before rating each sample. On two distinct sessions of the same day, the assessors were given duplicate sample preparations. This study was approved by the Research Ethics Committee of Gaziantep University (File number: 424187).

3.2.10 Statistical assessment

The mean values of at least four measurements, along with standard deviations, were provided as the experiment results. The evaluation was realized using SPSS 25.0 (IBM Corp., New York, USA) software. The results of the analyses were all put through a one-way ANOVA test to identify changes at a significance level of 5% in the mineral content, colour values, textural parameters and sensory scores as a function of processing and pH level. Duncan's multiple range test was then used to determine the significant differences among the findings.

3.3 Results and discussion

The bulgur industry uses various pH levels of the cooking water to produce products with a firm texture and yellow colour. As such, producers can benefit from the results of this study about the impact of pH in boiling water. In order to determine their effects on the various quality features, bulgur was produced using the pH range that might be suitable and employed in the bulgur plants, which is 3 to 11.

3.3.1 pH and proximate composition

Since pH 6–7 is generally considered to be the ideal pH range for growing wheat, the pH value of wheat likewise fluctuates within this range (Dhillon et al., 2020; Vitosh, 1994). The wheat (Table 3.1) used in the study to produce bulgur had a pH of 6.32, which was in line with data published in previous research (Rasheed et al., 2023). In the final product, the bulgur samples cooked in acidic and alkaline waters had pH values less than 6, whereas the bulgur sample cooked in neutral pH water had a pH value comparable to wheat. Following the stages of drying and debranning, the wheat sample cooked in the most alkaline water had the highest pH value, with values roughly falling between 6 and 7. This investigation showed that the pH values of cooked wheat and dried, debranned and milled wheat (bulgur) are significantly ($P \leq 0.05$) impacted by the pH of the cooking water. Even though wheat has a fairly high dry matter content, cooking has caused the grains to absorb water into their structure, bringing the moisture level down to about 50%. The products became safe and the moisture content was once again decreased following the drying process. It is also important to note that the pH of cooking water affects the ability of the grain to absorb water before cooking ($P \leq 0.05$). Since moisture content is the primary determinant of the microbiological safety of grains and whole grain products, moisture levels between 14 and 16 % are considered to be safe ranges for these products (Rasheed et al., 2023).

Regarding the ash content, it was found that after cooking, the ash content of the samples made with alkaline cooking water diminished while the ash content of the samples made with acidic and neutral cooking water ascended. Conversely, following drying and debranning, the amount of ash in bulgur samples decreased dramatically in comparison to wheat, except for bulgur which was produced at neutral pH. According to conformable findings by Savas & Basman (2016), debranning resulted in a significant (P≤0.05) decrease in the ash content of all samples except for those prepared with cooking water at neutral pH. The protein content of wheat is crucial for the nutritional value and textural integrity of bulgur. A greater quantity of nitrogenous matter enables the starch to combine with the proteins to create a more robust structure (Bayram & Öner, 2006; Koca & Anıl, 1996). Previous studies have indicated that the protein content of wheat varies throughout cultivars and ranges from 10.68 to 15.2% (d.b.) (Koca & Anıl, 1996; Rasheed et al., 2023; Savas & Basman, 2016). The protein content of wheat is higher than that of cooked wheat and bulgur samples. Additionally, the results showed that the cooking waters at pH 5 and 11 improved the ability of the product to retain protein following cooking, drying and bran separation (Table 3.1). This study was significant because it showed that the pH of the cooking water could be adjusted to control hard texture and the amount of protein retained.

According to earlier research (Koca & Anıl, 1996; Rasheed et al., 2023), the fat content of different wheat types was found to vary between 1.5% and 3.0% (d.b.) based on the cultivar and type of wheat. Ertaş & Türker (2012) observed that there was no statistically significant difference in the fat content of the soaked products when bulgur made from common beans was soaked in water with varying pH levels. Similarly, the results of this investigation demonstrated that, despite variations in the fat level of bulgur samples during cooking, the total fat content stayed statistically indifferent (P>0.05). Regardless of the pH of the water used for cooking, the amount of fat decreased in all samples following the drying and debranning processes. The most important component of wheat, starch is found in the endosperm and plays a vital role in the manufacture of bulgur. Starch is one of the most important sources of energy in food produced worldwide. The starch in bulgur expands and turns gelatinous throughout the production process by absorbing water, which facilitates easier cooking and digestion as well as the development of the characteristic properties of the product (Koca & Anıl, 1996; Solah et al., 2015). According to the investigations of various researchers (Ertaş & Türker, 2012; Ertaş & Türker, 2014), when bulgur is produced from a variety of raw materials using soaking water with varying pH values, it has been observed that the soaking pH of water has variable effects on a variety of raw materials. According to the current study, all cooked wheat samples had less starch, possibly because it transfers to the water during the cooking process, but all bulgur samples showed a significant (P≤0.05) increase in starch after drying and debranning when compared to wheat. It was deduced from the final product that bulgur made at neutral and acidic pH had more starch than the others.

Table 3.1 Changes in pH and nutritional traits of Durum wheat and bulgur prepared with five cooking waters changing in pH at different steps of production

Sample	pH of CW	pH	Dry matter (g/100g)	Ash content (g/100g)	Protein content (g/100g)	Fat content (g/100g)	Starch content (g/100g)
Durum wheat (raw material)	-	6.32 ± 0.01c	90.32 ± 0.13ab	1.63 ± 0.08a	13.95 ± 0.24a	1.62 ± 0.06a	64.88 ± 0.65d
Cooked wheat	3	5.41 ± 0.18C	51.63 ± 0.59A	1.67 ± 0.13BC	13.25 ± 0.27B	1.20 ± 0.09A	61.14 ± 0.80AB
	5	5.39 ± 0.06C	49.29 ± 0.30C	2.07 ± 0.11A	13.89 ± 0.18A	1.08 ± 0.19A	60.41 ± 0.66B
	7	6.34 ± 0.05A	50.66 ± 0.48AB	1.99 ± 0.28AB	13.45 ± 0.14B	1.29 ± 0.08A	61.24 ± 0.38AB
	9	5.06 ± 0.05D	49.72 ± 0.89BC	1.51 ± 0.25C	13.39 ± 0.06B	1.08 ± 0.05A	61.73 ± 1.02A
	11	5.98 ± 0.33B	49.37 ± 1.09C	1.51 ± 0.02C	13.84 ± 0.14A	1.15 ± 0.21A	61.49 ± 0.82AB
Fine bulgur	3	6.23 ± 0.05c	91.04 ± 0.13a	1.15 ± 0.12c	12.54 ± 0.27c	1.38 ± 0.04b	68.04 ± 0.10b
	5	5.98 ± 0.15d	88.45 ± 0.16bc	1.44 ± 0.06b	13.12 ± 0.17b	1.18 ± 0.11c	68.14 ± 0.85b
	7	6.51 ± 0.01b	88.85 ± 1.42c	1.59 ± 0.05a	12.74 ± 0.13c	1.36 ± 0.14bc	69.49 ± 1.12a
	9	6.45 ± 0.03b	90.98 ± 1.32a	1.51 ± 0.07ab	12.86 ± 0.25bc	1.32 ± 0.08bc	66.03 ± 1.00cd
	11	6.99 ± 0.11a	89.12 ± 1.32bc	1.40 ± 0.09b	13.09 ± 0.15b	1.45 ± 0.19ab	67.01 ± 0.48bc

CW: cooking water. Chemical attributes except for dry matter are expressed on a dry basis.

Results are indicated as the average of two independent experiments on double-production of each treatment ± standard deviation (n=2×2).

a-d: Divergent small letters in the same column denote a significant variation between wheat and fine bulgur samples produced after screening (α = 0.05).

A-D: Divergent uppercase letters in the same column denote a significant variation between the bulgur samples after cooking (α = 0.05).

3.3.2 Functional properties

Phenolic content and antioxidant capacities of wheat, cooked wheat and bulgur samples are displayed in Table 3.2. Because of their positive effects, health-conscious consumers are increasingly inclined to purchase foods high in phenolic content. Whole wheat can have antioxidant effects on the body, lower oxidative stress and be useful in the prevention of numerous diseases because it is high in phytochemicals. Wheat has phenolic compounds that are unevenly distributed throughout the grain and are primarily found in the bran; hence, the amount of phenolic compounds in wheat may vary depending on the processing methods (Fares et al., 2010; Piironen et al., 2009). The amount of phenolic compounds in wheat was determined to be 1057.85 mg/kg, which is consistent with the range of results that other studies have previously reported. According to earlier reports, it was determined that the cooking process reduces the amount of phenolic content; however, samples cooked with water in the pH 3–9 range did not differ statistically (Ertaş & Türker, 2012; Fares et al, 2010; Ragaee et al., 2006) and the sample cooked with water at pH 11 had a higher concentration of phenolic substances than the other samples. The current investigation confirmed that the bran has a high concentration of phenolic compounds. Because the bran is separated from the wheat by the debranning process, a decrease in the amount of phenolic substances was noted in all sample groups. Regarding the antioxidant capacity of the samples, after drying and debranning, it was discovered that the antioxidant activities of the samples prepared with alkaline pH water were higher than those of the other samples. However, the differences in the antioxidant activities of the samples after cooking were not statistically significant. Based on the results of antioxidant activity and phenolic content, it can be concluded that the bioactive characteristics of bulgur are positively impacted by cooking water with very alkaline pH.

Table 3.2 Changes in bioactive properties of Durum wheat and bulgur prepared with five cooking waters changing in pH at different steps of production

Sample	pH of CW	Total phenolic content (mg GAE/kg, d.b.)	Antioxidant activity (% Inhibition)
Durum wheat (raw material)	-	1057.85 ± 38.39a	87.92 ± 0.27c
Cooked wheat	3	744.91 ± 54.81B	86.71 ± 0.67A
	5	810.65 ± 77.07B	87.71 ± 0.36A
	7	803.26 ± 44.84B	87.13 ± 1.32A
	9	770.55 ± 45.68B	86.60 ± 0.75A
	11	916.91 ± 44.18A	87.74 ± 0.65A
Fine bulgur	3	721.43 ± 12.87c	89.76 ± 0.20b
	5	801.45 ± 21.48b	90.07 ± 0.20b
	7	713.60 ± 13.07c	89.44 ± 0.69b
	9	683.36 ± 34.14c	91.49 ± 0.81a
	11	783.49 ± 18.22b	91.24 ± 0.10a

CW: cooking water. d.b: dry basis. GAE: gallic acid equivalent.

Results are indicated as two independent analyses on double-production of each treatment ± standard deviation (n=2×2).

a-d: Divergent small letters in the same column denote a significant difference between wheat and fine bulgur samples produced after screening (α = 0.05).

A-D: Divergent uppercase letters in the same column denote a significant difference between the bulgur samples after cooking (α = 0.05).

3.3.3 The influence of the pH of cooking water on the mineral content

The human body needs minerals for a variety of essential processes, therefore it is critical to consume enough amount of them to prevent diseases arising from their deficiencies. Prior studies have indicated that in Western nations, cereals are a major source of macro and microelements and they provide a substantial portion of the minerals needed for a diet. One of the macro minerals, calcium, contributes to the development of teeth and bones, regulates blood pressure and aids in the normal operation of the immune system. On the other hand, sodium is required for several metabolic processes and helps to regulate the electrolyte balance of the body. Of the trace minerals that were examined, iron is required for the synthesis of haemoglobin and a few enzymes, while zinc aids in the synthesis of numerous enzymes, is significant in taste and smell perception and promotes wound healing. Another trace mineral that is important for the regular operation of the nervous system and the synthesis of numerous enzymes is manganese (Gharibzahedi & Jafari, 2017; Piironen et al., 2009). One of the main sources of dietary minerals is wheat, which is a rich source of minerals. Table 3.3 shows how cooking, as well as the drying and debranning procedure, affect the mineral concentrations of bulgur samples cooked at varying cooking water pH levels. As per previous findings (Ertaş & Türker, 2012; Solah et al., 2015), it was revealed that all minerals experienced a decline, with the exception of sodium, following the cooking, drying and debranning processes. This decline was observed regardless of the sample groups. Additionally, there was no statistical differentiation (P>0.05) observed between the iron and zinc concentrations of samples after the drying and debranning processes. As previously mentioned, the pH of cooking water affects various minerals in different ways and after drying and debranning, all sample mineral levels significantly (P≤0.05) decrease. This is related to the fact that the bran, which is separated from the wheat during the debranning process, contains the majority of the minerals. The findings show that cooking with water with an excessively alkaline pH value had a favourable influence on the iron level of samples after cooking, but had the reverse effect on zinc. The outcomes of the research demonstrate that when bulgur was produced, cooking with alkaline water led to a greater loss of all minerals. For this reason, it is best to use neutral or nearly neutral acidic water when cooking to preserve the minerals in the final product.

Table 3.3 Mineral concentration of Durum wheat and bulgur prepared with five cooking waters changing in pH at different steps of production

Sample	pH of CW	Fe (mg/kg, d.b.)	Zn (mg/kg, d.b.)	Mn (mg/kg, d.b.)	Ca (mg/kg, d.b.)	Na (mg/kg, d.b.)
Durum wheat (raw material)	-	42.04 ± 6.82a	36.18 ± 1.39a	33.04 ± 1.29a	205.65 ± 13.05a	39.41 ± 4.87d
Cooked wheat	3	21.64 ± 0.12B	37.46 ± 2.09A	33.15 ± 1.97A	190.21 ± 1.48A	55.65 ± 7.68B
	5	20.41 ± 4.55B	34.73 ± 2.85AB	30.12 ± 1.64AB	189.85 ± 3.68A	91.74 ± 12.33AB
	7	17.54 ± 6.27B	35.54 ± 1.84AB	28.22 ± 0.12B	182.58 ± 3.77B	186.0 ± 54.9B
	9	24.81 ± 4.64B	34.53 ±0.94AB	29.05 ± 4.37AB	174.52 ± 6.18C	116.6 ± 20.4AB
	11	34.21 ± 5.20A	33.16 ± 2.91B	31.15 ± 2.07AB	166.89 ± 0.42D	1173.3 ± 108.6A
Fine bulgur	3	24.84 ± 0.01b	26.90 ± 1.39b	14.40 ± 1.60b	168.74 ± 2.74bc	37.02 ± 4.87d
	5	18.33 ± 5.38b	28.17 ± 1.07b	10.70 ± 1.14c	169.03 ± 1.75bc	60.57 ± 2.04d
	7	19.70 ± 0.14b	28.47 ± 0.66b	10.11 ± 1.37c	172.26 ± 2.83bc	212.83 ± 45.07b
	9	16.53 ± 3.23b	28.42 ± 2.11b	8.21 ± 1.13d	185.91 ± 19.05b	140.79 ± 14.62c
	11	15.57 ± 2.79b	27.81 ± 1.79b	7.86 ± 1.35d	161.41 ± 4.30c	943.26 ± 58.98a

CW: cooking water. d.b: dry basis.

Results are indicated as the average of two independent experiments on double-production of each treatment ± standard deviation (n=2×2).

a-d: Divergent small letters in the same column denote a significant difference between wheat and fine bulgur samples produced after screening (α = 0.05).

A-D: Divergent uppercase letters in the same column denote a significant difference between the bulgur samples after cooking (α = 0.05).

3.3.4 Colour results

Customers consider colour as the primary criterion for quality since it shapes their initial opinion of the food and it has a significant influence on the marketing and sales of the product (Wrolstad & Smith, 2017). Bulgur colour plays a significant role in customer selection and products with higher luminosity and yellowness are favoured (Yılmaz & Koca, 2020). The yellow colouration of bulgur stems from lipophilic carotenoids found in the endosperm, including lutein and β-carotene (Lachman et al., 2017). Cooking increased the YI and b* scores in all samples, but had no significant ($P>0.05$) impact on the L* and a* scores of any sample other than the pH 11 sample. With the exception of the sample cooked with the most alkaline (pH 11) water, colour differences between the sample groups after cooking originated from the difference between the L* and a* scores vanishing following the bran removal process. As illustrated in Table 3.4, the statistical ($P\leq0.05$) difference degrees of b* and YI values after cooking show parallelism with the differences in following the drying and debranning processes. The results of this study showed that the manufacturing process of bulgur increased the L* and b* values of wheat, decreased the a* and YI values. It was also revealed that highly alkaline cooking water (pH 11) caused the bulgur to become discoloured (not a bright green colour).

Table 3.4 Colour parameters of Durum wheat and bulgur prepared with five cooking waters changing in pH at different steps of production

Sample	pH of CW	L*	a*	b*	YI
Durum wheat	-	52.64 ± 0.85c	9.38 ± 0.23a	25.85 ± 0.21d	75.51 ± 0.52a
Cooked wheat	3	52.50 ± 0.94A	8.48 ± 0.14B	33.07 ± 0.77B	85.68 ± 1.10C
	5	51.41 ± 0.32B	8.70 ± 0.23AB	33.75 ± 0.31AB	88.18 ± 1.02B
	7	50.81 ± 0.36B	9.28 ± 0.22A	34.60 ± 0.31A	90.74 ± 0.41A
	9	51.04 ± 0.36B	8.86 ± 0.35B	33.15 ± 1.37B	87.81 ± 2.53AB
	11	48.71 ± 0.48C	7.56 ± 0.12C	31.69 ± 0.22C	86.13 ± 0.70AB
Fine bulgur	3	68.73 ± 0.37a	5.95 ± 0.17b	31.49 ± 0.72b	68.26 ± 1.37c
	5	68.25 ± 0.30a	6.18 ± 0.04b	32.71 ± 0.54a	70.55 ± 0.63b
	7	68.62 ± 0.54a	5.98 ± 0.12b	32.74 ± 0.10a	70.13 ± 0.48b
	9	68.46 ± 0.60a	6.02 ± 0.21b	31.27 ± 0.41b	68.19 ± 0.94c
	11	65.34 ± 0.65b	5.47 ± 0.11c	30.27 ± 0.59c	67.88 ± 0.63c

CW: cooking water. YI: yellowness index.

Results are indicated as the average of two independent experiments on double production of each treatment ± standard deviation (n=2×2).

a-d: Divergent small letters in the same column denote a significant difference between wheat and fine bulgur samples produced after screening (α = 0.05).

A-D: Divergent uppercase letters in the same column denote a significant difference between the bulgur samples after cooking (α = 0.05).

3.3.5 Changes in texture parameters

The textural qualities of bulgur showed varying results when cooked in alkaline and acidic solutions (Table 3.5). Food acceptability among consumers is influenced by several quality characteristics, one of which is texture. In this instance, commenting on the bulgur quality necessitates an understanding of textural parameters. Hardness, springiness, gumminess and chewiness results showed that there were statistically insignificant differences in these qualities in bulgur samples following cooking as well as during the drying and debranning process (P>0.05). On the other hand, the findings of multiple investigations revealed that using more alkaline water when cooking vegetables (Brandt et al., 1984) and noodles (Moss et al., 1986) results in products with softer textures. In contrast to our findings, the researchers also reported that more alkaline cooking medium improved the colour and appearance of the products, suggesting that these changes may be related to the structure and content of the food products. After cooking, the effect of pH varied in cohesiveness and resilience variables. Following the drying and debranning processes, the samples cooked in the most acidic (pH 3) and alkaline (pH 11) cooking mediums showed the lowest cohesiveness values. Furthermore, it was discovered that, following the drying and debranning processes, there was no statistically significant (P>0.05) difference in the cohesiveness values of the samples cooked in neutral or nearly neutral acidic and alkaline cooking waters. Ultimately, following the drying and debranning processes, the resilience values of samples were statistically unchanged (P>0.05), the differences between them eventually disappearing after cooking. The hardness, springiness, cohesiveness, gumminess, chewiness and resilience values of all of the samples of bulgur were negatively impacted by the cooking and drying-debranning processes and the results were lower than those of wheat in all of the aforementioned parameters.

3.3.6 Sensory evaluation

Sensory properties are one of the most important factors that consumers consider when buying food. In this regard, Table 3.6 examines and illustrates the impact of acidity/alkalinity on the sensory characteristics of cooked (pilaf) and uncooked (raw) food. Along with the colour results, the scores of the odour and yellowness characteristics of the cooked and uncooked bulgur samples did not appear to differ (P>0.05), with the exception of the sample made with highly alkaline (pH 11) water. Considerable differences (P≤0.05) in the taste characteristics of the cooked samples were found among the sample groups. Although the sample made with the highest alkaline water had the only unfavourable influence on taste, it is noted that the texture was negatively impacted significantly (P≤0.05) at pH values higher than neutral. The sensory acceptance of both cooked and raw bulgur samples was adversely impacted by the preparation of bulgur using a very high alkaline water content.

Table 3.5 Texture profile of Durum wheat and bulgur prepared with five cooking waters changing in pH at different steps of production

Sample	pH of CW	Hardness (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Durum wheat (raw material)	-	46965.05 ± 5094.59a	0.70 ± 0.06a	0.63 ± 0.05a	29872.59 ± 5389.39a	20992.35 ± 4408.81a	0.48 ± 0.05a
Cooked wheat	3	4993.82 ± 671.52A	0.67 ± 0.09A	0.60 ± 0.01A	3002.87 ± 448.78A	2031.41 ± 577.19A	0.37 ± 0.01A
	5	4673.50 ± 179.27A	0.58 ± 0.07A	0.51 ± 0.04B	2557.19 ± 165.73A	1580.36 ± 64.29A	0.34 ± 0.02C
	7	5114.00 ± 1425.87A	0.57 ± 0.11A	0.58 ± 0.02A	2718.99 ± 974.80A	1633.62 ± 865.45A	0.37 ± 0.01AB
	9	4860.51 ± 732.78A	0.62 ± 0.06A	0.58 ± 0.05A	2925.67 ± 562.12A	1611.44 ± 606.26A	0.36 ± 0.02ABC
	11	4405.68 ± 867.32A	0.66 ± 0.15A	0.56 ± 0.02B	2443.23 ± 443.36A	1632.24 ± 546.13A	0.35 ± 0.01BC
Fine bulgur	3	4415.18 ± 457.64b	0.52 ± 0.03b	0.45 ± 0.01c	2006.48 ± 193.07b	1047.24 ± 155.40b	0.16 ± 0.00b
	5	2173.71 ± 199.19b	0.59 ± 0.02b	0.54 ± 0.02b	1169.78 ± 60.82b	684.96 ± 22.34b	0.17 ± 0.02b
	7	2292.58 ± 571.71b	0.55 ± 0.05b	0.52 ± 0.04ab	1170.82 ± 207.63b	639.07 ± 52.37b	0.17 ± 0.02b
	9	3189.11 ± 152.18b	0.56 ± 0.01b	0.52 ± 0.02ab	1657.06 ± 138.31b	919.35 ± 66.61b	0.16 ± 0.01b
	11	4157.41 ± 594.03b	0.56 ± 0.07b	0.49 ± 0.01bc	2026.96 ± 265.47b	1128.77 ± 114.58b	0.15 ± 0.01b

CW: cooking water.

Results are indicated as the average of triplicate analysis on double-production of each treatment ± standard deviation (n=3×2).

a-d: Divergent small letters in the same column denote a significant difference between wheat and fine bulgur samples produced after screening (α = 0.05).

A-D: Divergent uppercase letters in the same column denote a significant difference between the bulgur samples after cooking (α = 0.05).

Table 3.6 Sensory attributes of bulgur samples cooked with cooking water at different pH levels

Sample	pH of CW	Uncooked Bulgur			Cooked Bulgur (Pilaf bulgur)				
		Odour	Yellowness	Overall Acceptability	Odour	Yellowness	Taste	Texture	Overall Acceptability
Fine bulgur	3	6.73 ± 1.17a	7.13 ± 0.88a	7.13 ± 1.09a	7.22 ± 0.67a	7.11 ± 1.05a	7.10 ± 0.57a	7.18 ± 0.40ab	7.00 ± 0.77b
	5	6.77 ± 1.29a	7.10 ± 0.84a	7.06 ± 0.42a	7.43 ± 0.53a	7.00 ± 1.15a	7.18 ± 0.75a	7.09 ± 0.70ab	7.00 ± 0.63b
	7	7.00 ± 1.02a	7.18 ± 0.82a	7.13 ± 0.77a	7.86 ± 0.38a	7.36 ± 0.67a	7.64 ± 0.50a	7.45 ± 0.52a	7.64 ± 0.50a
	9	7.25 ± 1.16a	7.00 ± 0.98a	7.00 ± 1.08a	7.17 ± 0.75a	7.00 ± 0.93a	7.09 ± 0.70a	6.73 ± 0.79b	6.91 ± 0.70b
	11	5.33 ± 0.94b	4.38 ± 0.98b	5.07 ± 1.09b	5.71 ± 0.76b	5.44 ± 0.88b	5.09 ± 0.83b	5.64 ± 0.81c	5.64 ± 0.81c

CW: cooking water.

a-d: Divergent letters in the same column denote a significant difference between the fine bulgur samples produced after screening (α = 0.05).

(n=2×12).

3.3.7 Assessment of FTIR spectra

Regarding the many components it contains, the FTIR spectra of the wheat and bulgur samples (Figure 3.1) depicted several bands. Polysaccharides were the source of the wide band in the 1200-800 cm^{-1} range. The peak at 995 cm^{-1}, located in the middle of this band, was claimed to represent C-OH bending. This band continued between 1149 and 851 cm^{-1} and it was suggested that this represented starch bands because it was linked to the antisymmetric C-O-C stretching mode of glycosidic linkage and β, (1-4) bonds. Esterification of carbonyl groups with aromatic esters was indicated by the weak band at 1744 cm^{-1}. Protein bands associated with amides I (stretching of C=O) and II (bending of NH and stretching of CN) are seen through the peaks of 1635 and 1540 cm^{-1}, respectively. Some studies have indicated that the 1368–1240 cm^{-1} band may be related to arabinoxylans and may result from distinct vibrational absorption of C–O, C–H and C–C bonds. The signal at 2925 cm^{-1} was related to lipid molecules and was caused by the stretching and bending modes of C-H and C=O bonds. Prior research has indicated that the peak at 3270 cm^{-1}, which is associated with the starch content, is caused by the O-H bond stretching (Amir et al., 2013; Barron & Rouau, 2008).

3.3.8 Thermal characteristics

The main factor that shows the appropriate cooking of wheat in bulgur production is the gelatinization of starch. When wheat is boiled with enough water, it goes through several physicochemical changes that lead to gelatinization (Certel & Ertugay, 1992; Schirmer et al., 2015). According to Certel & Ertugay (1992), the range of 52–82 °C is where gelatinization of durum wheat takes place. The gelatinization temperature was found to be between 64 and 74 ºC, as shown in Figure 3.2. The lack of a peak for gelatinization in the bulgur samples suggested that all of the bulgur samples had fully achieved gelatinization as a result of cooking, indicating that the cooking process was done appropriately.

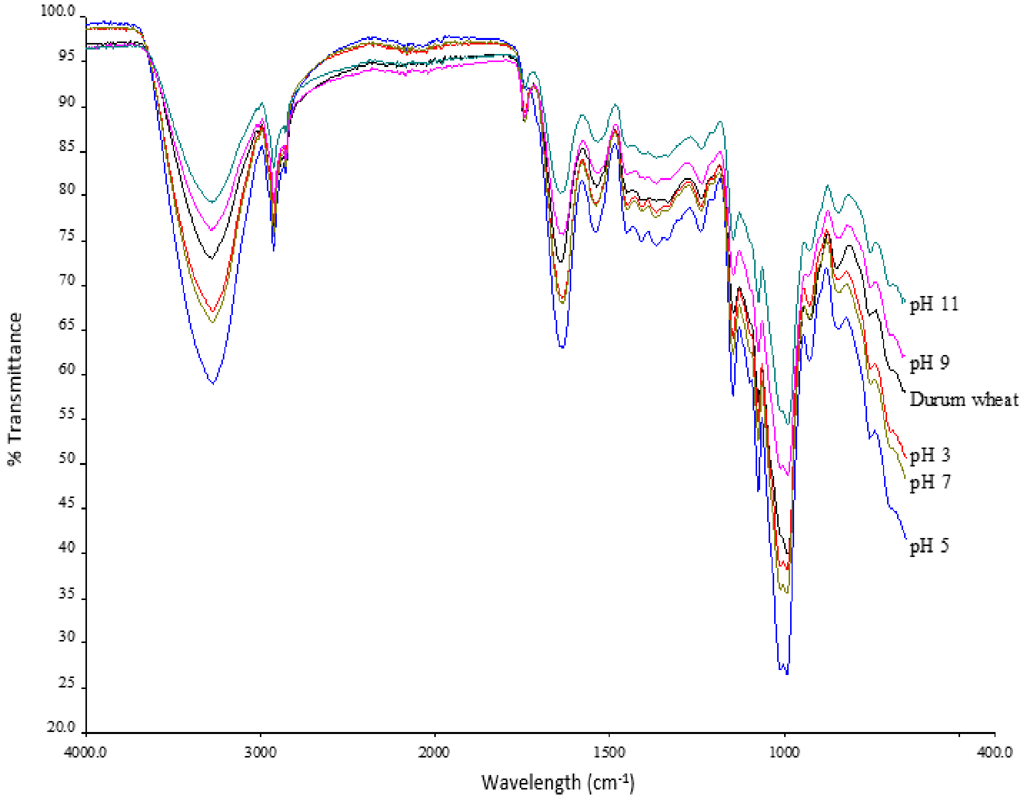

Figure 3.1 FTIR spectra of Durum wheat and bulgur samples cooked with cooking water at various pH levels

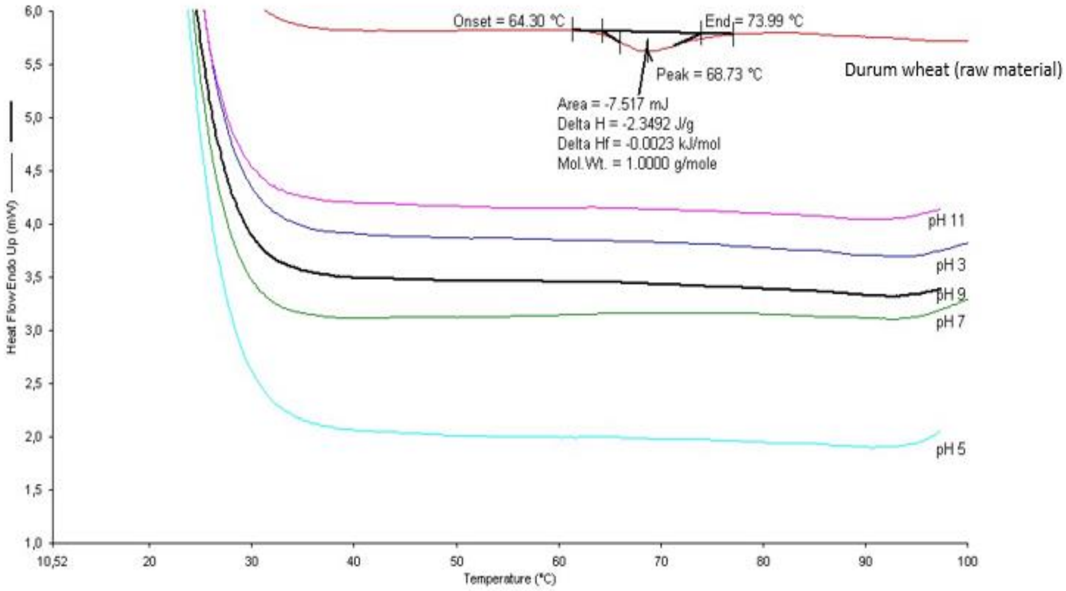

Figure 3.2 DSC thermogram of Durum wheat and bulgur samples cooked with cooking water at various pH levels

3.4 Conclusions

The second main component in the manufacturing of bulgur is the cooking water and its pH significantly affects the bioactive compounds, sensory and chemical and micronutrient contents of bulgur. It has been demonstrated by the DSC data that, independent of pH, wheat starch gelatinizes throughout the bulgur production process. Mid-FTIR spectra showed, as predicted, that there was no structural variation in wheat during bulgur production. The functional properties of the samples were positively impacted by the production process using water at pH 11, while the mineral contents were negatively impacted. Furthermore, while cooking in acidic and neutral waters produced the desired bright yellow colour, cooking in water with a pH of 11 increased the unfavourable non-bright green colour. According to the findings of the sensory investigation, bulgur made with water that has a neutral pH is the most favoured by consumers, while cooking with excessively alkaline water appears to negatively impact the appeal of the products.

CHAPTER 4
THE IMPACT OF WATER HARDNESS AND PROCESSING ON THE QUALITY PROPERTIES OF BULGUR

Summary

The texture and colour of bulgur during the cooking process are greatly influenced by the hardness of the water, which is a crucial criterion for food quality when it is utilised as a direct ingredient in production. In this respect, bulgur was produced using water of three different hardness (soft, hard and very hard). To determine the effects of water hardness during bulgur production, chemical and functional properties, mineral content, colour values, textural, thermal, structural and sensory parameters of both cooked wheat (after cooking operation) and final bulgur (after cooking, drying, bran separation and milling processes) were examined. Utilising very hard water throughout the bulgur production process helps to preserve the minerals in the structure of wheat and, consequently, the bulgur that is produced. The antioxidant activity of wheat samples during cooking and drying, debranning and milling was adversely impacted by water hardness. The yellowness of bulgur is reduced when cooked in very hard water, leading to a production problem, as demonstrated by colour and taste analysis. According to the results, it is advised to use soft water for making bulgur because cooking with very hard water negatively affects the functional and sensory qualities of bulgur.

4.1 Introduction

Bulgur, a whole wheat product, is mainly prepared by cooking, drying, tempering, debranning, milling and categorising according to the sizes of Durum wheat. The use of bulgur, which was previously mostly consumed by Türkiye, the Middle East, the Near East and North African countries, has recently increased in Europe and other Western countries as well. This has led to an acceleration of research on the subject (Giambanelli et al., 2020; Narwal et al., 2020). Bulgur is becoming more and more popular since it is low in glycemic index, easy to cook and versatile—it can be used in a variety of dishes, including salads, soups and baked products (Deethardt, 1976). The main elements affecting bulgur quality are the steps in the production procedure and the raw ingredients used in the preparation. The most important steps that impact bulgur quality are the cooking and debranning procedures used during manufacture (Koca & Anıl, 1996). Compounds are transferred from water to bulgur and from bulgur to water during cooking. Water influences food characteristics through molecular interactions with various food ingredients, whereas food composition and characteristics also change (Franks et al., 2019; Kasaai, 2014; Malcolmson & Matsuo, 1993). Taking all of this into account, it can be concluded that the composition of the water used to cook bulgur can change the composition and quality features of bulgur.

Particular consideration should be given to the composition of water when it is employed as a component in food manufacturing since it can impact the chemical content, structure, texture, colour and odour properties of food (Kasaai, 2014). The effects of varying water hardness during the cooking of cowpeas (Uzogara et al., 1992), spaghetti (Malcolmson & Matsuo, 1993) and brewing tea (Franks et al., 2019) have been studied by a number of researchers. These findings of research show that each type of food has a different reaction to water hardness. Water hardness is commonly expressed in mg of calcium carbonate equivalent per litre since the calcium ions in the water are the primary cause of water hardness. The World Health Organisation (2011) has classified the hardness of water into four categories: <60 mg/L of $CaCO_3$, soft; 60-120 mg/L of $CaCO_3$, moderately hard; 120-180 mg/L of $CaCO_3$, hard; and >180 mg/L of $CaCO_3$, very hard.

The type of wheat used, the ingredients in the cooking water and the techniques employed for drying and cooking all affect the qualitative attributes of bulgur. The impact of wheat variety (Giambanelli et al., 2020; Koca & Anıl, 1996) and processing techniques (Savas & Basman, 2016) on bulgur quality have been thoroughly examined in the literature. Standardising the type of wheat and manufacturing parameters is relatively easy, but standardising the cooking water is more difficult. As a result, there is currently no research on this topic in the literature. Artificially hardened water is a more practical way to find out the impact of hardness on food because the characteristics of water from tap water and other local water sources change over time

(Franks et al., 2019). Regarding the impact of water hardness on the texture and colour of bulgur, there is a scarcity of information within the industry. Thus, in this study, wheat, cooked wheat and fine bulgur made with water adjusted to three different hardness levels (53, 129 and 269 mg/L of $CaCO_3$) were all subjected to extensive examination of quality characteristics (chemical, physical, textural, structural and sensory features).

4.2 Materials and methods

4.2.1 Reagents

The following materials were purchased from Sigma Co. (St. Louis, MO, USA): hydrochloric acid (HCl), tungstophosphoric acid hydrate, hexane, AAS grade calcium (Ca) and iron (Fe) standard solutions, methanol, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical, sodium carbonate (Na_2CO_3) and Folin-Ciocalteu's reagent. Zinc (Zn), manganese (Mn) and sodium (Na) standard solutions for AAS were purchased from Perkin Elmer (PerkinElmer Inc., USA).

4.2.2 Production of bulgur, sampling and experimental set-up

Durum wheat (*Triticum durum* cv. Güneyyıldızı) was procured from Tiryaki Agro Food Co. (Gaziantep, Türkiye) and water for cooking and chemical analysis was acquired using a MilliQ Advantage A 10 water demineralization device from Millipore (Molsheim, France). In order to achieve the appropriate levels of hardness in the water, food-grade $CaCI_2$ was purchased from Kimbiotek Kimyevi Mad. San. ve Tic. Co. (İstanbul/Türkiye). Water hardness was adjusted to 53, 129 and 269 mg/L of $CaCO_3$ using 1000 ppm $CaCI_2$ solution made of demineralized water. Demineralized water was used, the EDTA method (Harris, 2003) was used to continually measure the hardness of water and the $CaCl_2$ solution was added to adjust the hardness levels of water to the desired levels. Following the cleaning of the wheat, 97 °C of boiling water was used to commence the cooking process and wheat was added at a ratio of 1/1.8 (w/v) to the water. After that, the grains were boiled until all of the starch had gelatinized. Following cooking, the samples were removed and kept in plastic containers at a temperature of -18°C to assess the pH, chemical composition, total phenolic content, antioxidant activity, mineral content (Fe, Zn, Mn, Ca and Na), colour (L*, a*, b* and YI (Yellowness Index)) and textural attributes. After cooling, cooked wheat was dried in a packed bed drier (MK II, Sherwood Scientific, England) at 70 °C to about 12% (w.b.) of moisture. Approximately 17% (w.b.) of moisture was achieved by soaking the dry bulgur in water for 25 min. The bran of tempered wheat was separated by a bran separator (Merba Makine, Türkiye) and then ground using and a disc mill (Tekpa Laboratory Systems, Türkiye). Finally, fine bulgur (milled bulgur with sieves between 0.5 and 2 mm) was taken and stored in plastic containers at +4 °C in order to be used in upcoming analyses. FTIR, DSC and sensory analyses were also performed on these samples in addition to the previously described tests for the cooked samples. The cooked wheat samples were ground using a grinder (Bosch, TSM6A014R, Germany) prior to pH, chemical, total phenolic content, antioxidant capacity and mineral analyses. Additionally, the wheat and fine bulgur were ground in a mortar in order to perform thermal and structural tests.

4.2.3 Determination of pH, chemical content and colour properties

The pH values, total dry matter, ash, protein, fat and starch contents and CIE colour parameters (L*, a*, b* and YI values) of wheat, cooked wheat and fine bulgur samples were determined by the same methods in section 3.2.3.

4.2.4 Methods for determination of the bioactive properties

Total phenolic contents and antioxidant activities of the samples were specified by the procedures given in section 3.2.4 after obtaining the extracts.

4.2.5 Determination of mineral content

The amount of minerals was evaluated by applying the same methods as indicated in section 3.2.5.

4.2.6 Assessment of textural profile

The textural properties of the samples were measured by performing the method in section 3.2.6.

4.2.7 Application of FTIR Spectroscopy

The spectra of wheat and fine bulgur samples were achieved by applying the procedure given in section 3.2.7.

4.2.8 Determination of the thermal properties

Thermal characteristics of wheat and fine bulgur samples were determined by following the same method provided in section 3.2.8.

4.2.9 Sensory Evaluation

The same procedure was implemented on the samples as given in section 3.2.9.

4.2.10 Statistical evaluation

The mean and standard deviations of four measurements (duplicate analyses of two productions of each batch) were used to present the results of all analyses. The assessment was conducted using the statistical package SPSS 25.0 (IBM Corp., New York, USA) by applying a one-way analysis of variance (ANOVA) with a significance level of $P \leq 0.05$ and Duncan's multiple range test. Additionally, a Paired-Samples T-test was applied to compare the bulgur (the effect of drying and debranning) and cooked wheat (the effect of cooking) samples that were made using the same water hardness.

4.3 Results and discussion

Research is conducted in bulgur-producing plants to get the brilliant yellow colour that is desired by the consumer (Koca & Anıl, 1996). The aforementioned qualities of bulgur may be impacted by variations in the hardness of the water used in its manufacture. In light of these, the current study aimed to broaden the scope of the study by defining the quality attributes of bulgur made using water ranging in hardness from 53 to 269 mg/L of $CaCO_3$. Researchers and manufacturers will benefit from the findings of the study regarding how cooking water affects product quality.

4.3.1 Chemical characteristics of wheat and bulgur samples

Comparing the characteristics of wheat and bulgur samples made with varying amounts of hard water after cooking, as well as the drying and debranning procedures, allowed for a discussion of the chemical properties. Table 4.1 lists the pH, protein, fat, ash, total dry matter and starch contents of raw wheat, cooked wheat and bulgur samples. In terms of the pH results, it can be deduced that cooking lowers the pH value of wheat independent of the hardness of water. On the other hand, following the drying and debranning procedures, the pH levels of every sample increased. The pH levels of the wheat and bulgur produced with soft water did not appear to change (*P*>0.05), whereas the samples produced with harder waters showed a rise in pH (*P*≤0.05), albeit not in a way that was consistent with the hardness degree of cooking water. According to the findings of the study, the pH value is raised by the drying and debranning operations. Given that wheat bran includes phenolic acids, including ferulic acid and phytic acid, this rise may be the result of their elimination (Onipe et al., 2015). Wheat typically has a dry matter content of more than 87% (w.b.) (Koca & Anıl, 1996; Rasheed et al., 2023). As the wheat cooked, water was absorbed into its structure, resulting in a sharp decline in dry matter (*P*≤0.05) across all sample groups. The amount of dry matter increases in proportion to the water hardness, which is a noteworthy finding in the dry matter results of cooked wheat. Following the drying procedure, all bulgur samples had dry matter contents exceeding 89% (w.b.). The main factor influencing the ash content of wheat is the soil in which it is grown; the findings of previous studies (Caba et al., 2012; Savas & Basman, 2016) are comparable to the value of 1.63 g/100 g found in this investigation. Water hardness and the cooking method did not significantly alter the amount of ash (*P*>0.05), however, the debranning process greatly reduced the amount of ash in the sample cooked with only soft water (Ercan, 1986). This can be explained by the fact that during the cooking process, minerals from the bulgur produced with harder water permeate into the wheat and the debranning process has less of an impact on the mineral matter content of these samples than it does on those produced with soft water.

Utilising wheat high in protein, such as *Triticum durum*, during the production process is crucial for maintaining the nutritional and technological quality of bulgur. The high protein content of wheat grain helps to develop a harder texture through the interaction of proteins with starch during cooking (Koca & Anıl, 1996). It has been shown that commercial wheat cultivars range from 8 to 16% protein (Ragaee et al., 2006). Examining the variations in the protein content of bulgur samples, it was found that the protein content of cooked wheat and bulgur samples made with the same water hardness did not differ significantly (*P*>0.05). It was figured out that the hardness of the cooking water did not affect the amount of protein in bulgur (*P*>0.05).

The fat content of wheat was 1.62 g/100 g, in line with the earlier findings (1.5–3 g/100 g) of other researchers (Rasheed et al., 2023). Statistical assessment revealed a significant reduction (*P*≤0.05) in fat content in all samples and this reduction increased intensely with increasing hardness. The amount of fat in the same sample batches following the drying and debranning operations is consistent with the findings following cooking and it is observed that the amount of fat reduces as the water hardness increases. In reference to fat outcomes, Koca & Anıl (1996) and Rasheed et al. (2023) revealed consistent data that could account for this decline. The levels of fat in bulgur and wheat made with soft water differed not significantly (*P*>0.05), whereas those made with harder water showed a decrease (*P*≤0.05) in comparison to wheat. As one of the main energy sources in the world, starch is essential to the manufacturing of bulgur, particularly during the cooking process. One of the most crucial indicators that bulgur has been cooked properly is the full gelatinization of the starch in the wheat (Koca & Anıl, 1996; Ragaee et al., 2006). The starch observations show that the cooking procedure reduced the amount of starch in all samples (*P*≤0.05), but the reduction augmented with increasing water hardness. Water hardness had varying effects on the amount of starch in different operations (after cooking and after drying and debranning). Following the drying and debranning, there was an increase in the starch content of samples due to the increased water hardness.

Table 4.1 Chemical characteristics of Durum wheat and bulgur cooked using three cooking waters differing in hardness at different production stages

Sample	Hardness of cooking water*	pH	Dry matter (g/100g, d.b.)	Ash content (g/100g, d.b.)	Protein content (g/100g, d.b.)	Fat content (g/100g, d.b.)	Starch content (g/100g, d.b.)
Durum wheat (raw material)	-	6.32 ± 0.01Ac	90.32 ± 0.13Aab	1.63 ± 0.08Aa	13.95 ± 0.24Aa	1.62 ± 0.06Aa	64.88 ± 0.65Ad
Cooked wheat	53	5.74 ± 0.66Bx	51.27 ± 1.14Cx	1.70 ± 0.08Ax	13.64 ± 0.32Ax	1.20 ± 0.07Bx	62.37 ± 0.80Bx
	129	4.91 ± 0.13Cx	51.80 ± 0.87BCx	1.41 ± 0.28Ax	13.36 ± 0.40ABx	1.09 ± 0.04Cx	60.39 ± 1.24Cx
	269	5.16 ± 0.06Cx	52.72 ± 0.54Bx	1.64 ± 0.20Ax	12.86 ± 0.36Bx	1.12 ± 0.00Cx	59.25 ± 1.30Cx
Bulgur	53	6.33 ± 0.01cx	91.40 ± 0.70ay	1.24 ± 0.12by	13.42 ± 0.14bx	1.59 ± 0.05ay	66.06 ± 0.57cy
	129	6.39 ± 0.01ay	89.90 ± 1.08by	1.57 ± 0.03ax	13.27 ± 0.04bx	1.32 ± 0.07by	67.80 ± 0.41ay
	269	6.36 ± 0.03by	91.39 ± 0.42ay	1.59 ± 0.01ax	13.23 ± 0.29bx	1.35 ± 0.07by	67.02 ± 0.22by

*calculated hardness of cooking water in mg/L of $CaCO_3$. d.b: dry basis.

Displayed results are the mean of twice analyses on duplicate preparation of each batch± standard deviation (n=2×2).

a-d: Different lowercase letters within the same column represent significant differences between the wheat (raw material) and bulgur samples (α = 0.05).

A-D: Different capital letters within the same column represent significant differences between the wheat (raw material) and cooked wheat samples (α = 0.05).

x-y: Unequal letters within the same column represent significant differences between the cooked wheat and bulgur samples prepared with the same water hardness (α = 0.05).

4.3.2 Bioactive attributes of wheat and bulgur samples

Consuming functional foods that are high in phenolic compounds and have antioxidant properties is becoming more popular because they are beneficial for human health (Caba et al., 2012). Based on earlier research, wheat has been shown to contain a wide range of phytochemicals with antioxidant properties, which means that it can help prevent several diseases by reducing oxidative stress. Wheat contains a lot of phenolic compounds, however, they are distributed unevenly throughout the grain, with the bran having the highest concentration of these compounds (Liyana-Pathirana & Shahidi, 2007). Therefore, the bioactive properties of wheat are diminished by wheat processing, particularly the bran removal procedure. Table 4.2 presents the bioactive properties of Durum wheat and bulgur that were produced using varying degrees of water hardness. The total phenolic content of bulgur varies between 621 and 2034 mg/kg GAE (Caba et al., 2012; Rasheed et al., 2023) due to variations in the phenolic content of wheat and production characteristics. The phenolic content of the samples is unaffected ($P>0.05$) by the hardness of the cooking water. The findings of the study demonstrate that the total phenolic content of bulgur is negatively impacted ($P\leq0.05$) by the cooking and drying and debranning operations. Table 4.2 shows that there is a positive correlation between the amount of antioxidant and phenolic compounds. Additionally, a strong positive correlation ($R^2=0.94$) was shown by Beta et al. (2005) between the total phenolic content and antioxidant capacity of wheat. Hard water was found to increase the total phenolic content in cooked wheat, even though the increase was not statistically significant ($P>0.05$). However, very hard water reduced the total phenolic content in cooked wheat in a manner that matched the results of the antioxidant capacity. The outcomes supported the findings of Vinci et al. (2022), which demonstrated the dose-dependent impact of calcium ions on total phenolic content and antioxidant activity. Following the drying and debranning processes, the product made with hard water had the lowest antioxidant activity and the maximum antioxidant activity after cooking. The fact that the phenolic compounds in the bran are bound by calcium during cooking and subsequently released during the debranning process could help to explain this. In contrast, compared to bulgur produced in other waters, the total phenolic content in the product cooked in very hard water is less negatively affected by the debranning process because calcium may react with phenolic substances like water-soluble anthocyanins and transfer into the endosperm

(Vinci et al., 2022). All bulgur samples showed lower antioxidant activity when compared to wheat, however soft and very hard water had a less adverse influence on antioxidant activity than the product prepared with hard water following cooking and drying and debranning operations.

Table 4.2 Functional properties of Durum wheat and bulgur cooked using three cooking waters differing in hardness at different production stages

Sample	Hardness of cooking water*	Total phenolic content (mg GAE/kg, d.b.)	Antioxidant activity (% Inhibition)
Durum wheat (raw material)	-	1057.85 ± 38.39Aa	87.92 ± 0.27Aa
Cooked wheat	53	800.68 ± 44.31Bx	85.86 ± 0.82Bx
	129	807.20 ± 45.21Bx	87.45 ± 0.89Ax
	269	795.44 ± 32.31Bx	85.96 ± 0.39Bx
Bulgur	53	727.27 ± 19.22by	84.74 ± 1.21bcx
	129	722.98 ± 33.99by	83.85 ± 0.79cy
	269	741.10 ± 18.22by	85.72 ± 0.39bx

*calculated hardness of cooking water in mg/L of $CaCO_3$. d.b: dry basis. GAE: gallic acid equivalent.

Displayed results are the mean of twice analyses on duplicate preparation of each batch± standard deviation (n=2×2).

a-d: Different lowercase letters within the same column represent significant differences between the wheat (raw material) and bulgur samples ($\alpha = 0.05$).

A-D: Different capital letters within the same column represent significant differences between the wheat (raw material) and cooked wheat samples ($\alpha = 0.05$).

x-y: Unequal letters within the same column represent significant differences between the cooked wheat and bulgur samples prepared with the same water hardness ($\alpha = 0.05$).

4.3.3 Colour values of wheat and bulgur samples

Since colour is the primary factor influencing the acceptance of food by the customer, the food industry has placed a higher priority on tracking and enhancing colour in order to produce food in the colour preferences of the consumer base. It is also the most crucial component in describing the quality of bulgur and products with higher brightness and yellowness values are favoured more (Clydesdale, 1993). Carotenoids are responsible for the golden colour of endosperm, while phenolic substances are linked to the dark colour of the wheat bran (Lachman et al., 2017). All bulgur samples show that cooking has a decreasing influence on the L* and a* values and an increasing effect on the b* and YI values. While the a* and YI values of all samples decreased as a result of drying and debranning processes, the L* value increased while the b* values did not change in a statistically significant way (*P*>0.05) (Table 4.3). Both after cooking and after drying and debranning, the colour values of the samples cooked with soft and hard water followed similar trends, whereas the samples cooked with very hard water showed distinct behaviours. While the process of removing bran did not increase the yellowness value of samples, it improved their brightness value, which helped the bulgur achieve the intended colour. The colour values of the bulgur samples showed that very hard cooking water has a negative effect on the colour and lowers the yellowness value of the bulgur. According to Enaru et al. (2021), this effect may be explained by the possibility that the anthocyanins in the bran of wheat may react with calcium ions in the water to form a blue colour (a decrease in b* value). This colour passes into the endosperm during cooking and cannot be eliminated by debranning. This mechanism is further supported by the observation that bulgur produced with very hard water has the highest total phenolic content.

Table 4.3 Colour values of Durum wheat and bulgur cooked using three cooking waters differing in hardness at different production stages

Sample	Hardness of CW*	L*	a*	b*	YI
Durum wheat (raw material)	-	52.64 ± 0.85Ab	9.38 ± 0.23Aa	25.85 ± 0.21Cc	75.51 ± 0.52Ba
Cooked wheat	53	50.83 ± 0.22Bx	8.76 ± 0.18Bx	32.45 ± 0.57Bx	86.88 ± 0.78Ax
	129	50.61 ± 0.55Bx	8.58 ± 0.14BCx	32.64 ± 0.31Ax	87.11 ± 1.15Ax
	269	50.20 ± 0.34Bx	8.33 ± 0.33Cx	31.70 ± 0.93Bx	85.68 ± 2.15Ax
Bulgur	53	67.11 ± 0.90ay	6.08 ± 0.24by	31.86 ± 0.51ax	69.98 ± 1.04by
	129	67.48 ± 0.45ay	6.05 ± 0.20by	31.93 ± 0.62ax	69.79 ± 1.06by
	269	67.45 ± 0.91ay	5.88 ± 0.28by	31.10 ± 0.34bx	68.43 ± 0.82cy

CW: cooking water. *calculated hardness of cooking water in mg/L of $CaCO_3$.

YI: yellowness index.

Displayed results are the mean of twice analyses on duplicate preparation of each batch± standard deviation (n=2×2).

a-d: Different lowercase letters within the same column represent significant differences between the wheat (raw material) and bulgur samples (α = 0.05).

A-D: Different capital letters within the same column represent significant differences between the wheat (raw material) and cooked wheat samples (α = 0.05).

x-y: Unequal letters within the same column represent significant differences between the cooked wheat and bulgur samples prepared with the same water hardness (α = 0.05).

4.3.4 Mineral content of wheat and bulgur samples

Minerals have a variety of roles in the body and because they are necessary for metabolism to function normally, a lack of them can lead to several illnesses. Because iron and zinc are immune system-related elements that also aid in the creation of enzymes, when their deficiencies are intolerably high in the body, they can be lethal (Gharibzahedi & Jafari, 2017). Although wheat and its product, bulgur, are also essential sources of wholesome nutrition since they are high in essential minerals, the mineral concentrations of both foods vary depending on the processing techniques used (Ragaee et al., 2006). Mineral distribution in wheat varies, with the majority of the minerals found in the bran. The findings of the mineral analysis (Fe, Zn, Mn, Ca and Na) for wheat, cooked wheat and bulgur produced with different levels of hardness in the cooking water are shown in Table 4.4. According to the findings, the processes of debranning and cooking have an adverse effect on the mineral content. Except for Ca ($P \leq 0.05$), all other minerals were reduced during cooking, although Fe was not significantly affected ($P > 0.05$). Additionally, the wheat that was cooked in very hard water showed a rise in calcium content that was in agreement with the results from previous research (Haring & Van Delft, 1981; Uzogara et al., 1992). The mineral amount results showed a decreasing trend during the debranning procedure; however, bulgur made with very hard water showed less mineral loss. Research has recently been conducted worldwide to reduce malnutrition caused by mineral deficiencies. (Gharibzahedi & Jafari, 2017). Therefore, the current study can support the development of production strategies for maintaining mineral content in food structure. More minerals are retained in bulgur made with very hard water because divalent cations (Ca, Mn and Zn) most likely form complexes with other substances, like phenolic compounds (Vinci et al., 2022) and then enter the endosperm (Ercan, 1986). As a result, compared to other samples, the mineral content of this product fluctuates less.

Table 4.4 Mineral content of Durum wheat and bulgur cooked using three cooking waters varying in hardness at different production steps

Sample	Hardness of cooking water*	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Ca (mg/kg)	Na (mg/kg)
Durum wheat (raw material)	-	42.04 ± 6.82Aa	36.18 ± 1.39Aa	33.04 ± 1.29Aa	205.65 ± 13.05Ba	39.41 ± 4.87BCc
Cooked wheat	53	36.92 ± 4.56Ax	34.45 ± 1.79Ax	27.96 ± 2.93Bx	193.32 ± 2.89Bx	71.18 ± 13.78Ax
	129	34.22 ± 4.91Ax	30.86 ± 2.40Bx	24.06 ± 2.78BCx	198.73 ± 2.11Bx	44.74 ± 7.72Bx
	269	35.61 ± 4.07Ax	31.17 ± 2.16Bx	23.58 ± 2.88Cx	223.74 ± 7.14Ax	28.73 ± 4.55Cx
Bulgur	53	17.80 ± 2.80bcy	27.65 ± 0.70by	7.04 ± 1.08cy	175.54 ± 7.20cy	53.56 ± 8.07cx
	129	15.31 ± 2.69cy	28.45 ± 2.67bx	5.10 ± 1.29dy	191.26 ± 7.77bcx	83.74 ± 0.39ax
	269	22.04 ± 3.15by	28.75 ± 0.97bx	25.95 ± 1.13bx	197.15 ± 6.45bx	60.67 ± 4.76by

*calculated hardness of cooking water in mg/L of $CaCO_3$. Mineral contents are indicated on a dry basis.

Displayed results are the mean of twice analyses on duplicate preparation of each batch± standard deviation (n=2×2).

a-d: Different lowercase letters within the same column represent significant differences between the wheat (raw material) and bulgur samples (α = 0.05).

A-D: Different capital letters within the same column represent significant differences between the wheat (raw material) and cooked wheat samples (α = 0.05).

x-y: Unequal letters within the same column represent significant differences between the cooked wheat and bulgur samples prepared with the same water hardness (α = 0.05).

4.3.5 Textural attributes of wheat and bulgur samples

The measured texture values of wheat, cooked wheat and bulgur samples are given in Table 4.5. Like pasta and rice, the texture of bulgur is a quality characteristic that greatly influences consumer choice. Following cooking, the hardness values of all the wheat samples made with varying hardness waters dramatically decreased. In addition, statistically significant ($P \leq 0.05$) reductions were found in the other texture characteristics (cohesiveness, gumminess, chewiness and resilience), with the exception of the springiness value of each sample group upon cooking. Drying and debranning did not affect any significant changes ($P > 0.05$) in the other bulgur samples; instead, it only raised the hardness value of bulgur produced with very hard water (5531.70g prior to drying and debranning and 6204.85g following drying and debranning). The outcomes of the study did not align with those of a previous paper (Yılmaz & Koca, 2020) because of variations in the texture assessment parameters, sample preparation, processing conditions during bulgur manufacture and granule size that resulted. Springiness, cohesiveness and resilience values of all samples were reduced by the drying and debranning processes, however, its effect on chewiness and gumminess varied. In this case, it is important to emphasise that every step in the bulgur production process has a decreasing impact on every textural attribute.

Table 4.5 Textural parameters of Durum wheat and bulgur prepared using three cooking waters differing in hardness at different production stages

Sample	Hardness of CW*	Hardness (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Durum wheat (raw material)	-	46965.05 ± 5094.59Aa	0.70 ± 0.06Aa	0.63 ± 0.05Aa	29872.59 ± 5389.39Aa	20992.35 ± 4408.81Aa	0.48 ± 0.05Aa
Cooked wheat	53	5352.80 ± 805.98Bx	0.72 ± 0.11Ax	0.57 ± 0.02Bx	3046.07 ± 446.72Bx	2192.50 ± 522.43Bx	0.36 ± 0.01Bx
	129	7941.47 ± 1167.95Bx	0.75 ± 0.05Ax	0.64 ± 0.02Ax	5138.19 ± 918.06Bx	3886.79 ± 910.26Bx	0.39 ± 0.01Bx
	269	5531.70 ± 389.15Bx	0.73 ± 0.12Ax	0.55 ± 0.03Bx	3031.11 ± 259.67Bx	2193.69 ± 168.80Bx	0.35 ± 0.01Bx
Bulgur	53	5944.01 ± 1337.94bx	0.50 ± 0.02by	0.44 ± 0.03cy	2584.92 ± 442.18bx	1286.26 ± 216.60bx	0.17 ± 0.01by
	129	6812.68 ± 772.03bx	0.53 ± 0.03by	0.49 ± 0.01by	3344.87 ± 446.19by	1779.69 ± 272.52by	0.17 ± 0.01by
	269	6204.85 ± 434.60by	0.48 ± 0.02by	0.44 ± 0.02cy	2737.61 ± 173.71bx	1323.76 ± 90.31by	0.16 ± 0.00by

CW: cooking water. *calculated hardness of cooking water in mg/L of $CaCO_3$.

Displayed results are the mean of twice analyses on duplicate preparation of each batch± standard deviation (n=2×2).

a-d: Different lowercase letters within the same column represent significant differences between the wheat (raw material) and bulgur samples (α = 0.05).

A-D: Different capital letters within the same column represent significant differences between the wheat (raw material) and cooked wheat samples (α = 0.05).

x-y: Unequal letters within the same column represent significant differences between the cooked wheat and bulgur samples prepared with the same water hardness (α = 0.05).

4.3.6 Mid FTIR spectra of wheat and bulgur produced

The FTIR transmittance spectra of wheat and bulgur samples made with varying hardness waters are displayed in Figure 4.1. The O-H stretching area from hydrogen bonding connected to the aliphatic and aromatic groups of alcohol and water is responsible for the peaks situated approximately at 3270 cm^{-1}. Based on previous research, it can be concluded that the C-H stretch bond is responsible for the peak at 2925 cm^{-1}, which is connected to lipids and saturated components. Starch and cellulose structures appear to be the source of these two peaks. The ester groups of cellulosic structures or the ester bonds of carboxylic groups are responsible for the small peak observed at 1744 cm^{-1}. The peaks in the bands of 1635 (amide I) and 1535 cm^{-1} (amide II), which corresponded to the stretching of C=O and the bending of N-H and C-N, respectively, were found to be peptides. Prior studies suggested that the peaks at 1368 and 1239 cm^{-1} might be connected to cellulosic structures and could be caused by C-H bond deformation. The deformation of several polysaccharides is also depicted by the branching peaks at 1150 and 1077 cm^{-1}. Based on evidence from Amir et al. (2013) and Bledzki et al. (2010), it is assumed that the deep peak at 995 cm^{-1} indicates C-OH bending, which is connected to β-glycosidic bonds. The acquired FTIR spectra verify that bulgur is chemically similar to wheat and that no significant structural changes occur during the production process. Ultimately, the FTIR spectrum demonstrates that there were no structural alterations brought about by the hardness of the water used to produce bulgur.

4.3.7 Controlling of starch gelatinization by thermal analysis

The starch in the wheat needs to be fully gelatinized after cooking in order to make bulgur. When water is added to wheat and heated during cooking, physicochemical changes take place, starch gelatinizes and the grain structure hardens and becomes glassy (Certel & Ertugay, 1992). The temperature range at which Durum wheat gelatinizes when utilised in manufacturing is 64–74 ºC (Figure 4.2), which is consistent with the value given by Certel & Ertugay (1992). The absence of a gelatinization peak in the bulgur samples indicates that the starch in the wheat has completely gelatinized and that the cooking process was completed correctly. This means that the gelatinization of bulgur was not significantly impacted by the hardness of the water.

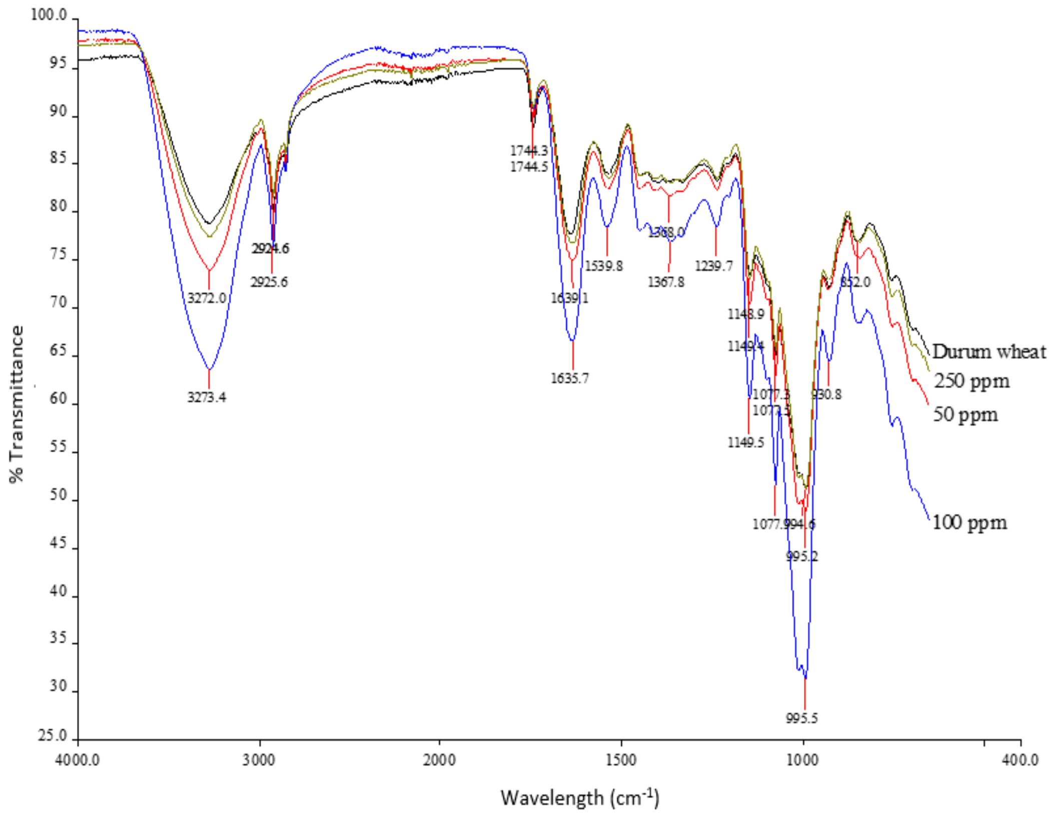

Figure 4.1 FTIR spectra of Durum wheat (raw material) and bulgur samples prepared with water having discrete hardness

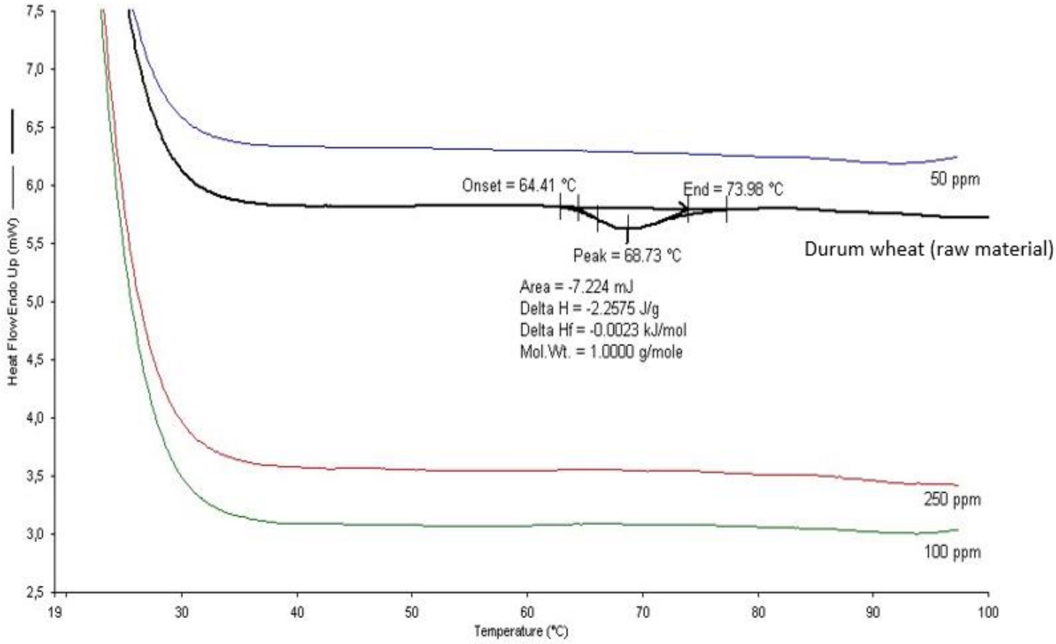

Figure 4.2 DSC thermograms of Durum wheat (raw material) and bulgur samples prepared with water having discrete hardness

4.3.8 Sensory assessment of uncooked (raw) and cooked (pilaf) bulgur samples

The primary factors that influence food purchases and maintain consumer preference and purchasing behaviour are its sensory qualities in addition to its nutritional qualities. As a result, performing sensory studies during production trials is crucial. In this context, the sensory properties of raw bulgur and cooked bulgur (pilaf) made with various hardened waters were examined and listed in Table 4.6. The yellowness values of the raw samples did not differ significantly (P>0.05) from the colour values, however the odour score decreased (P≤0.05) when the hard water was utilised. The colour and yellowness value of cooked bulgur (pilaf bulgur) were negatively impacted by very hard water. However, neither the cooked (pilaf) nor the uncooked overall acceptability of bulgur showed a significant difference (P>0.05) between the samples. Finally, the odour, taste and texture of the cooked bulgur samples (pilaf) were not significantly altered by the hardness of the water.

Table 4.6 Sensory assessment results of raw (uncooked) and cooked (pilaf) bulgur samples prepared using three cooking waters varying in hardness

Sample	Hardness of cooking water*	Raw Bulgur			Cooked Bulgur (Pilaf bulgur)				
		Odour	Yellowness	Overall Acceptability	Odour	Yellowness	Taste	Texture	Overall Acceptability
Fine bulgur	53	6.87 ± 0.83ab	6.93 ± 0.86a	6.93 ± 1.10a	7.43 ± 1.13a	7.17 ± 0.98a	6.83 ± 1.47a	6.71 ± 1.38a	6.71 ± 0.95a
	129	6.35 ± 0.94b	7.11 ± 0.76a	6.80 ± 0.94a	6.71 ± 0.95a	6.57 ± 0.53ab	6.33 ± 1.51a	6.57 ± 0.98a	6.14 ± 1.07a
	269	7.17 ± 0.96a	6.47 ± 0.95a	6.90 ± 1.21a	7.00 ± 0.82a	6.00 ± 1.10b	6.50 ± 1.22a	6.75 ± 0.89a	6.29 ± 0.76a

*calculated hardness of cooking water in mg/L of $CaCO_3$. (n=2×10).

a-d: Different letters in the same column represent significant differences between the bulgur samples produced with water having various hardness (α = 0.05).

4.4 Conclusions

The findings of the study showed that the hardness of the water used to cook wheat into bulgur affects the chemical, physical, functional and sensory qualities of bulgur. As a result, the hardness of water can be optimised to enhance its quality and minimise manufacturing problems. There were no apparent differences in the FTIR spectra of wheat and bulgur made with varying amounts of water hardness, indicating that water hardness does not affect the structural composition of bulgur. Although cooking wheat in very hard water lowers the mineral loss of bulgur at the end of production, it also lowers the yellowness value, which is thought to be the primary quality parameter for bulgur. Based on the results, it can be concluded that while water hardness has no impact on the textural characteristics of bulgur, very hard water negatively affects other characteristics by lowering the yellowness value. As a result, it is advised against using very hard water for making bulgur because it can negatively impact the colour and functional qualities of the product.

CHAPTER 5
THE INFLUENCE OF IRON CONTENT OF WATER AND PROCESSING ON THE QUALITY PROPERTIES OF BULGUR

Summary

Based on its versatility in a variety of cuisines, bulgur (a whole wheat product) has gained global notice recently. Wheat and water are the two main materials used to make bulgur. Bulgur quality has not been studied in relation to the composition of the water. Due to its ability to oxidise and react with phenolic substances while also firming the structure of foods, iron in water may affect the colour of food adversely. Thus, the impact of the iron content of water on bulgur quality was investigated in this study. Three distinct concentrations of iron (0, 1 and 2 ppm) in water were used to conduct the experiment to investigate the impact of iron levels on bulgur quality. The production of bulgur was negatively impacted by the use of water containing 2 ppm iron, which resulted in a decrement in the L* value and an increment in the YI. Antioxidant activity was also significantly decreased in bulgur made with water containing 2 ppm iron. When the water used to produce bulgur had up to 2 ppm of iron, the quality of the bulgur was not adversely affected. The amount of phenolic and mineral compounds in bulgur as well as its textural qualities were unaffected by the iron content of water. The colour and antioxidant activity of bulgur is thus adversely affected by excessive iron concentration in the cooking water. As a result, it is advised to produce bulgur using iron-free water.

5.1 Introduction

As wheat contains functional components such as unsaturated fatty acids, dietary fibre, minerals, vitamins and phytochemicals in addition to carbohydrates and proteins, consuming wheat products is an essential component of a balanced diet (Ficco et al., 2014; Solah et al., 2015). In terms of nutrition, bulgur is the wheat product that is most comparable to wheat. It has undergone pre-processing to make it more palatable, durable and easier to cook (Hayta et al., 2003; Narwal et al., 2020). Cooking, drying, tempering, debranning, milling and classifying are the primary steps in the production process (Heid, 1964; Ercan, 1986). Based on their sizes, bulgur can be divided into coarse and fine categories. Whereas fine bulgur is used to make tabbouleh and meatballs, coarse bulgur is typically used to make pilaf (Hayta et al., 2003). Although most bulgur is produced and consumed in Türkiye and the surrounding Middle Eastern and North African nations, Western countries have also searched for recipes which include bulgur (Heid, 1964; Yılmaz & Koca, 2020). Research also indicates that because of its use in tabbouleh salad, fine bulgur has become more popular in Europe due to migration from Africa and the Middle East and cultural interaction has made it an essential component of contemporary French cuisine (Maxwell, 2019; Maxwell & DeSoucey, 2016). Due to these factors, scientific research on bulgur has recently shown renewed interest. The qualities of the wheat, the water utilized in manufacturing, the cooking operation (because of water absorption) and the debranning operation (due to the loss of bioactive substances) are the most crucial quality parameters in the manufacturing of bulgur (Savas & Basman, 2016; Yılmaz & Koca, 2020). Despite the fact that the effects of processing methods and wheat varietals on bulgur quality have been researched and reported (Savas & Basman, 2016; Yılmaz & Koca, 2020) the influence of the chemical parameters of water has not been studied.

Although there is no health concern associated with iron in water, it may have an unpleasant taste and odour. Water supplies, machinery and piping systems in bulgur factories can all lead to iron contamination. In practical terms, bulgur producers are seeking the cause of the texture hardening and colour fading of grains. It is crucial to figure out the impact of iron within water in affecting the colour, texture and other quality attributes of bulgur through this research. In the food plants, well water that is safe microbiologically is frequently utilised. When pumped straight from a well, anaerobic groundwater can comprise several mg/L of ferrous iron without turbidity or discolouration. Water containing iron may cause reddish-brown discolouration by oxidation or reaction with phenolic chemicals in some foodstuffs. High levels of iron in water were shown to have serious negative effects in manufacturing and have an adverse impact on product quality in two dairy facilities that were examined. It was uncovered that the water of two the industries had 1.070 and 1.810 mg/L of iron, respectively (Boguniewicz-Zablocka et al., 2019). Due to the fact that water is the primary ingredient used in bulgur manufacture, its quality may be greatly impacted by the characteristics of the water used in its production. In light of this, the purpose of this study is to thoroughly examine the potential impacts of iron content (0, 1 and 2 ppm) on the various quality attributes (chemical attributes, mineral content, functional, colour, textural and thermal properties) of wheat, cooked wheat (in order to track the influence of cooking) and bulgur samples (in order to identify the integrated effect of drying and debranning).

5.2 Materials and methods

5.2.1 Chemicals

Hydrochloric acid (HCl), tungstophosphoric acid hydrate, hexane, methanol, 2,2-diphenyl-1-picrylhydrazyl (DPPH), sodium carbonate (Na_2CO_3), iron chloride ($FeCI_3$), Folin-Ciocalteu's reagent, Ca and Fe standard solutions for AAS were acquired from Sigma Co. (St. Louis, MO, USA), whereas Zn, Mn and Na standard solutions for AAS were obtained from Perkin Elmer Co. (PerkinElmer Inc., USA).

5.2.2 Materials and bulgur processing

Bulgur samples were prepared using Durum wheat (*Triticum durum* cv. Güneyyıldızı) from Tiryaki Agro Gıda San. ve Tic. Co (Gaziantep/Türkiye) and distilled water from A MilliQ Advantage A 10 (Molsheim, France). Water was adjusted to have 0, 1 and 2 ppm of iron using a 100 ppm $FeCI_3$ solution. The wheat (1 kg) was cooked by adding it to 1.8 L of boiling water (97 ºC). After that, a certain quantity of the cooked samples was taken and stored at -18 °C in plastic containers for further examinations (pH, mineral and chemical content, bioactive traits, colour and textural characteristics). Then, they were cooled and dried at 70 °C in a packed bed drier (MK II, Sherwood Scientific, England). After that, a debranner was used to separate the bran after it had been soaked to around 17% (Merba Makine, Mersin, Türkiye). The bulgur that was sized between 0.5 and 2 mm (fine bulgur) was finally reduced in size using a disc grinder (Tekpa Laboratory Systems, Ankara, Türkiye) and it was then placed in plastic containers and kept at +4 °C to be utilised in subsequent experiments. Along with the previously described examinations of cooked wheat, investigations using differential scanning calorimetry (DSC) and Fourier-transform infrared spectroscopy (FTIR) were conducted on wheat and bulgur samples. Analysis of bulgur was done at fine-sized bulgur.

5.2.3 Determination of chemical and colour attributes

The chemical properties and colour parameters of the wheat, cooked wheat and bulgur samples were the same as given in section 3.2.3.

5.2.4 Assessment of functional properties

Total phenolic contents and antioxidant activities were determined after acquiring the extracts of the samples by following the procedures indicated in section 3.2.4.

5.2.5 Quantification of mineral content

The amount of minerals was specified by the method provided in section 3.2.5.

5.2.6 Determination of textural parameters

The two-cycle compression method as detailed in section 3.2.6 was applied for detection of the textural properties of the samples.

5.2.7 Infrared Spectroscopy (FTIR) measurements

The infrared spectrum of wheat and fine bulgur samples was collected by following the same method provided in section 3.2.7.

5.2.8 Measurement of thermal properties

The DSC profile of wheat and fine bulgur samples was achieved by the same method indicated in section 3.2.8.

5.2.9 Sensory evaluation of bulgur samples

The sensory characteristics of uncooked (raw) and cooked bulgur (pilaf) samples were realized by 12 trained panellists for those familiar with eating bulgur and those not. The samples were evaluated by 3 Africans (Botswana, via Erasmus + program), 1 Tunisian (via Erasmus + program), 1 Iraqi and 7 Turkish panellists aged between 26-56 years. Before the evaluation was made, the panellists were trained in the characteristics of bulgur and the scoring method. Yellowness and overall acceptability of uncooked and cooked bulgur samples were scored considering a 9-point (1-dislike extremely, 9-like extremely) hedonic scale. Nevertheless, in the evaluation of odour, 1 indicates the lowest iron odour, while 9 indicates the highest. For cooked bulgur samples (pilaf), bulgur was cooked in water (1:2, w/v) until entire the water was absorbed and then cooled to room temperature. 5 g of sample was served on a plate randomly coded with 3-digit numbers. Each sample was evaluated by the panellists two times. Inspections were conducted in separate cabinets enlightened with white light. Duplicate preparations of samples were served to the assessors at two different sessions on the same day. The ethical approval of this study was obtained from the Research Ethics Committee of Gaziantep University (File number: 424187).

5.2.10 Statistical analysis of the results

The data were presented as the mean and standard deviations of a minimum of four measurements. All analyses were conducted as two experiments of duplicate manufacturing of each sample group. The statistical evaluation was conducted by applying the same method in section 3.2.10.

5.3 Results and discussion

The bulgur factories use well water that satisfies microbiological standards for manufacturing operations, which is stored in steel or iron tanks. Consequently, the soluble iron in well water as well as the transfer from iron tanks, pipelines and equipment to water may result in an increment in the concentration of iron in the water, which could affect the qualitative characteristics of bulgur, particularly the occurrence of hard texture and darkening. These facts led to the design of this study, which evaluated the impact of iron levels (0, 1 and 2 ppm) of water on different aspects of the quality of cooked wheat and bulgur. The producers and researchers may benefit from the findings of the study to figure out more about iron in water product quality.

5.3.1 Chemical composition

The chemical properties (pH, total dry matter, total ash, fat, protein and starch content) of the wheat, cooked wheat and bulgur samples are presented in Table 5.1. The pH of the cooked wheat ascended in proportion to the rise in the iron concentration of the cooking water. This may be because there is a concentration differential between the water and the wheat, allowing more acidic compounds to pass into the water. Additionally, iron reduces acidity and raises pH when it develops complexes with acidic compounds like phytic acid (Marolt et al., 2020). Following debranning and drying, there was a significant rise ($P \leq 0.05$) in the pH of the samples made using water containing 0 and 1 ppm of iron. The cause of this might be that, after cooking, the majority of the acidic substances in these samples were located in the bran portion and were eliminated along with the bran.

Table 5.1 illustrates that the dry matter content of wheat is 90.32% (w.b.). The dry matter in every sample group diminished significantly ($P \leq 0.05$) as a result of water absorption throughout the cooking process. The dry matter content of samples of cooked wheat and fine bulgur was found to be unaffected by the iron content of the cooking water. Following drying and debranning, it was noted that the dry matter content increased to more than 88% (w.b.). For a hard texture to form after cooking, it is essential to use high-protein wheat varieties, such as *Triticum durum*, during the manufacturing procedure (Koca & Anıl, 1996). However, there were no significant variations ($P > 0.05$) observed in the protein levels of the fine bulgur and cooked wheat samples made with various water types.

The fat results show that all cooked wheat samples and all bulgur samples had lower fat contents than wheat (1.62%, d.b.). Similar results were reported by Koca & Anıl (1996) in relation to fat, which could explain this decline. The effect of drying and debranning processes on the quantity of fat in bulgur is not significant since the amount of fat in the same sample groups after the drying and debranning processes is consistent with the results of post-cooking. Bran removal leads to an increase in the amount of fat in the dry matter, which is the source of the increase in fat content following the drying and debranning operations. In wheat, starch serves as the primary energy source. Following cooking, all samples showed a decrease in comparison to wheat; however, starch levels in the cooked wheat rose in harmony with the increase in iron levels. The development of the iron-starch complex may be related to this (Somsook et al., 2005). Following the drying and debranning operations, there were no significant variations ($P > 0.05$) observed among the samples. According to earlier research (Koca & Anıl, 1996; Savas & Basman, 2016), wheat contains ash in the range of 1.25-1.85% (d.b.) and the amount varies according to the type of wheat and growing environment, which is in line with the results. The results showed that there was no statistically significant difference ($P > 0.05$) between the ash content of samples and the amount of iron.

Table 5.1 Chemical characteristics of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at varied levels

Sample	Iron content of CW (ppm)	pH	Dry matter (g/100g)	Protein (g/100g)	Fat (g/100g)	Starch (g/100g)	Ash (g/100g)
Durum wheat (raw material)	-	6.32 ± 0.01Ac	90.32 ± 0.13Ab	13.95 ± 0.24Aa	1.62 ± 0.06Aa	64.88 ± 0.65Ab	1.63 ± 0.08Aa
Cooked wheat	0	5.58 ± 0.01B	53.08 ± 0.16B	13.25 ± 0.51B	1.17 ± 0.14BC	59.30 ± 0.34D	1.59 ± 0.21A
	1	6.21± 0.02A	53.55 ± 0.74B	12.79 ± 0.32B	1.06 ± 0.01C	60.13 ± 0.42C	1.46 ± 0.09A
	2	6.48 ± 0.36A	53.06 ± 1.50B	13.21 ± 0.34B	1.23 ± 0.11B	60.82 ± 0.31B	1.69 ± 0.21A
Fine bulgur	0	6.41 ± 0.01b	88.68 ± 0.53c	13.37 ± 0.14ab	1.41 ± 0.06bc	66.11 ± 0.66a	1.50 ± 0.08a
	1	6.41 ± 0.01b	90.46 ± 0.36b	13.45 ± 0.18b	1.35 ± 0.06c	66.90 ± 0.67a	1.50 ± 0.17a
	2	6.45 ± 0.02a	91.26 ± 0.19a	13.16 ± 0.11b	1.49 ± 0.06b	67.06 ± 0.91a	1.48 ± 0.11a

CW: cooking water. Chemical properties except for dry matter are specified on a dry base.

The outcomes are the average of twice analyses on double production of each sample group ± standard deviation.

a-c: Dissimilar small letters in the same column represent significant variations between the wheat and fine bulgur samples (α = 0.05).

A-D: Dissimilar uppercase letters in the same column represent significant variations between the wheat and cooked wheat samples (α = 0.05).

5.3.2 Functional characteristics

Due to its high phytochemical content, wheat can reduce oxidative stress and thus have antioxidant properties that can restrain a variety of diseases. In wheat, the outer portions of the grain contain the majority of the phenolic compounds (Fares et al., 2010). Table 5.2 displays the bioactive attributes, which include total phenolic content and antioxidant capacity. It may be inferred from the total phenolic content results that the cooked wheat samples steadily decreased as the iron content increased. The reason for this could be that, because anthocyanins are soluble in water, after cooking these components move from the bran into the water. The decreased amount of phenolics in cooked wheat processed with water containing 2 ppm iron can be explained by the interaction of iron with phenolic compounds (Enaru et al., 2021; Ficco et al., 2014). There were no significant differences (P>0.05) in the total phenolic content of bulgur samples made with water that contained varying concentrations of iron. Nevertheless, the variations between cooked wheat samples and wheat were insignificant (P>0.05), wheat cooked in water containing iron (1 and 2 ppm) indicated an increment. In both the bulgur and cooked wheat samples, there is an inverse relationship between total phenolic content and antioxidant capacity. Correlations that are compatible have also been obtained by other researchers. This could be a result of samples exhibiting better antioxidant activity that includes fewer phenolic compounds (Nenadis & Tsimidou, 2010).

5.3.3 Colour properties

Customers prefer brilliant yellow colour bulgur, which is considered one of the key quality characteristics (Yılmaz & Koca, 2020). The colour compounds in wheat and eventually bulgur comprise mainly carotenoids (mostly situated in the endosperm) and anthocyanins (usually particularly located in the bran) (Ficco et al., 2014). In contrast to wheat, the b* and YI values increased as the wheat cooked, but the L* and a* values declined. The drying and debranning operations caused the opposite effect (Table 5.2). The primary cause of the colour changes that occur while cooking is the release of anthocyanins into the water; in contrast, colour changes occur after the drying process as a result of the bran separation. The results indicate that up to 2 ppm of iron in the cooking water, there is no significant difference in the colour of bulgur. The bulgur samples showed an increase in L* and b* values (P≤0.05) when compared to wheat, resulting in the achievement of the intended brilliant yellow colour in bulgur manufacturing.

5.3.4 Mineral content

Adequate mineral intake is important since minerals are essential for metabolic activities. Even though grains are one of the main sources of minerals for diet, processing may lower the content of minerals. Elements including Ca, Na, Fe, Zn and Mn are found in wheat and their amounts vary depending on the variety and growth circumstances (Piironen et al., 2009). The findings demonstrate that the iron content of cooked wheat samples was lower than that of raw wheat and that the cooked wheat made with water containing 1 ppm of iron exhibited a significant ($P \leq 0.05$) difference from wheat (Table 5.3). This is related to the mass transfer of iron from wheat to water. Zn showed a similar tendency as well. There was a decrease in Fe and Zn due to the debranning operation. Less Mn was detected in all cooked wheat samples than in wheat ($P \leq 0.05$). On the other hand, after the drying and debranning operations, this impact dissipated and no significant variations ($P > 0.05$) were identified between the Mn contents of bulgur samples. The transfer of Mn into wheat during cooking may be the cause of the eradication of differences following drying and debranning operations.

The results of calcium revealed that all cooked wheat and bulgur samples had less calcium than wheat. This occurs as a result of Ca entering the water during cooking and then being eliminated during the debranning operation. There is no statistically significant difference ($P > 0.05$) in the levels of Ca between the sample groups for either the bulgur or cooked wheat samples. All cooked wheat samples showed a decrease ($P \leq 0.05$) in Na when compared to raw wheat. Regarding Na, no statistically significant difference ($P > 0.05$) was found between the sample groups in cooked wheat. Na varies between bulgur samples and wheat as well as between bulgur sample groups that were produced.

Table 5.2 Functional and colour properties of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at varied levels

Sample	Iron content of CW (ppm)	Total phenolic content (mg/GAE kg, d.b.)	Antioxidant capacity (% Inhibition)	L*	a*	b*	YI
Durum wheat (raw material)	-	1057.85 ± 38.39Aa	87.92 ± 0.27ABa	52.64 ± 0.85Ac	9.38 ± 0.23Aa	25.85 ± 0.21Bb	75.51 ± 0.52Ba
Cooked wheat	0	941.19 ± 63.03B	87.45 ± 0.61B	50.61 ± 0.37B	8.92 ± 0.17BC	33.33 ± 0.25A	88.63 ± 0.86A
	1	871.38 ± 35.66B	88.76 ± 0.85A	50.60 ± 0.46B	8.99 ± 0.21B	32.99 ± 0.91A	88.22 ± 1.15A
	2	779.29 ± 45.51C	88.73 ± 0.71A	51.27 ± 0.40B	8.69 ± 0.07C	33.27 ± 0.57A	87.58 ± 0.56A
Fine bulgur	0	698.91 ± 25.44b	85.72 ± 0.39c	67.35 ± 0.28b	6.21 ± 0.20b	30.62 ± 0.24a	68.16 ± 0.75bc
	1	679.77 ± 36.19b	90.02 ± 0.92a	68.02 ± 0.60a	5.95 ± 0.17b	30.43 ± 0.53a	67.17 ± 1.11c
	2	709.05 ± 28.20b	81.79 ± 0.32d	66.93 ± 0.56b	6.16 ± 0.11b	30.74 ± 0.64a	68.57 ± 1.10b

CW: cooking water. d.b: dry base. GAE: gallic acid equivalent. YI: yellowness index.

The outcomes are the average of twice analyses on double production of each sample group ± standard deviation.

a-c: Dissimilar small letters in the same column represent significant variations between the wheat and fine bulgur samples (α = 0.05).

A-D: Dissimilar uppercase letters in the same column represent significant variations between the wheat and cooked wheat samples (α = 0.05).

Table 5.3 Mineral concentrations of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at varied levels

Sample	The iron content of cooking water (ppm)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Ca (mg/kg)	Na (mg/kg)
Durum wheat (raw material)	-	42.04 ± 6.82Aa	36.18 ± 1.39Aa	33.04 ± 1.29Aa	205.65 ± 13.05Aa	38.15 ± 3.88Ac
Cooked wheat	0	34.71 ± 4.96AB	33.01 ± 3.31AB	22.55 ± 1.75B	169.73 ± 7.40B	19.23 ± 6.19B
	1	33.19 ± 4.85B	31.54 ± 1.93B	19.96 ± 0.04B	162.78 ± 4.44B	24.76 ± 3.09B
	2	37.54 ± 0.14AB	34.51 ± 0.52AB	16.68 ± 2.75C	175.77 ± 11.59B	20.97 ± 2.43B
Fine bulgur	0	18.73 ± 0.11b	26.58 ± 0.95b	22.67 ± 1.25b	149.12 ± 4.30b	72.54 ± 7.72a
	1	20.91 ± 3.00b	26.46 ± 0.59b	24.28 ± 1.21b	147.76 ± 2.03b	59.56 ± 5.49b
	2	22.01 ± 2.64b	25.72 ± 1.02b	22.99 ± 0.13b	144.31 ± 2.33b	36.18 ± 7.09c

Mineral contents are expressed on a dry basis.

The outcomes are the average of twice analyses on double production of each sample group ± standard deviation.

a-c: Dissimilar small letters in the same column represent significant variations between the wheat and fine bulgur samples (α = 0.05).

A-D: Dissimilar uppercase letters in the same column represent significant variations between the wheat and cooked wheat samples (α = 0.05).

5.3.5 Thermal properties

The primary determinant of proper bulgur cooking during bulgur production is the gelatinization of starch. Water addition and heating bring about physicochemical modifications in wheat, resulting in the gelatinization of the starch that makes the grain structure firm and glassy (Certel & Ertugay, 1992). As can be seen from Figure 5.1, the gelatinization temperature of the starch of Durum wheat is detected in the interval of 64-74 ºC. The lack of a gelatinization peak in the bulgur samples indicates that the cooking process was completed appropriately and the wheat was fully gelatinized. Thus, the gelatinization of starch in the wheat was not notably impacted by the iron content of the cooking water.

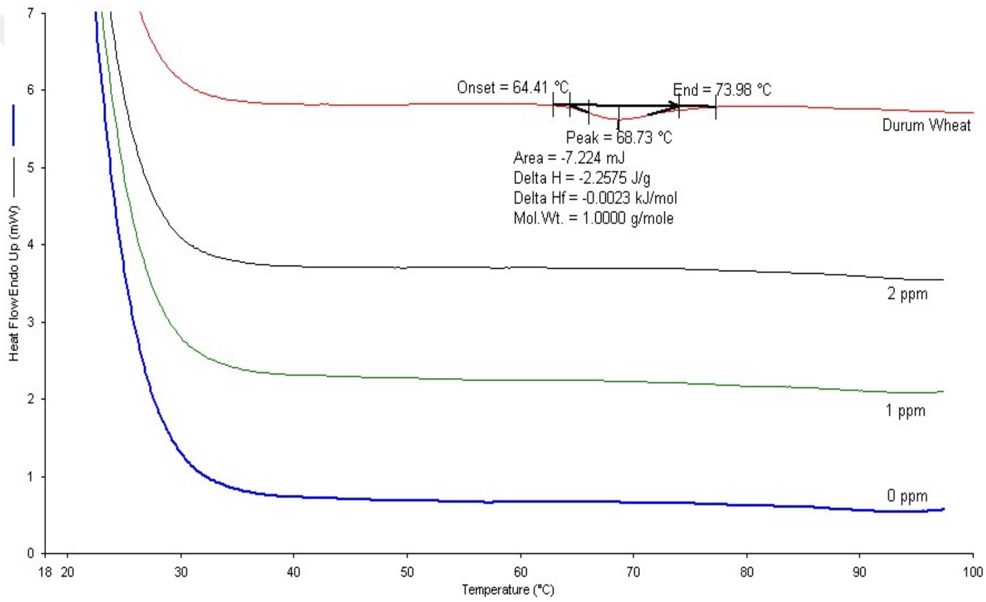

Figure 5.1 Thermal analysis plot of wheat and bulgur samples

5.3.6 Assessment of FTIR spectra

The FTIR spectra of the wheat and bulgur samples showed various bands, indicating the components they contain (Figure 5.2). Based on earlier research, it is inferred that the peaks ranging from 1150 to 840 cm^{-1} correspond to polysaccharides. The deep peak located at 995 cm^{-1} in the middle of this band signifies C-OH bending, which is connected to β-glycosidic bonds. Peaks at 1368 and 1239 cm^{-1}, may be the result of C-H bond breakage and be linked to cellulosic conformation. Peaks in the bands of 1643 (amide I) and 1533 cm^{-1} (amide II) were used to identify the peptides responsible for the stretching of C=O and C-N, as well as the bending of N-H. The connections of esters with cellulosic or carboxylic groups are relevant to the tiny peak seen at 1744 cm^{-1}. Previous studies have indicated that starch and cellulose groups were responsible for the peaks at approximately 3285 and 2924 cm^{-1}. The former investigations indicate that the C-H and C=O stretch bonds, which are linked to lipids, are the cause of the peak at 2925 cm^{-1}. Finally, the peaks at nearly 3270 cm^{-1} are caused by the O-H bonds, which are linked to the structures of alcohol and water (Amir et al., 2013; Bledzki et al., 2010). By analysing the obtained FTIR spectra, it can be concluded that bulgur and wheat are nearly chemically identical, with no notable conformational changes noticed during the production process. Consequently, the FTIR spectrum demonstrates that the iron content of the cooking water used to make bulgur did not cause any structural changes.

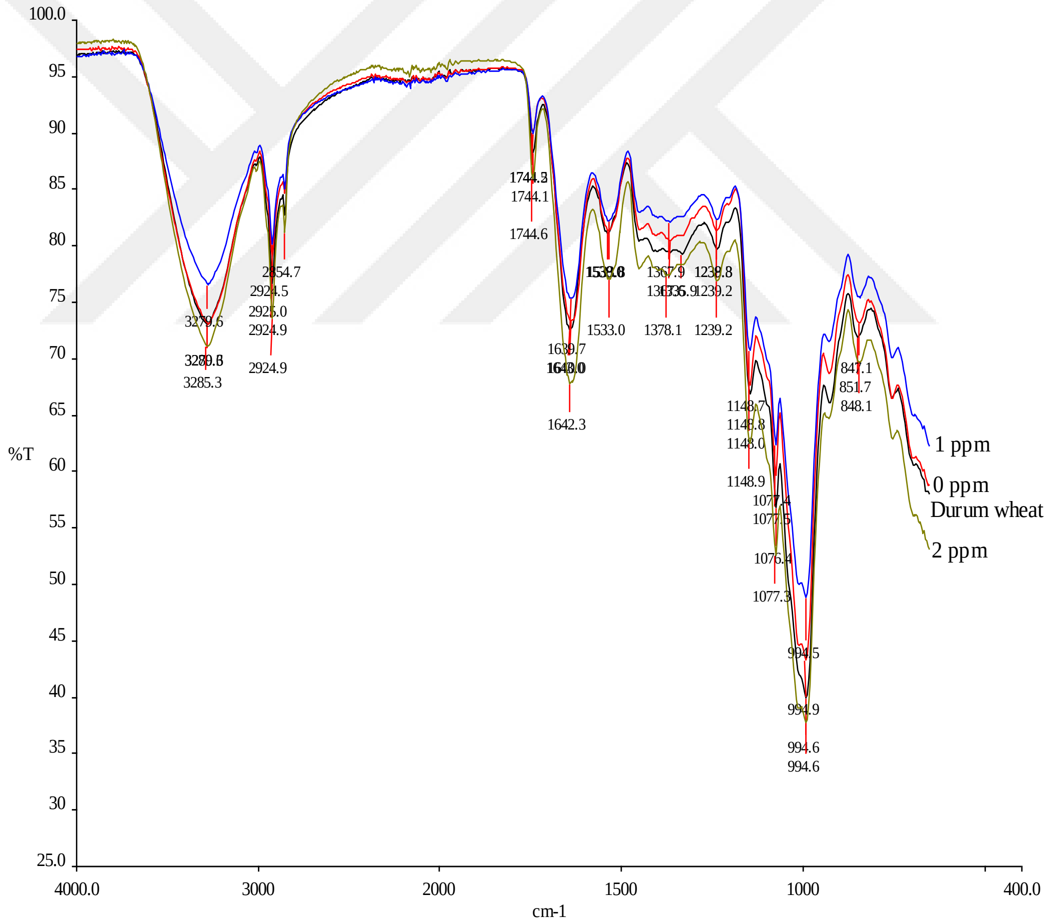

Figure 5.2 FTIR spectra of wheat and bulgur samples

5.3.7 Texture profile analysis

The influence of cooking, and drying and debranning operations on the textural parameters of wheat is indicated in Table 5.4. For all cooked wheat sample groups, there were no significant changes (*P*>0.05) in the cohesiveness and springiness results. All of the cooked wheat values of the sample groups showed lower values (*P*≤0.05) as compared to raw wheat in terms of hardness, gumminess, chewiness and resilience. The texture of bulgur is significantly influenced by cooking, and drying and debranning operations, as seen by the decrease in all texture profile characteristics examined for all fine bulgur samples when compared to wheat. Additionally, it was determined that the bulgur sample made by cooking without iron (0 ppm) had lower resilience, cohesiveness, hardness and gumminess values than other bulgur samples. Since the difference appeared after the drying process, this may have more to do with the moisture content of samples than the iron content in the cooking water.

5.3.8 Sensory evaluation

In addition to their nutrient and functional attributes, sensory characteristics also play a crucial role in the purchasing of foods consistently. Thus, sensory tests must be carried out in the pilot production to specify the acceptability of the product by the consumer. From this perspective, the sensory properties of raw and cooked (pilaf) fine bulgur samples produced with cooking water containing different amounts of iron (0, 1 and 2 ppm) were determined and represented in Table 5.5. The odour scores of raw bulgur samples remained statistically almost the same up to 2 ppm iron content of cooking water used in the production whereas the odour was affected adversely after 2 ppm of iron content (*P*≤0.05). In parallel with the colour analysis, no significant difference (*P*>0.05) was detected between the yellowness values of raw bulgur samples. On the other hand, raw bulgur samples that were produced using iron-free cooking water were found to be superior to those containing iron in terms of overall acceptability. Nevertheless, it was noted that these effects disappeared (*P*>0.05) when the samples were cooked and no significant variations were specified between the yellowness, odour and acceptability values of the samples after cooking.

Table 5.4 Texture results of wheat, cooked wheat and fine bulgur produced with three cooking waters containing iron at varied levels

Sample	The iron content of cooking water (ppm)	Hardness (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Durum wheat (raw material)	-	46965.05 ± 5094.59Aa	0.70 ± 0.06Aa	0.63 ± 0.05ABa	29872.59 ± 5389.39Aa	20992.35 ± 4408.81Aa	0.48 ± 0.05Aa
Cooked wheat	0	6302.40 ± 223.35B	0.65 ± 0.07A	0.58 ± 0.04B	3683.81 ± 303.08B	2381.70 ± 252.48B	0.37 ± 0.03B
	1	9130.21 ± 961.60B	0.74 ± 0.07A	0.64 ± 0.03AB	5892.28 ± 858.64B	4410.78 ± 1020.14B	0.38 ± 0.02B
	2	9004.26 ± 682.55B	0.72 ± 0.03A	0.67 ± 0.03A	6083.93 ± 658.72B	4408.21 ± 501.47B	0.39 ± 0.02B
Fine bulgur	0	8668.39 ± 693.35c	0.48 ± 0.07b	0.39 ± 0.01c	3364.07 ± 332.29c	1634.57 ± 387.55b	0.17 ± 0.01c
	1	14380.57 ± 1379.31b	0.49 ± 0.04b	0.45 ± 0.01b	6492.41 ± 790.69bc	3146.10 ± 331.90b	0.24 ± 0.02b
	2	17618.12 ± 2138.29b	0.54 ± 0.06b	0.47 ± 0.02b	8302.68 ± 1414.61b	4455.02 ± 986.71b	0.26 ± 0.02b

The outcomes are the average of twice analyses on double production of each sample group ± standard deviation.

a-c: Dissimilar small letters in the same column represent significant variations between the wheat and fine bulgur samples (α = 0.05).

A-D: Dissimilar uppercase letters in the same column represent significant variations between the wheat and cooked wheat samples (α = 0.05).

Table 5.5 Sensory assessment of raw and cooked (pilaf) fine bulgur samples

Sample	Iron content of CW (ppm)	Raw			Cooked (Pilaf)		
		Odour	Yellowness	Overall Acceptability	Odour	Yellowness	Overall Acceptability
Fine bulgur	0	1.17 ± 0.31b	6.97 ± 1.09a	7.29 ± 0.89a	3.7 ± 1.5a	6.11 ± 2.20a	6.57 ± 1.40a
	1	1.27 ± 0.37b	6.17 ± 1.14a	6.53 ± 0.81b	4.0 ± 2.4a	7.00 ± 1.50a	7.50 ± 1.31a
	2	1.57 ± 0.42a	6.64 ± 1.20a	6.42 ± 1.08b	4.8 ± 2.0a	6.11 ± 1.36a	6.86 ± 1.07a

CW: cooking water. (n=2×10).

a-d: Dissimilar letters within the same column represent significant variations between different bulgur samples (α = 0.05).

5.4 Conclusions

The findings of the study demonstrated that the use of iron content of cooking water at 2 ppm in bulgur production resulted in a decrement in the L* value while improving the YI value and affecting the colour adversely. Based on the DSC graph, it has been determined that wheat starch gelatinized appropriately in all samples during the bulgur production process. There is no significant difference in the proximate compositions of bulgur samples depending on the iron content of the cooking water. The iron level of the cooking water had a variable effect on the mineral content of the cooked wheat samples, but the debranning procedure removed this effect. Thus, it can be concluded that there are no remarkable variations in the textural characteristics of cooked wheat and fine bulgur samples due to the iron concentration of the cooking water. However, it can be advised that water with more than 1 ppm iron not be used in the manufacturing of bulgur because of the potential adverse effects on colour and antioxidant activity.

CHAPTER 6
CONCLUSIONS

In the bulgur production industry, obtaining brilliant yellow bulgur is crucial since it is more favoured by customers. Therefore, in the bulgur industry, efforts are ongoing to optimize bulgur colour at all stages of production.

The cooking process is one of the most critical stages in bulgur production as it is the operation that has the most impact on the transformation of wheat into bulgur. Although the effects of wheat type on bulgur quality in bulgur production have been examined, the effect of the chemical composition of water, which is the most used component in bulgur production in quantity, on bulgur quality has been neglected and not investigated.

The present research was carried out to examine the influences of acidity, hardness and iron content, which are the most important chemical properties of water used in bulgur production, on bulgur quality, to elucidate the effects of these variables, whose effects are not completely known in the bulgur industry, on bulgur quality and to fill the gap in the literature on this subject.

The study disclosed that;

- The acidity, hardness and iron content of cooking water of wheat to produce bulgur can be used as a tool to improve the colour of bulgur and regulate excess water remaining after wheat cooking.
- The highest amount of mineral content in the post-cooking water (Fe, 2.28 mg/L; Ca, 46.02 mg/L; Zn, 15.40 mg/L) was found in the most acidic water, while the lowest mineral content except for Zn was in the most alkaline water.
- The substance transfer rate from wheat to water during cooking and the gelatinization reaction of starch in the structure of wheat comply with the zero-order reaction model.

- Since cooking with extremely acidic and alkaline water causes more substances to transfer into the cooking water, the wastewater resulting from cooking with these waters can be more harmful to the environment, as they have high pH values (for the cooking water having pH 3, the pH after cooking is 4.99, for the cooking water having pH 11, the pH after cooking is 9.48) and contain more organic matter that can be used by microorganisms and increase the BOD value of wastewater.
- Cooking with soft water increased the rate of Brix, hardness, turbidity and changed the L* and b* values and led more substances to transfer into water.
- The gelatinization rate of wheat during cooking was soft water > hard water > very hard water. Therefore, it has been determined that as water hardness increases, cooking time also increases and the amount of energy required for cooking also increases.
- The amount of Mn (7.86 mg/kg dry matter) and Ca (161.41 mg/kg dry matter) in bulgur prepared with extremely alkaline water (pH 11) significantly ($P \leq 0.05$) decreases.
- Cooking with extremely alkaline water (pH 11) has a negative influence on the colour of wheat and causes darkening problems.
- Cooking water acidity had no significant effect ($P > 0.05$) on the texture parameters (hardness, springiness, gumminess, chewiness and resilience) of bulgur.
- In the evaluations made by the panellists on uncooked bulgur, it was determined that the odour, yellowness and general acceptability scores of bulgur produced with extremely alkaline (pH 11) water were lower than other samples.
- For the cooked bulgur (pilaf) samples, the bulgur prepared with alkaline water was found to be less acceptable than bulgur produced with acidic and neutral water, according to the assessment of the panellists.
- Water hardness did not have a significant effect ($P > 0.05$) on bulgur texture, but there was a decrease in the yellowness values of bulgur produced with very hard water.
- As a result of the sensory analysis of cooked bulgur (pilaf) samples, the most desirable bulgur products in terms of yellowness were determined as soft water > hard water > very hard water, respectively. However, it was determined that

these products did not show any significant difference ($P>0.05$) in terms of acceptability.

- The amounts of ash, Fe, Mn and Ca were higher ($P\leq 0.05$) in bulgur produced with very hard water than in others.
- The effect of the iron content of the cooking water on the proximate composition (moisture, ash, protein, fat and starch content), total phenolic and mineral content of bulgur was not statistically significant ($P>0.05$).
- The iron content of the cooking water had no significant effect ($P>0.05$) at the levels of 0, 1, and 2 ppm on the colour and texture of bulgur.
- The presence of very high amounts of iron (2 ppm) in cooking water had a negative effect ($P\leq 0.05$) on antioxidant activity.
- The general acceptability scores of bulgur manufactured with iron-containing waters were shown to be lower in the evaluation of panellists for the uncooked bulgur samples; however, this effect was eliminated in the cooked samples.
- FTIR analysis showed that the chemical composition of water did not cause a change in the structure of bulgur and that bulgur structurally contained all the components in wheat and therefore its structure was similar to wheat.
- Debranning operation reduces the amount of phenolic substances in bulgur, regardless of the chemical composition of the cooking water.
- The influence of pH, hardness and iron content of water on the quality of bulgur can be summarized as follows:

Parameter	Moisture content	Ash content	Protein content	Fat content	Starch content	L*	a*	b*	YI	TPC	AA	Ca	Fe	Mn	Zn	Na	Hardness
pH	S	S	S	S	S	S	S	S	S	S	S	S	NS	S	NS	S	NS
Hardness	S	S	NS	S	S	NS	NS	S	S	NS	S	S	S	S	NS	S	NS
Iron	S	NS	NS	S	NS	S	NS	NS	S	NS	S	NS	NS	NS	NS	S	S

S: Significant effect; NS: Non-significant effect (at $\alpha = 0.05$ level). YI: Yellowness Index. TPC: Total Phenolic Content. AA: Antioxidant activity.

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PROJECTS

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PUBLICATIONS

Refereed Journal Articles

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- **Michel, S.**, Bayram, M. (2024). Influence of cooking water hardness on the chemical, colour and textural characteristics of bulgur at different processing stages. *Journal of Cereal Science*, 115, 103826.
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Conference Papers Published in Refereed Proceedings

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