Influence of genotype, environment and post-harvest processing on quality of wheat grain (*Triticum aestivum*) – a review

Influência do genótipo, ambiente e processamento pós-colheita na qualidade do grão de trigo (*Triticum aestivum*) – uma revisão

Influencia del genotipo, el medio ambiente y el procesamiento posterior a la cosecha en la calidad del grano de trigo (*Triticum aestivum*): una revisión

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ABSTRACT
Wheat has been gaining ground and increasing its visibility due to its unique composition and the amount of bioactive compounds that are beneficial to human health. It has now been proven that the genotype and the growing environment have a major influence on the grain's technological properties, as well as on the bakery properties, which is the largest sector in which wheat is used. With a high demand for production, it is also important to take into account the management during the drying and storage process, so that there are no significant losses of bioactive compounds and dry mass of the grain. The aim of this study was therefore to cover the latest research about the influence of genotype, environment and processing on the bioactive compounds, technological and baking properties of wheat grains.

Keywords: wheat, genotype, growing environment, processing, technological parameters, nutritional properties.

RESUMO
O trigo vem ganhando espaço e aumentando sua visibilidade devido à sua composição única e à quantidade de compostos bioativos benéficos à saúde humana. Está agora comprovado que o genótipo e o ambiente de cultivo têm uma grande influência nas propriedades tecnológicas do grão, bem como nas propriedades da panificação, que é o maior setor em que o trigo é utilizado. Com uma grande demanda de produção, também é importante levar em consideração o manejo durante o processo de secagem e armazenamento, para que não haja perdas significativas de compostos bioativos e de massa seca do grão. O objetivo deste estudo foi, portanto, cobrir as pesquisas mais recentes sobre a influência do genótipo, do ambiente e do processamento nos compostos bioativos, nas propriedades tecnológicas e de panificação dos grãos de trigo.
Palavras-chave: trigo, genótipo, ambiente de cultivo, processamento, parâmetros tecnológicos, propriedades nutricionais.

RESUMEN
El trigo ha ido ganando terreno y aumentando su visibilidad debido a su composición única y a la cantidad de compuestos bioactivos que son beneficiosos para la salud humana. Ahora se ha comprobado que el genotipo y el entorno de cultivo tienen una gran influencia en las propiedades tecnológicas del grano, así como en las propiedades de la panadería, que es el sector más grande en el que se utiliza el trigo. Con una alta demanda de producción, también es importante tener en cuenta la gestión durante el proceso de secado y almacenamiento, para que no haya pérdidas significativas de compuestos bioactivos y masa seca del grano. El objetivo de este estudio fue, por lo tanto, cubrir las últimas investigaciones sobre la influencia del genotipo, el medio ambiente y el procesamiento en los compuestos bioactivos, las propiedades tecnológicas y de cocción de los granos de trigo.

Palabras clave: trigo, genotipo, ambiente de cultivo, procesamiento, parámetros tecnológicos, propiedades nutricionales.

1 INTRODUCTION
Wheat production has increased dramatically over the years achieving 796.6 million tons in 2023 (ABITRIGO, 2022). The increase in world wheat production is related to the expansion of cultivation areas and advances in genetic improvement, taking into account the climate changes that have been taking place over the years.

Wheat grains have an excellent nutritional composition, such as phytochemical with antioxidant properties (Studnicki et al., 2016). The main phytochemicals found in wheat grain are the phenolic compounds that are concentrated in the outer layers of the grain and its consumption is associated with a reduction in the incidence of chronic diseases such as diabetes and cardiovascular problems. In addition, wheat grain is widely used in food industry mainly for bread and pasta production due to the high viscoelasticity provided by its proteins. This characteristic makes wheat grain an essential ingredient for the development of bakery products with appropriated technological and sensory proprieties. Although wheat has interesting technological and nutritional properties for food production, its properties can be severely affected by the genotype, the growing environment and the processing it has undergone.
Wheat quality parameters are proven to be affected by genotype, environment and the interaction of these factors (Studnicki et al., 2016). In addition, the metabolites available in the grains are directly linked to the external stimuli the plant receives, especially during the grain-filling phase (Farooq et al., 2014). Therefore, an environment that exposes a crop to adverse climatic conditions, such as heat or water stress, is unfavorable for some of the quality attributes of wheat that are important in the industry (Cho et al., 2018). In this regard, the present review provides a comprehensive report present in the current literature about the effects of genotype, environment and wheat processing on the technological properties, baking proprieties and metabolite composition. Based on this approach, this review article analyzed the main findings in the literature about the effects of genotype, environment and wheat processing on wheat quality obtained by searching the Web of Science database.

2 THE ROLE OF GENOTYPE IN WHEAT QUALITY
2.1 EFFECT OF GENOTYPE ON TECHNOLOGICAL PROPRITIES

Among the technological properties, the most studied factors are the wheat products, whose characteristics depend on the genotype used. Wheat grain presents great importance to the food industry, since it is the raw material used for various products that are essential to the human diet, such as bread, cookies, cakes and pasta. The final quality of the product therefore depends on the quality of the wheat flour, which consequently depends on the technological quality of the grain. In addition, of the various products that come from wheat, each one has different characteristics, which are the result of the genetics and growing conditions of the grain and, therefore, require raw materials with specific characteristics for their purpose. In this sense, the technological quality of the flour is a determining factor in the characteristics of the final product (Santos et al., 2022). This topic will cover the most recent studies in the literature about the effect of genotype on the technological properties of wheat such as gluten index, thousand grain weight, hectolitre weight and bakery proprieties.

A study carried out by Gagliardi et al. (2020) evaluated the effects of four wheat genotypes grown in Italy (Marco Aurelio, Pietrafitta, Quadrado and Redidenari)
combined with three different nitrogen dosages (36, 90, 120 kg.ha\(^{-1}\)) in two years (2017 and 2018) on wheat yield parameters and technological quality. The results showed that the Marco Aurélio genotype had the highest yield, with a value of 7.11 t.ha\(^{-1}\). The Redidenari genotype showed higher values for protein content and gluten index, with values of 15.97% and 70.28, respectively. These values showed that wheat flour extraction yield is associated with the interaction between starch and the protein matrix in the endosperm, which is a parameter that varies between genotypes. The influence of genotype led to an increase in the proportions of monomeric gliadins, with the Redidenari genotype showing an increase in α/β-type gliadin.

In addition, Nehe et al. (2019) evaluated the grain yield, yield components, quality characteristics and baking characteristics of 35 spring wheat genotypes grown in Turkey. The results obtained from the research showed that yields in all cultivars ranged from 4,102 to 6,657 kg.ha\(^{-1}\). The Izimir genotype had the highest thousand grain weight of 35.9 g and hectolitre weight of 73.5 g, both results being influenced by the genotype. The yield of Adana genotypes (6416 kg.ha\(^{-1}\)) was relatively higher than Izmir genotype (5887 kg.ha\(^{-1}\)) and Adapazari genotype (5205 kg.ha\(^{-1}\)). It was observed in this study that yield and grain quality characteristics were strongly influenced by genotype. The significant change in the performance of 35 cultivars suggests that breeding programs have been able to successfully develop adoptive cultivars for specific locations.

In a study carried out by Ruisi et al. (2021), the effect of 10 ancient durum wheat genotypes (Timilia, Russel, Biancuccia, Realforte Rosso, Tripolino, Scorsonera, Perciasacchi, Azizias, Bidi, Senador Cappelli) and five modern durum wheat genotypes (Iride, Creso, Vertola, Saragolla, Simeto) grown in southern Italy on technological properties were evaluated. It was possible to observe that the variation in the weight of a thousand grains depended directly on the genotype. Biancuccia genotype showed a value of 38.4 g and Perciasacchi genotype showed a value of 65.0 g, both belonging to the classification of ancient durum wheat. Regarding hectolitre weight, there was a variation in the results, with the Aziziah genotype showing the lowest value of 73.1 kg.hl\(^{-1}\) and the Creso genotype showing the highest value of 84.3 kg.hl\(^{-1}\). Thousand-grain weight and hectolitre weight are positively correlated with semolina yield. Thus, high values are desirable in
order to positively influence market grade and price. The results obtained are in line with the study carried out by De Vita et al. (2010) who analyzed a large set of durum wheat genotypes (creole varieties, modern varieties and advanced breeding lines).

Santos et al. (2022) carried out the physicochemical characterization of 14 wheat genotypes (Campeiro, ORS Vintecinco, ORS1401, ORS1402, Marfim, Jadeite, Ametista, ORS Vintesete, Topázio, Nobre, Iguacu, Sintonia, Sossego and Alpaca) from Brazilian winter. The results obtained showed that the average ash content was 0.77% and ranged from 0.54 to 1.24% in the 14 wheat flours, in accordance with the Brazilian legislative guideline for refined wheat flour (maximum ash value: 1.4%) (BRASIL, 2005). Since the ash content generally indicates the contamination of the flour with bran particles during milling and therefore provides an estimate of the degree of separation of the bran and germ from the endosperm during milling. The presence of bran also darkens the color of the products. Increasing the ash content in flour is attractive from a nutritional point of view. However, it has a negative impact on the flour's technological characteristics (Hemery et al., 2011).

Moreover, the main product produced from wheat flour is bread and its derivatives. Improvements in terms of yield and baking quality have been achieved mainly through the creation of new genotypes that possess characteristics aimed at these parameters (Hemery et al., 2011). Oliveira et al. (2022) characterized the baking properties of 12 wheat genotypes grown in the Brazilian Cerrado. It was observed that the paste temperature measured by the Rapid Visco Analyser (RVA) varied from 82.20°C (BRS 264 C) to 94.63°C (BRS 404 U). The peak viscosity ranged from 850.50 (PF 120.212 C) to 3,285.00 (CPAC 09236 U); the decomposition viscosity ranged from 76.50 (PF 120.337 M) to 1,555.50 CP (BRS 264 M); the indentation ranged from 595.00 (PF 120.337 C) to 1. 815.00 CP (CPAC 0886 I); and the final viscosity ranged from 1,228.50 (PF 120.337 C) to 3,831.00 CP (CPAC 0872 I), showing great variation between the samples and providing a wide range of applications as end products. When grouping the same genotypes grown in different locations, some parameters such as final viscosity showed little variation (10%) for most genotypes. For some genotypes (CPAC 09236 and BRS 264),
the setback or peak viscosity values varied slightly, demonstrating that final viscosities were significantly influenced by genotype (Oliveira et al. (2022)).

Kaur et al. (2020) carried out the characterization of 50 wheat genotypes grown in Mexico in order to identify the best bakery wheat genotypes with high micronutrient content, especially zinc, iron and important nutritional characteristics, in line with the objective of exploring the interactions between the parameters studied. The results obtained showed that the highest value for gluten content was 3.46. The quality of the gluten is important due to its ability to retain water, viscosity, firmness and flexibility of the dough. The protein in gluten corresponds directly to the whole grain and an increase in the protein content of wheat flour is positively correlated with the gluten content. The sedimentation value is a measure of the strength of the gluten in wheat flour and is based on the fact that the gluten protein absorbs water. The sedimentation value of the wheat flour ranged from 36.56 and 48.50 cc respectively. The gluten content represents the positive correlation with the sedimentation value, which depends on the composition of the proteins.

2.2 EFFECT OF GENOTYPE ON NUTRITIONAL PROPRIETIES

Wheat is an excellent source of nutrients such as proteins, carbohydrates, vitamins, and bioactive compounds, including carotenoids, phenolic acids, flavonoids, and anthocyanins. These phytochemicals are mainly concentrated in the bran and have been shown to have a variety of potential health benefits, including anti-diabetic, cholesterol-lowering, anti-inflammatory and anti-cancer properties (Dykes, 2019).

Beleggia et al. (2013) evaluated the effect of four durum wheat genotypes (Creso, Simeto, Svevo and Saragolla) on the metabolite profile. The variation between the genotypes was statistically significant for the contents of tocopherols (β-tocopherol and γ-tocopherol) and for the phytosterols (campsterol and stigmasterol). The highest campsterol content was in the Saragolla cultivar (86.12 μg.g⁻¹), while the Creso genotype had the highest amounts of stigmasterol (40.58 μg.g⁻¹), β-tocopherol (1.91 μg.g⁻¹) and γ-tocopherol (1.98 μg.g⁻¹).
Santos et al. (2022) quantified phenolic compounds through metabolomic analysis of 14 wheat genotypes (Campeiro, ORS Vintecinco, ORS1401, ORS1402, Marfim, Jadeite 11, Ametista, ORS Vintesete, Topázio, Nobre, Iguaçu, Sintonia, Sossego and Alpaca) from Brazilian winter. They showed different levels of technological property and commercial classes indicating end use, according to the rheological properties of the gluten, which in the study were classified as low, medium and high. The results obtained showed that the phenolic compound content of the superior wheat flours was significantly higher than that of the low and medium wheat flours, with values of 15%, 3% and 11% respectively. This study identified a total of 43 phenolic compounds, including isomers. Some compounds were fully confirmed by reference standards, such as: caffeic acid, ferulic acid, p-coumaric acid and sinapic acid, present in the free and bound extracts. Overall, five classes of phenolic compounds were found in this study: flavonoids (32%), phenolic acids (30%), other polyphenols (26%), stilbenes (7%) and lignans (5%).

Martini et al. (2014) evaluated the influence of ten durum wheat genotypes (Achilles, Anco Marzio, Claudio, Duilio, Dylan, Iride, Normanno, Saragolla, Simeto and Svevo) grown in Italy on phenolic acids and phenolic compounds. The genotype with the highest content of total phenolic acids was Achilles (1254.7 mg.kg⁻¹), while the lowest value was determined for Saragolla (906.3 mg.kg⁻¹). With regard to bound phenolic acids, the Simeto genotype had the highest value (169.6 mg.kg⁻¹), while the Iride genotype had the lowest value (114.6 mg.kg⁻¹). For free phenolic acids, the Duilio genotype had the highest value (6.7 mg.kg⁻¹) and the Dylan genotype had the lowest value (3.1 mg.kg⁻¹). It is suggested that these differences are attributed to the different methods used for extraction, which do not always include the contribution of the different forms of phenolic compound content to the total content. Furthermore, the different standards used for quantification may provide an additional explanation for these differences. This hypothesis is supported by the consideration that the data seem comparable to those found by Brandolini et al. (2013) who evaluated the conjugated and bound forms and used ferulic acid as a standard.

Lia et al. (2022) evaluated the lutein content of 262 Chinese wheat genotypes, in which 157 of them were traditional varieties, 88 modern cultivars and 17 introduced
cultivars, along with the agronomic characteristics of each cultivar. However, the results obtained in the study varied tenfold, from 0.87 to 8.90 μg.g⁻¹ of lutein. In another study using 217 Chinese wheat cultivars grown in two environments, it was found that the highest lutein content of the grain was only 5 times higher than the lowest (Li et al., 2016), and the content values were 10 times lower than in the present citation. The differences between the two studies are probably due to Li et al. (2016) using mainly modern cultivars, which almost certainly had less genetic diversity than the mini core collection, and were possibly selected to give white flour.

Lv et al. (2013) evaluated the effect of 10 wheat genotypes grown in four environments (Clarksville, Keedysville, Poplar Hill and Wye Maryland) on carotenoid content. In the results found, it was observed that the composition of carotenoids including lutein, zeaxanthin and β-carotene was examined for all wheat flour samples. Lutein and zeaxanthin were detected in all the wheat flour samples. Total carotenoids in the wheat flour samples ranged from 0.02 to 0.15 μg.g⁻¹ of wheat flour among all the genotypes grown in the different locations. With the exception of the USG3315 genotype, the wheat flour samples from the Wye location had the highest concentrations of lutein, zeaxanthin and total carotenoids, ranging from 0.34 to 0.69 μg.g⁻¹, 0.10 to 0.18 μg.g⁻¹ and 0.08 to 0.15 μg.g⁻¹, respectively, compared to the same genotype grown in the other three locations. While, the wheat varieties grown at Poplar Hill had lower or the same concentration of carotenoids as those grown at other locations, suggesting that the growing location can alter the composition of carotenoids.

3 THE ROLE OF GROWING ENVIRONMENT IN WHEAT QUALITY
3.1 EFFECT OF GROWING ENVIRONMENT ON TECHNOLOGICAL PROPERTIES

One of the most practical ways of expanding and developing new genotypes is to relate them to as many growing environments as possible. This will allow for a wide range of production levels, as well as greater characterization of the environments studied, in order to achieve greater productivity through better use of the genetic potential of the genotypes (Studnicki et al., 2016).
Silveira et al. (2020) evaluated the effect of 13 genotypes (Ametista, BRS 331, BRS Parrudo, CD 1303, FPS Certero, Marfim, ORS Vintecinco, TBIO Iguacu, TBIO Mestre, TBIO Sintonia, TBIO Sinuelo, TBIO Sossego and TBIO Toruk) grown in the state of Rio Grande do Sul, on the technological properties, hectolitre weight, thousand-grain weight and colorimetric profile of raw and cooked grains. The results obtained for the hectolitre weight analysis showed that this parameter varied from 73.75 kg/hL for the TBIO Sintonia genotype to 79.83 kg/hL for the CD 1303 genotype. The thousand-grain weight of all the genotypes ranged from 29.40 to 35.61 g, with BRS Parrudo and TBIO Toruk representing the highest values obtained.

In general, environmental factors, including the physicochemical characteristics of the soil, geographical latitude, moderately high temperature, adequate soil moisture and sufficient solar radiation can improve the quality of wheat (Kong et al., 2013). Combined with the use of an adaptable genotype, the synergism between genotype and environment is exploited. This interaction results in quality flour and, consequently, quality of products (Kong et al., 2013). Oliveira et al (2022) evaluated the baking properties of 34 wheat genotypes grown in five cities in the Brazilian Cerrado (Madre de Deus de Minas, Coromandel, Piumhi, Uberaba and Iraí de Minas), and concluded that the characteristics of the flour paste can be affected by the environmental conditions of the growing site during grain development (Oliveira et al, 2022).

Eljak et al. (2018) determined the effect of environment on the baking quality of high-yielding Sudanese wheat cultivars in three different environments. Their various soil types and environmental conditions characterize the three growing environments (New Halfa, Ad Douiem and Gezira). The results obtained indicated that the gluten properties of wheat flours are significantly affected by environmental conditions. The highest falling numbers ranged from 597.0 and 589.3 s for the samples grown in New Halfa and Gezira, respectively, while the lowest value was recorded at 383.3 s for the sample grown in Ad Douiem, suggesting that the growing environment affected the falling number of the wheat flour. In general, the falling numbers resulting from the α-amylase activity of all the samples were relatively high. This can be attributed to the dry weather during grain
filling and the harvest time that subsequently disrupts α-amylase activity (Hamad et al., 2014).

Vignola et al. (2016) studied the influence of wheat cultivation in three environments (Reconquista, Marcos Juarez and Barrow) harvested at two different times of the year, totaling six different environmental conditions, and its effect on amylose content and starch properties. The results showed that the amylose content ranged from 17.57 to 36.47%. Similar results were found by Blazek and Copeland (2008) found values ranging from 35 to 43% for durum wheat. These results suggest that the environment was the main factor responsible for the increased variability observed. This is because the environment has some degree of influence due to its ability to regulate the activity of enzymes involved in starch biosynthesis.

3.2 EFFECT OF GROWING ENVIRONMENT ON NUTRITIONAL PROPERTIES

The metabolite composition of wheat grain is closely related to the environment in which it was grown. Since any type of stress on the plant leads to greater release of compounds as a form of defense. Bellato et al. (2013) analyzed the phenolic, 5-n-alkylresorcinol and catechin composition of wheat in two growing environments (Jesi and Foggia) located in central and southern Italy. The results showed that the values of total phenolic compounds ranged from 19.0 to 192.4 μg.g⁻¹. The content of 5-n-alkylresorcinols ranged from 161.3 to 405.8 μg.g⁻¹, which is similar to other studies. While catechin values ranged from 19.0 to 192.4 μg.g⁻¹. The analysis showed that the environment was the main factor contributing to the total variation in the measured parameters.

Martini et al. (2015) analyzed the total antioxidant, phenolic acid and total phenolic activity of durum wheat grown in three environments: Montelibretti, Jesi, and Foggia, located in Rome, Italy. According to the results presented, the average value of phenolic acids ranged from 810.9 mg.kg⁻¹ (Forggia) to 1208.2 mg.kg⁻¹ (Montelibretti). On average, Montelibretti had the highest total phenolic acid content (1017.4 ± 116.2 mg.kg⁻¹), slightly higher than Foggia (975.8 ± 106.7 mg.kg⁻¹) and Jesi (968.6 ± 95.4 mg.kg⁻¹). The values obtained in this study appear to be higher than those reported in the literature for different durum wheat genotypes, years of cultivation and/or agro climatic areas.
(Brandolini et al., 2013). The phenolic compound content of the three cultivated environments ranged from 2162.7 mg.kg\(^{-1}\) (Foggia) to 1321.0 mg.kg\(^{-1}\) (Jesi). The bound form of the total phenolic compound content prevailed over the conjugated and free forms, with an average value of \(1280.7 \pm 316.2\) mg.kg\(^{-1}\).

**4 EFFECT OF PROCESSING ON WHEAT QUALITY**

**4.1 EFFECT OF PROCESSING ON TECHNOLOGICAL PROPERTIES**

The processing of wheat grains, such as drying and storage, alters the technological properties, since during this process there is a change in moisture, which results in a reduction in hectolitre weight, which is one of the factors indicating a good flour yield (Karaoglu et al., 2010). Mosqueda et al. (2013) examined the effect of drying methods (forced air convection, microwave and microwave-convection) and temperature on the protein quality of Wheat Distillery Dried Soluble (CDS) wheat grains. The results obtained showed that the average crude protein content increased as the level of condensed distiller solubles (CDS) in the blend was increased. Regression analysis showed that the linear model was significant for the level of CDS. The average protein content of samples generated from forced-air convection-dried, microwaved and microwaved samples with varying levels of CDS in all three sets of samples, the average crude protein content also showed similar increasing trends as the amount of CDS in the mixtures increased. Average differences in protein were also observed that were affected by the factors and factorial interactions. In samples dried by forced-air convection, the level of CDS and the temperature of the drying air were significant.

Kibar (2015) evaluated the effects on quality properties in real storage conditions and galvanized steel silos for wheat varieties (cv. Bezostaya and Lancer) in the storage period of 180 days. The quality properties of wheat, hectolitre weight and thousand-grain weight, were monitored in the laboratory in three repetitions at regular intervals. As a result, the hectolitre weight of the Lancer wheat genotype decreased from 77.49 kg.hL\(^{-1}\) by 10.27% over the duration of storage. The results at 90 and 120 days were statistically similar.
Hectolitre weight is an indicator of grain quality used as an approximate measure of expected flour yield. Better flour yield and quality would be achieved if wheat grains had a higher hectolitre weight (Karaoglu et al., 2010). Hectolitre weight decreased throughout storage for both genotypes. This decrease may be related to moisture variations (gain or loss) during these periods. Variations in hectolitre weight during storage have been reported to be mainly associated with the moisture content of the grain (Karaoglu et al., 2010). In addition, the decrease in hectolitre weight is mainly due to the decrease in grain density during the storage period. The rate of reduction in hectolitre weight of Lancer wheat was higher than Bezostaya wheat. The hectolitre weight decreased as the length of the storage period increased for three wheat varieties.

The weight of a thousand grains varied according to storage time, which decreased from 35.74 to 28.97 g as the storage period increased from day 0 to day 180. This can be used to determine the potential flour yield for stored wheat grains, and is accepted as the main quality factor by the milling industry (Karaoglu et al., 2010). As the storage period increased, the thousand-grain weight of both wheat genotypes decreased steadily.

Karaoglu et al. (2010) evaluated the effects of storing wheat grains in the ear and out of the ear, under storage conditions such as temperature and storage time and grain moisture content on the quality of milled flour from stored wheat. The grain moisture contents were 12, 14 and 16%, and kept at 10, 20 and 30 °C for a period of 9 months. The conditions tested had a significant influence on the hectolitre weight of the grains, which decreased in hectolitre weight of wheat stored in grain form was greater than that of wheat stored in ear form at the end of 6 months of storage. While the opposite effect was observed at the end of 9 months of storage. Storage in ear form generally had a better preservation effect on hectolitre weight than storage in grain form at 16% moisture for all storage times and temperatures.

Moreover, Stuknytė et al. (2014) evaluated the effect of drying at 60-70ºC for 14 hours (LT), and at a temperature greater than 70ºC for 8 hours (HT), on the starch and proteins of wheat spaghetti by analyzing the Paste Properties (RVA). The results presented showed that the paste temperature at which an initial increase in viscosity occurred was higher in the raw HT spaghetti (80ºC) compared to the LT sample (65.4ºC). The raw
LT spaghetti had a higher maximum viscosity and final viscosity than the HT spaghetti. This means that the starch in the raw LT spaghetti had a greater swelling capacity. In contrast, the high paste temperature of raw HT spaghetti may be related to the presence of new bonds promoted by HT in the starch granules.

Zweifel et al. (2003) investigated the impact of high temperature (HT) drying at 80 or 100°C on the starch and protein fraction, and their role in the structure and texture of pasta. High drying temperatures were applied at an early (eHT), intermediate (iHT) or late stage of the drying cycle (IHT), and a temperature of 55°C was used as the control temperature. With the results obtained, it was noted that in all the drying cycles, an early stage reduced the moisture content of the product from 27 to 13 g.100g⁻¹; an intermediate stage from 20 to 13 g.100g⁻¹; and a late stage from 15 to 13 g.100g⁻¹. The final moisture content of the spaghetti was 11.2 - 0.16 g.100g⁻¹. Depending on the drying temperature, the total drying time varied from 4 to 10 hours. Thus, the drying profiles applied do not allow the effects of temperature and time to be fully separated. In addition, drying at 55°C for 10 hours caused almost no changes in the extent of glutenin denaturation. The sum of the gliadin and glutenin content is 15.5%, slightly higher than the total protein content of the semolina (14.3%). This is probably due to incomplete separation of the two proteins, i.e. partial coprecipitation of gliadin and glutenin during the separation process. For all the HT drying profiles, the solubility values remained fairly constant during the pre-drying phase at 55°C.

From the point at which the temperature was raised to 80 or 100°C, a decrease in the solubility of glutenin and gliadin was observed, with the decrease being more pronounced for drying at 100°C than at 80°C. Drying at 80°C reduced the extraction capacity of glutenin and gliadin by 35 and 25%, while drying at 100°C reduced the soluble protein content by 90 and 65%, respectively. Drying in the eHT and lHT phases resulted in similar denaturation rates during the HT phase and similar levels of protein solubility at the end of drying. These results confirm previous studies which have found that the extractability of gluten proteins, in particular the glutenin fraction, decreases on heating to 80°C (Aktan and Khan, 1992).
The number of drops was clearly influenced by the temperature and relative humidity inside the silo. This is in line with previous reports that showed an increase in the number decreasing with the duration of storage. The initial values of the falling number were high enough to avoid problems related to amylase activity. After several months of storage, especially at high temperatures, α-amylase activities can decrease significantly. This can negatively affect the baking process, since α-amylase activities can cause the dough fermentation process to slow down (Aktan and Khan, 1992).

4.2 EFFECT OF PROCESSING ON NUTRITIONAL PROPERTIES

After the grain has been harvested, one of the processing stages is storage and/or processing. The first stage of grain processing is drying. After drying, the grains are stored until they are processed. During exposure to high drying temperatures, changes occur in the metabolite profile, which is often reduced due to heat treatment (Ramos et al., 2022). During the storage stage, where the grains still have their metabolism active, there is a reduction in quality parameters (Cañizares et al., 2021), influencing the metabolite profile of these grains.

In order to characterize the content of phenolic compounds in various wheat genotypes, Rakic et al. (2020) quantified the metabolites of three wheat grain genotypes (Simonida, Dragana and Ljiljana) grown in Southeastern Europe and stored for 12 to 24 months at a pre-defined temperature of 25°C. They noted that during the 12 and 24 months of storage, the amount of phenolics varied from 9.44 to 10.50 mgGA.g⁻¹, obtaining a significant change. Wang et al. (2013) also reported a significant impact of cultivars and growing conditions on phenolic levels in wheat. Each variety has a different distribution of phenolics in the endosperm and bran.

Aung et al. (2023) evaluated the physicochemical and structural characteristics, bioactive components, amino acids, volatile profiles, phenolic compounds and antioxidant potential of wheat drinks at various stages of preparation. Samples of raw wheat, sprouted wheat, steamed sprouted wheat and steamed sprouted wheat were used. The results obtained showed that steamed germinated wheat had the highest level of bioactive components which were 2.46 mg.g⁻¹ of GABA, 0.72 mgCE.g⁻¹ of total flavonoid content,
4.66 μM TE.g⁻¹ of 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity and 10.20 mM TE.g⁻¹ Trolox equivalent of antioxidant capacity. P-coumaric, ferulic, siringic and caffeic acids were detected. The FT-IR spectra revealed similar band positions for all the samples. A principal component analysis clearly discriminated between each stage of preparation and established that sprouted wheat had the highest amino acid content, while steamed sprouted wheat had the highest bioavailability and the greatest abundance of volatiles and phenolic compounds.

5 CONCLUSIONS AND FUTURE TRENDS

Understanding the functionality of bioactive compounds is extremely important when it comes to processing wheat. A lot of research has been done on the properties of bakery products, given that this is the largest area in which wheat is consumed, but the composition of flour used in bakery products is the key to producing a more nutritious commercial product, which is what is currently winning over consumers. The above research highlights the distribution of information on wheat's bioactive compounds, and it is hoped that this will increasingly drive research and the development of new products that maintain the grain's bioactive composition.

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