FOOD
RESEARCH

Evaluation of the industrial quality of Moroccan durum, soft and red wheat landraces

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Abstract

Wheat landraces are a treasure trove of genetic resources in Morocco and are very appreciated by farmers for their excellent grain quality. Therefore, an evaluation of the industrial quality of wheat landraces is necessary. The objective of this study was to determine the physico-chemical properties of three species of Moroccan wheat landraces (durum, soft and red) in order to evaluate the technological quality and to deduce the industrial value. For this purpose, seventy-five samples of the three species were collected from Moroccan farmers during the 2019-2020 agricultural season. The analyses concerned dimensional and physico-chemical characteristics, such as the 1000-kernel weight, specific weight, moisture, total ash and carotenoid pigment content. The results of the dimensional characterization showed that the three species have distinct physical structures. The agro-morphological characterization revealed exceptional values for red wheat. The moisture content recorded was lower than the maximum limit set by international standards (14.5%). The determination of the total ash content indicates that red wheat (3.25±0.64%) is ashier than durum (2.23±0.42%) and soft wheat (2.11±0.68%). The carotenoid pigment content recorded in red wheat (9.11±1.60 ppm) exceeds that of durum wheat (7.54±1.21 ppm), while soft wheat is low in carotenoid pigment (1.19±1.13 ppm). The results revealed that the three examined species meet the quality requirements of the semolina and the milling industries. This finding will promote national wheat production to reach international standards.

1. Introduction

In Morocco, cereals are the main food resource, both for human consumption and for animal feed (Choueiri, 2003). Because of its high nutritional value, wheat remains the most frequently consumed cereal by the Moroccan population. It contributes enormously to the caloric and protein intake of the population across the country (Doré *et al.,* 2006).

Given its geographic position and the climatic conditions favorable to its cultivation, Moroccan wheat production is optimal. It is largely self-sufficient to satisfy the Moroccan people's requirements (Harbouze *et al.,* 2019).

Traditionally, wheat production is associated with the food industry's processing sector. It constitutes a vitally important raw material for the manufacture of flour (durum and soft wheat) and semolina (durum and red wheat) by milling and semolina factories in the primary processing industry. These two derivative products are mainly used in the industrial pastry and the manufacture of pasta and couscous from durum and red wheat semolina, as well as in the bakery and cookie industry from soft wheat flour in the secondary processing industry. Furthermore, the grains of this cereal constitute a desired raw material of choice for the starch and gluten industries (Pierre, 2000). However, these common industrial practices have evolved along with the technological advances that have modernized food production conditions. This evolution is being driven by an increasing demand for the quality of their finished and semi-finished products.

In a competitive context, quality improvement could influence the preferences of consumers whose demand

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for imported wheat is increasing (Aït El Mekki, 2006). Because of this preference, the wheat industry should consolidate its efforts at all levels to ensure that markets are supplied with wheat of high quality.

Currently, the industrialization of agriculture has led to the selection of modern wheat varieties due to their high yields and attractive technological qualities. Despite their low yields, wheat landraces are attracting renewed interest from farmers, industrialists, and consumers, due to their strong adaptations to certain abiotic stresses and high grain quality. They constitute unexploited natural resources and a natural reservoir well known among farmers for their technological properties intended for the manufacture of various cereal products (Kaplan Evlice, 2021).

As a result, an evaluation of the industrial quality of wheat grains is necessary. It serves as a first quality control, which is critical for their selection in order to optimize the quality of grain supply. In this context, this study aims to determine the physicochemical properties of three species of Moroccan wheat landraces (durum, soft, and red wheat) in order to assess their quality levels and estimate their industrial use value.

2. Materials and methods

2.1 Plant materials

During the 2019-2020 agricultural season, 75 samples of wheat landrace, including 37 durum wheat, 37 soft wheat, and 1 red wheat, were collected from farmers through 12 Moroccan regions. The geographic distribution of the collected samples is shown in Figure 1.
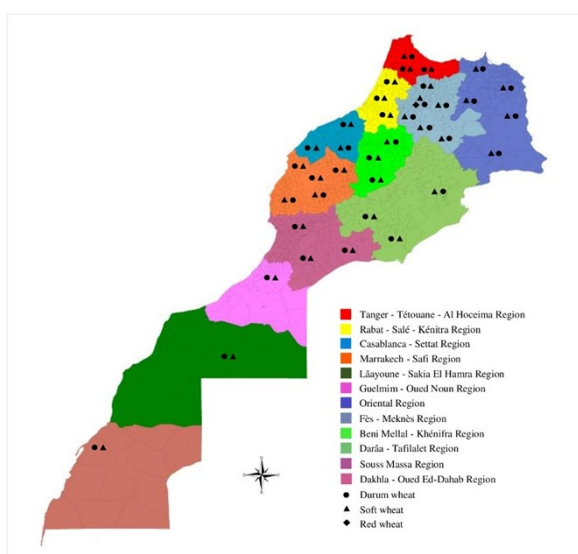

Figure 1. Geographical distribution of Moroccan durum, soft and red wheat landraces collected from farmers in 12 Moroccan regions.

The samples were stored in food storage boxes in a dry place at room temperature to prevent the degradation of their technological, nutritional, and sanitary qualities, with weekly ventilation to prevent the development of insect pests.

2.2 Quality assessment

2.2.1 Dimensional characteristics

To determine the average size of the three studied species of wheat grains, 100 grains were randomly chosen and their three linear dimensions, namely, length (L), width (W), and thickness (T) were measured using a digital Vernier calliper (ZJchao 200 mm LCD) with an accuracy of 0.02 mm.

Based on these three axial dimensions, other dimensional characters were calculated according to different formulas proven mathematically and geometrically by many researchers.

The arithmetic (D_a) and geometric (D_g) mean grain diameter (mm) were calculated from the axial dimensions measured earlier according to the following formulas (Mpotokwane et al., 2008):

$$D_a = (L + W + T) / 3$$
$$D_g = (L.W.T)^{1/3}$$

Where L = Length, W = Width and T = Thickness

Sphericity (%) is defined as the ratio of the surface area of a sphere having the same volume as the grain to the surface area of the grain and was calculated using the method of Hamdani et al. (2014).

$$\phi = ((L.W.T)^{1/3} / L) \times 100$$

The surface area (mm^2) of the grain was determined by analogy with a sphere of the same geometric mean diameter using the formula cited by Olajide and Ade-Omowaye (1999).

$$A_s = \pi . D_g^2$$

The volume (mm^3) of the individual wheat grains was calculated using the equation reported by Sobukola et al. (2011).

$$V = (\pi.L.W.T) / 6$$

The aspect ratio (%) of the grain was calculated using the following formula according to the method of Varnamkhasti et al. (2008):

$$R_a = (W / L) \times 100$$

2.2.2 Gravimetrical characteristics

2.2.2.1 Bulk density

Bulk density (kg/m^3) is described as the ratio of the mass of the sample to its total volume. It was determined by filling a 500 ml cylinder with wheat grains according to the method of Mariotti et al. (2006).

Bulk density = weight of sample / Volume

2.2.2.2 1000-Kernel weight

1000-kernel weight (TKW) was determined using a digital grain counter (Chopin - Numigral) and an electronic balance with 0.01 g accuracy (Kern EMS 6K1) according to AFNOR standard NF V03-702 (1981).

2.2.2.3 Specific weight

Specific weight, expressed as kg/hl, was measured with a Nilemalitre 7500 according to AFNOR Norme standard NF V03-719 (1996).

2.2.3 Moisture content

The moisture content was determined according to AFNOR standard method NF V03-707 (2010). A dry coded, clean crucible was placed in the oven for about 30 mins, cooled, and weighed. A quantity of 5 g of wheat grains was dried in an oven at atmospheric pressure of 130°C for 90 mins until a constant weight was obtained. The results of moisture content (%) were calculated thus:

$$\% \text{ Moisture} = (W_2 - W_3 / W_2 - W_1) \times 100$$

Where W_1 = Weight of empty crucible, W_2 = Weight of crucible + grains before drying and W_3 = Weight of crucible + grains after drying

2.2.4 Ash content

The ash content was determined according to AFNOR standard method NF V03-720 (2010). Wheat grains were weighted in an ash crucible in quantities of 5 g. The samples were then incinerated in a muffle furnace at 900°C until light gray or constant weight ash was obtained. The ash content was calculated using the following formula:

$$\% \text{ Ash content} = \text{weight of Ash} / \text{weight of sample}$$

2.2.5 Carotenoid pigment content

It represents the content of carotenoids extractable by water-saturated n-butanol and is expressed as micrograms of β-carotene per gram of dry matter (ppm). It is determined using the micro-method developed by Santra *et al.* (2003), based on the principle of the approved method ISO 11052 (1994).

After grinding, 125 mg of the experimental grind is mixed with 650 μL of water-saturated n-butanol in Eppendorf tubes (1.5 mL) and allowed to macerate in the dark for 16 to 18 hours at room temperature for β-carotene extraction. Then, the Eppendorf tubes were centrifuged at 10000 rpm for 10 min. The absorbance of the supernatant was measured at a wavelength of 440 nm on a spectrophotometer (Jenway™ - Model: Genova).

The carotene content (ppm) of the samples was calculated from the calibration curve made from pure β-carotene (Sigma C-9750).

2.3 Data analysis

Analysis was performed with Graph Pad Prism v8 software. Data shown are the mean average±standard deviation (SD) of three replicated experiments. Data were subjected to a one-way analysis of variance (ANOVA). Differences between mean values were compared by using Tukey's test at $p \leq 0.05$ probability levels.

3. Results and discussion

For each wheat species, a measurement of the three main morphometric parameters, length (L), width (W), and thickness (T), was performed. The mean values of the geometric characters are presented in Table 1. The mean dimension values revealed that the length, width, and thickness of durum wheat grains are 6.93±0.24 mm, 3.21±0.25 mm, and 3.12±0.30 mm, respectively. Those of soft wheat are 6.18±0.25 mm, 3.11±0.27 mm, and 3.09±0.33 mm, respectively, while those of red wheat are 7.19±0.27 mm, 3.34±0.28 mm, and 3.16±0.38 mm, respectively. The one-way variance analysis (ANOVA) revealed the absence of a significant difference between the axial dimensions of durum and red wheat grains ($p > 0.05$). Moreover, they are significantly larger ($p < 0.05$) than those of soft wheat.

These results are consistent with the work of several researchers on wheat species mainly cultivated for human consumption in certain countries. Indeed, Iqbal *et al.* (2015) reported values of 6.11 mm, 3.09 mm, and 2.74 mm for length, width, and thickness, respectively, of soft wheat from Pakistan. Values of 5.60 mm, 2.98 mm, and 2.48 mm were also reported for the length, width, and thickness respectively, of soft wheat from Egypt. In the same geographical location, Soliman *et al.* (2009) presented values of 7.07 mm, 3.16 mm, and 2.92 mm for durum wheat grains. In Russia, the commonly cultivated durum wheat measures between 5 - 7 mm in length and 2.4 - 3.6 mm in width. Ciulca *et al.* (2020) reported average grain dimensions higher than those determined in this study for Romanian durum wheat. Compared to other cereals, the dimensions of durum, soft, and red wheat grains were observed to fall within the same range as the dimensions of barley grains (Sanja *et al.,* 2010), and to be greater than those of buckwheat grains (Kaliniewicz *et al.,* 2015; Unal *et al.,* 2016), and smaller than those of maize grains (Özmerzi *et al.,* 2002; El-Abady, 2015).

Regarding the axial dimensions, the obtained results

Table 1. ANOVA analysis of dimensional and physico-chemical characteristics of Moroccan durum, soft and red wheat landraces.

	Replication Number	Durum Wheat	Soft Wheat	Red Wheat
Length (mm)	100	6.93±0.24[a]	6.18±0.25[b]	7.19±0.27[a]
Width (mm)	100	3.21±0.25[a]	3.11±0.27[b]	3.34±0.28[a]
Thickness (mm)	100	3.12±0.30[a]	3.09±0.33[b]	3.16±0.38[a]
Arithmetic Diameter (mm)	100	4.42±0.29[a]	4.12±0.59[b]	4.56±0.36[a]
Geometric Diameter (mm)	100	4.05±0.21[a]	3.85±0.36[b]	4.17±0.30[a]
Sphericity (%)	100	59.01±2.08[b]	61.97±1.87[a]	58.11±2.37[c]
Surface area (mm^2)	100	59.07±2.46[a]	47.14±2.33[c]	54.97±3.18[b]
Volume (mm^3)	100	36.94±2.15[b]	31.76±3.01[c]	39.81±3.14[a]
Aspect Ratio (%)	100	46.78±1.37[b]	50.91±1.23[a]	46.81±1.17[b]
Bulk density (kg/m^3)	10	542.21±3.55[b]	520.76±4.32[c]	551.41±3.07[a]
1000-Kernel weight (g)	10	56.07±1.15[b]	48.25±1.26[c]	61.43±1.97[a]
Specific weight (kg/hl)	10	77.91±1.94[b]	76.17±2.10[c]	79.64±2.17[a]
Moisture (%)	3	13.09±3.79[b]	13.44±3.72[a]	13.61±4.58[a]
Ash (%)	3	2.23±0.42[a]	2.11±0.68[a]	3.25±0.64[b]
Carotenoid pigment (ppm)	3	7.54±1.21[b]	1.19±1.13[c]	9.11±1.60[a]

Values are presented as mean±SD of triplicates. Values with different superscripts within the same row are statistically significantly different (p-value<0.05).

are in favor of a spheroid shape for the three categories of wheat grains undertaken in this study. This finding is confirmed by the morphometric study of wheat grains carried out by Evers and Millar (2002).

Table 2 shows the size distribution of the studied durum, soft and red wheat samples. The majority of the analyzed wheat grains (about 63% by number for the three wheat species) were medium-sized. The frequency distribution curves of length (L), width (W), and thickness (T) values of durum, soft, and red wheat grains showed a trend towards a normal distribution (Figure 2). A similar trend was reported by Othmani *et al.* (2015) for durum wheat.

The importance of the morphological characteristics analyzed in this experiment in the eliminatory treatment of silo waste was proven by Mohsenin (1986), subsequently facilitating the sorting operations. Indeed, the measurement of these characteristics is necessary to select the sieve separators, to design the grids and cells of sorting and granulometric classification (semolina, flour, bran), and to calculate the rate of extraction during milling (Al-Mahasneh and Rababah, 2007).

Arithmetic and geometric mean diameters were also calculated to characterize the grain geometry of the three studied wheat species (Table 1).

A statistically significant difference (p<0.05) was observed between the results of these two parameters. Thus, the arithmetic and geometric diameters of durum wheat (Da = 4.42±0.29 mm; Dg = 4.05±0.21 mm) are smaller than those of red wheat (Da = 4.56±0.36 mm; Dg
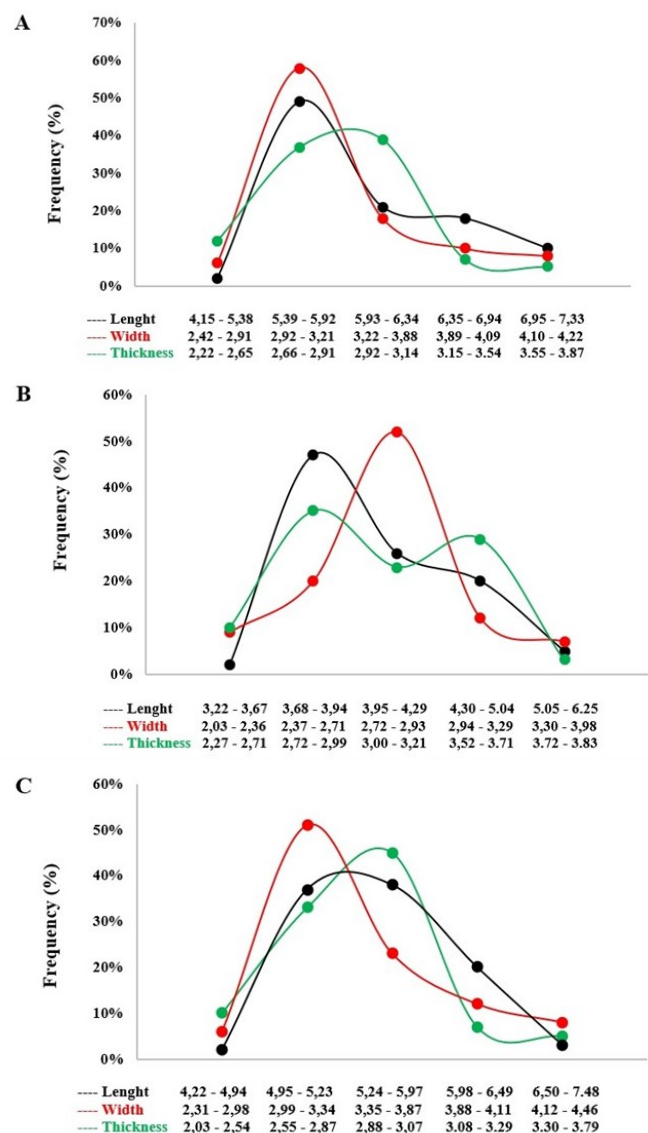

Figure 2. Frequency distribution curves of wheat grain dimensions. (A) Durum wheat (B) Soft wheat (C) Red wheat.

Table 2. Size distribution of wheat grains based on length (L), width (W) and thickness (T).

	Ungraded	Small	Medium	Large
Length L (mm)				
Durum wheat	4.15 – 7.33 (100)	4.15 – 5.61 (30)	5.62 – 6.81 (61)	6.82 – 7.33 (9)
Soft wheat	3.22 – 6.25 (100)	3.22 – 3.71 (21)	3.72 – 5.14 (59)	5.15 – 6.25 (20)
Red wheat	4.22 – 7.48 (100)	4.22 – 5.09 (26)	5.10 – 6.26 (63)	6.27 – 7.48 (11)
Width W (mm)				
Durum wheat	2.42 – 4.22 (100)	2.42 – 2.73 (46)	2.74 – 3.89 (51)	3.90 – 4.22 (3)
Soft wheat	2.03 – 3.98 (100)	2.03 – 2.60 (12)	2.61 – 3.19 (71)	3.20 – 3.98 (17)
Red wheat	2.31 – 4.46 (100)	2.31 – 3.00 (21)	3.01 – 4.05 (69)	4.06 – 4.46 (10)
Thickness T (mm)				
Durum wheat	2.22 – 3.87 (100)	2.22 – 2.65 (31)	2.66 – 3.20 (58)	3.21 – 3.87 (11)
Soft wheat	2.27 – 3.83 (100)	2.27 – 2.79 (30)	2.80 – 3.66 (63)	3.67 – 3.83 (7)
Red wheat	2.03 – 3.79 (100)	2.03 – 2.51 (30)	2.52 – 3.17 (67)	– 3.79 (3)

Range and frequency (%) in parenthesis

= 4.17±0.30 mm) and larger than those of soft wheat (Da = 4.12±0.59 mm; Dg = 3.85±0.36 mm).

Regarding the results, we found that the arithmetic and geometric mean diameters are smaller than the length and larger than the width and thickness for the three studied wheat species, with a significantly notable difference ($p<0.05$). A similar finding was reported in the study of Yousefian *et al.* (2021) with arithmetic and geometric diameters of 4.29 mm and 3.97 mm, respectively, and axial dimensions of 6.80 mm in length, 3.18 mm in width, and 2.88 mm in thickness for Iranian durum wheat.

The determination of these parameters remains useful to measure the projected seed area, which gives an indication of their behavior with respect to meteorological factors, mainly wind, which can cause breakage or lodging of wheat stems after flowering, thus allowing a better choice of growing regions (Mohsenin, 1986).

The surface area and volume of the grains of the three-studied wheat categories were calculated from the axial dimensions previously measured (Table 1).

From these results, the bidimensional and tridimensional aspects of durum wheat (S = 59.07±2.46 mm^2; V = 36.94±2.15 mm^3) are similar to those of red wheat (S = 54.97±3.18 mm^2; V = 39.81±3.14 mm^3) and distinct from those of soft wheat (S = 47.14±2.33 mm^2; V = 31.76±3.01 mm^3). Compared to other cereals belonging to the same family, the surface area and volume of the three studied wheat species were found to be lower than those of barley and higher than those of rye and oats grains (Shah *et al.,* 2016; Felizardo and Freire, 2018; Gierz *et al.,* 2022). The usefulness of these parameters for modeling grain drying, aeration, heating, and cooling, as well as in machine design, was confirmed by Mohsenin (1986).

Another physical property of the three studied species of wheat landraces is sphericity. Based on the calculated sphericity values of durum, soft, and red wheat grains reported in Table 1, we find that the three species showed the same spherical geometry. Similar values were reported by Gupta *et al.* (2020) and Yousefian *et al.* (2021) for Indian soft wheat and Iranian durum wheat species, respectively.

Given the sphericity values and the low aspect ratio, it can be inferred that the three studied species tend to slide on their flat faces rather than roll. The tendency to roll or slide is very important in the design of grain hoppers (Muzzalupo, 2013).

The determination of bulk density revealed significantly different ($p<0.05$) mean values of 551.41±3.07 kg/m^3, 542.21±3.55 kg/m^3, and 520.76±4.32 kg/m^3 for red, durum, and soft wheat grains, respectively, listed in descending order (Table 1). These results corroborate those of Akoja and Coker (2018) and Gupta *et al.* (2020) performed on Nigerian and Indian soft wheat species, respectively.

For other cereal species, Sanja *et al.* (2010) reported a higher value of 691.23 kg/m^3 for barley grains. While Shah *et al.* (2016) reported a low value of 393 kg/m^3 with oat grains. The observed variability in bulk density values can be attributed to grain size. In the grain industry, bulk density is a necessary data involved in the design of gran hoppers and storage facilities, as it affects the rate of heat and moisture transfer during the aeration and drying process (Al-Mahasneh and Rababah, 2007).

For 1000-kernel weight (TKW), we recorded mean values of 56.07±1.15 g, 48.25±1.26 g, and 61.43±1.97 g for durum, soft, and red wheat grains, respectively (Table 1). The red wheat mean value was significantly higher ($p<0.05$) compared to the other types of wheat. According to the scale established by Williams *et al.* (1988), durum and red wheat grains have TKWs

classified as very heavy, while TKWs of soft wheat rarely exceed 50 g and are classified as heavy to moderately heavy.

These results were in accordance with those commonly reported for Pakistani, Iranian, and Indian species of durum and soft wheat (FAO, 1996; Gupta et al., 2020; Yousefian et al., 2021).

In the same context, other studies carried out on other cereal species have revealed lower values for oat grains and higher ones for barley grains (Sanja et al., 2010; Shah et al., 2016).

Regarding the specific weight (SW), the obtained mean values for durum, red and soft wheat were 77.91±1.94 kg/hl, 79.64±2.17 kg/hl, and 76.17±2.10 kg/hl, respectively (Table 1). Statistically, a significant difference was recorded for SW means values among the evaluated wheat grains ($p > 0.05$). However, these values were relatively high, not widely dispersed, and comparable to those commonly reported. The obtained values are in accordance with the standards fixed by the Moroccan Agricultural Council (77 kg/hl), comparable to those fixed by the European Union (78 kg/hl) and the USA (77.2 kg/hl), and lower than the standards of Italy (82 kg/hl) and Canada (80 kg/hl) (Dick and Matsuo, 1988).

The results of 1000-kernel weight and specific weight measurements allowed us to deduce the potential of the three wheat landraces studied to produce a higher semolina and flour yield at the primary processing stage. This finding is a very important criteria for companies in the bakery, pastry, and biscuit sectors (Chasseray, 1991).

For farmers, these agronomic measurements will make it possible to calculate more accurately the seed doses needed to meet a seeding density target (Chasseray, 1991).

In the industrial sector, they represent essential parameters in the design of transport, conveying, and handling systems for the bulk handling of grains in their various forms (Warechowska et al., 2013).

On the other hand, these parameters are used to classify grade wheat batches in order to establish a standard commercial batch with the aim of promoting commercial transactions and generating quotes, not on a concrete sample of wheat, but on a definition made by the restrictions set on each grade (Blanco et al., 1988; Cubadda, 1988; Dick and Matsuo, 1988).

An evaluation of the alteration state of durum, soft and red wheat landraces was carried out by measuring the moisture content. According to the results, the moisture content values of all the species oscillate from 9% to 14%. These values are lower than the maximum limit (14.5%) defined by international standards (Codex Alimentarius, 1995). The humidity level recorded allows good preservation of wheat grains, ensuring permanent maintenance of the industrial and semi-industrial production of finished and semi-finished wheat products.

Similar results were reported by Iqbal et al. (2015) and Maurício et al. (2017) for Pakistani and Brazilian wheat grains, respectively. On the other hand, high levels were found in wheat from Bangladesh (Surovy et al., 2020), and low levels in Japanese and Iranian wheat grains (Tabatabaeefar, 2003; Morishita et al., 2020).

This observed disparity could be attributed to the influence of agronomic factors and prevailing climatic conditions during the growth period (Slaughter et al., 1992; Butt et al., 1997; Mahmood, 2004). High moisture levels are correlated with the triggering of proteolytic and lipolytic activities of the grains, leading to a degradation of their nutritional and technological qualities (Mahmood, 2004). It also creates a favourable environment for the growth of insect pests and the development of bacteria and moulds (Keran et al., 2009). In this case, continuous ventilation is necessary in order to lower the humidity level of the grains in storage and maintain optimal conservation over the long and medium-term.

The total ash content of the three wheat landraces tested shows that the red wheat grains (3.25±0.64%) are more ashy than the durum (2.23±0.42%) and soft (2.11±0.68%) wheat grains. The normalized values of the wheat ash content are between 1.6% and 2.0% (Codex Alimentarius, 1995). Significantly high levels were recorded for red wheat. This high ash content level reflects a high mineral content, which is required for the proper functioning of the human body. Thus, the use of Moroccan wheat landraces by the food industry increases the nutritional value of the resulting products (bakery products, pasta, pastries, couscous).

Previous studies revealed similar ash content for durum and soft wheat grains. Surovy et al. (2020) and Yousefian et al. (2021) reported values reaching 1.99% and 2.56% for Bangladeshi and Iranian durum wheat, respectively. Furthermore, Safdar et al. (2009) and Kundu et al. (2019) reported rates ranging from 1.37% to 1.82%, and 1.27% to 1.93%, respectively, for Indian soft wheat. In contrast, Elbar et al. (2020) reported a much higher rate of 10.15% for Algerian durum wheat compared to Moroccan durum wheat. This observation could be explained by the variation of cultural practices related to the quantity and composition of the fertilizing elements applied. Soil conditions could also affect the

ash content since the mineralogical composition of soils is one of the determining factors of the quantitative and qualitative variability of the mineral content in wheat (Kaplan Evlice, 2021).

An important characteristic that affects the yellow color of pasta, a determining factor in the choice of consumption, is the extractable carotenoid content of albumen. The carotenoid pigment content recorded in red wheat samples (9.11±1.60 ppm) exceeds that of durum wheat (7.54±1.21 ppm), while soft wheat (1.19±0.13 ppm) is low in carotenoid pigment. Surovy *et al.* (2020) reported comparable levels of durum wheat from Bangladesh.

Normalized values for the carotenoid pigment content of durum wheat fluctuate between 4 and 8 ppm (Troccoli *et al.,* 2000). Red wheat has outstanding carotenoid pigment levels of 8 ppm. Given that it is a highly heritable characteristic that is independent of environmental conditions and cultivation practices, such promising results will be extremely valuable to properly using Moroccan red and durum wheat in wheat pasta quality breeding programs (Parker *et al.,* 1998; Elouafi *et al.,* 2001).

Based on the parameters determined during this study, it is obvious that the three types of wheat landraces farmed in Morocco have a satisfactory global quality for the needs expected by the manufacturers. Such quality will not only encourage the national production of wheat that will compete with international production but will also help to alleviate the economic recession that has affected the cereal industry worldwide.

4. Conclusion

In Morocco, the quality control of grain products raises great questions. The current study contributes to the assessment of the industrial quality of the Moroccan wheat landraces in order to bring various information to the actors of the cereal sector. Indeed, according to the data acquired via dimensional characterization, the physical structures of the three wheat species studied in this study are distinct. The detected moisture content levels were lower than the maximum limit (14.5%) defined by international standards, indicating satisfactory sample conservation. In terms of semolina yield traits, durum and red wheat grains have 1000-kernel weights classified as very heavy, whereas soft wheat grains have heavy to moderately heavy 1000-kernel weights with high specific weight. The determination of the total ash rate indicated that red wheat is more ashy than durum and soft wheat grains, indicating its richness in mineral content. Moreover, the carotenoid pigment content recorded in red wheat exceeded that of durum wheat, while soft wheat was low in carotenoid pigment. Overall, the conformity of the analyzed parameters to the wheat grain processing industry requirements encourages the food industry to use the Moroccan wheat landraces.

Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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