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Quality assessment of durum wheat landraces and modern varieties through physico-chemical properties

Hiba Trad[1a], Sourour Ayed[2a*], Jaime A.Teixeira da Silva[3], Afef Othmani[2], Imen Bouhaouel[1], Raouda Helel[4], Hajer Slim-Amara[1]

[1]University of Carthage, National Agronomic Institute of Tunisia, LR14AGR01, Genetics and Cereal Breeding Laboratory, 1082 Tunis, Tunisia
[2]University of Carthage, National Agricultural Research Institute of Tunisia, LR20-INRAT-02, Field Crops Laboratory, 2049 Ariana, Tunisia
[3] Independent researcher, P. O. Box 7, Miki-cho post office, Ikenobe 3011-2, Kagawa-ken 761-0799, Japan
[4] Central Analysis and Testing Laboratory, Laboratory of Plant Origin Products, Ministry of Industry and Technology, 23, Avenue Jawaher Lel Nehru, 1008 Montfleury, Tunisia
[a] These two authors contributed equally to this work
**: Corresponding author. E-mail: ayedsourour@yahoo.fr*

Abstract:
Background: *Durum wheat is a main staple food in the world. Landraces are locally adapted and are important genetic resources in new breeding programs to develop quality attributes of wheat varieties. Therefore, this study aims to compare some physico-chemical properties of improved durum wheat genotypes with those of landraces and to identify traits that correlated positively with protein content for use as selection criteria in durum wheat breeding programs.*
Materials and Methods: *In this study, grains of eight Tunisian durum wheat genotypes, including six landraces (Azizi, Mahmoudi, Ouerd Bled, Arbi, Chili and Biskri) and two improved varieties (Karim and Razzek) were used. Variation in quality attributes was determined by evaluating select physical (1000 kernel weight (TKW) and vitreousness) and chemical characteristics (protein, moisture, ash and falling number).*
Results: *ANOVA analysis revealed significant genotypic differences in the tested parameters. Landraces, when compared to improved genotypes, exhibited high TKW, indicating high milling yield potential (~5%). In addition, milled wheat of all landraces had a high protein content (17.18- 18.9% on dry weight (DW) basis) and semolina content (16.19-18.38% DW), which did not exceed 13.13% and 12.54%, respectively in the improved varieties. The high falling number of milled samples (394-473.5s) and of semolina (461-853.5s) indicated extremely low amylolytic activity. Landraces conserved semolina moisture content better than improved genotypes. Landraces had significantly higher mineral content (2.5% DW in milled wheat and 1.78% DW in semolina) than improved genotypes (<1.73% and 1.09%), as assessed from ash content. Principal component analysis (PCA) explained 68.94% of total variability. From PCA, four landraces (Arbi, Biskri, Chili and Ouerd Bled), which showed the best physico-chemical characteristics, can be used as parents for improving durum wheat quality. The degree of vitreousness and protein content of milled wheat were highly negatively correlated ($r=-0.93$; $P<0.01$). Semolina protein content was also highly negatively correlated ($P<0.01$) with the degree of vitreousness ($r=-0.94$) and semolina moisture content ($r=-0.72$), but positively correlated with semolina extraction rate ($r=0.21$) and highly correlated with ash content ($r=0.8$).*
Conclusion: *Studied landraces showed best physico-chemical properties compared to improved durum wheat genotypes. Also, semolina extraction rate and ash content can be used as selection criteria to improve grain protein content in durum wheat.*

Keywords: *Landraces; protein content; quality traits; variability*
Abbreviations: *AC: ash content; FN: falling number; MC: moisture content; MSY: mean semolina yield; PC: protein content; TKW: thousand kernel weight; V: vitreousness.*

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I. Introduction

Durum wheat (*Triticum turgidium* L. var. *durum*) represents only 8 to 10% of all wheat global cultivated acreage [1]. The Mediterranean Basin represents the largest production area worldwide and North Africa the most important import market [2]. Durum wheat originated and was domesticated in the Fertile

Crescent. This domestication process caused multiple changes in the plant that were generated the establishment of local landraces which were largely cultivated until the first decades of the 20^{th} century but by the spread of modern durum wheat cultivars (semi-dwarf), as consequence of the Green Revolution [3], these landraces confined to the niche areas of cultivation and their preservation and maintenance being trusted gene banks, public research institutions and conservator farmers. Nowadays, landraces are important genetic resources characterized by its adaptation to their origin agro-ecological zones and its preservation is important for avoiding genetic erosion and to using this materiel in new breeding programs [4]. Indeed a supplementary attention is given to the durum nutritional values and health effects on consumer and interest in the physiochemical content of local and modern durum wheat varieties and this trend led to the rediscovery and reutilization of durum wheat landraces.

Durum wheat is important because of its grain quality, it is used in pasta, burghul and couscous production and its unique characteristics: hardness of kernel, vitreous endosperm and golden amber color which vary among durum wheat varieties [5-7]. These characteristics, along with its protein content and gluten strength, make it suitable for the manufacture of diverse food products and end products [8, 9]. According to Mariani et al. [10], the high quality of pasta is directly related to the best wheat quality. In fact, durum wheat, with high kernel weight, test weight, protein content, and gluten strength, will have good firmness, cooking stability and resiliency of cooked pasta products [8,11,12].

Couscous, which is made with durum semolina, is mainly consumed in North Africa [13]. In Tunisia, increasing food consumption of this cereal due to growing populations and an improved standard of living has led to changes in breeding strategies. Breeders have made great efforts to increase grain yields [14-17] and to improve biomass partitioning to grains [18,19]. In fact, wheat landraces are important genetic resources to improve the quality of new varieties [20]. Lopes et al. [21] reported that landraces from Algeria, Italy, Tunisia, Spain, France, Portugal, and Greece have high grain-filling rates. According these authors, these landraces are a best source of allelic variation for thousand kernel weight and biomass yield. Landraces have low yield compared to moderate varieties but more stable and always with superior nutritionally value [22]. However, several landraces have completely disappeared, and have already been replaced by new varieties [23]. This genetic erosion has resulted in a loss of genetic diversity and has led to the extinction of valuable quality-related resources, which have not been sufficiently exploited since such landraces harbor genes and gene complexes coding for novel quality traits [4, 24, 25].

Durum wheat quality is continually evolving in response to technological advances in milling and processing. Quality improvement is based on storage durability and on technological values such as moisture, falling number, protein and gluten content, and Zeleny sedimentation value [26], all of which are possible by evaluation and selection [27, 28] since wide variation exists in breeding materials. Limited information is available on breeding for quality of Tunisian durum wheat genotypes. The aim of this study was two-fold: i) to compare some physico-chemical properties of improved durum wheat genotypes with those of landraces; ii) to identify traits that correlated positively with protein content for use as selection criteria in durum wheat improvement programs.

II. Material And Methods

Durum wheat samples

Grains of eight Tunisian durum wheat genotypes, including six landraces (Azizi, Mahmoudi, Ouerd Bled, Arbi, Chili, Biskri) and two improved varieties (Karim and Razzek) obtained from the National Gene Bank of Tunisia, were used in this study. All genotypes were grown at the National Institute of Field Crops (INFC) located in northwest of Tunisia at an altitude of 131 m above sea level, and under the same field conditions without the application of any treatments. Plots (30 m^2) received 100 kg ha-1 of di-ammonium phosphate at sowing and 200 kg ha^{-1} of ammonium nitrate (half at the sowing stage and half at the tillering stage). The Herbicide Puma evolution (Fénoxaprop-P-Ethyl + Iodosulfuron-methyl Sodium + Méfenpyr-diethyl) was used at the rate of 1 l/ha was applied as treatment for weed control. Grain was harvested in July.

Measured parameters

Physical traits

Thousand kernel weight (TKW) was calculated with an electronic seed counter as the mean weight of three sets of 1000 grains per plot [29]. The degree of vitreousness was determined after sieving by hand and sorting kernels and after external inspection of each individual kernel by naked eye. All kernels that were not, beyond doubt, recognizable from the outside as being fully vitreous, were cut transversally with a scalpel and evaluated according to the appearance of the sectional areas of the endosperm. The separated kernels that were vitreous were weighed. Vitreousness was calculated as a percentage of vitreous kernels (w/w) in the sample [30].The moisture of the milled wheat samples [31] were determined before milling. Thereafter, the samples were placed in a hermetically sealed bottle and were conditioned by adding water. The quantity of water was determined by the following equation [31] in order to bring the final moisture to 16.5%:

W_{H2O}= [1-(m_1m_3/m_0m_2) ×100]

m_0= mass, in g, of the sample studied;

m_1= mass, in g, of the sample studied after drying;

m_2= mass, in g, of the sample taken before conditioning;

m_3= mass, in g, of the sample taken after conditioning.

Conditioning [32] was performed at ambient temperature 48h before milling. In two steps, the appropriate amount of water was added and mixed by hand, with 6-h rest periods in between to ensure better penetration of water into the kernel, and thus easier separation of bran from the endosperm. Samples were then milled into semolina using an ISO Brabender mill (Quadrumat junior, C.W. Brabender® Instruments, Inc., NJ, US) and mean semolina yield (MSY) was determined following an ISO method [32].

Chemical traits

The moisture content (MC) of milled wheat and semolina samples was determined by an ISO method [31]. Protein content (PC), which was assessed by a standard Kjeldhal method [33], was calculated after multiplying Kjeldhal nitrogen by 5.7 and was expressed on a dry weight (DW) basis. Ash content (AC) was determined after incinerating 4-5 g of grains in a muffle furnace at 550°C and expressed based on 14% MC [34]. Falling number (FN), the measure of amylase activity in milled wheat and semolina, was determined from 7g of wheat [35]. All analyses were conducted at the Laboratory of Plant Origin Products, Central Analysis and Testing Laboratory of the Ministry of Industry and Technology of Tunisia.

Statistical analysis

Analysis of variance (ANOVA) was applied to each quality parameter in order to estimate variation among durum wheat genotypes using a probability threshold of 5% and 1%. Significant differences between means were subjected to a *post-hoc* Turkey's test with significance at P<0.05. Principal component analysis (PCA) was performed to better classify the studied genotypes. All analyses were performed using SPSS 18.0 (IBM Corp., Armonk, NY, US) software as the mean of three replicates. The coefficient of variation (CV) was calculated as a measure of relative variability. Pearson's correlation coefficient (r) was also calculated as a measure of the degree of linear dependence between protein content and quality parameters.

III. Result and Discussion

Variations in traits

Pooled ANOVA revealed a highly significant difference (P<0.01) among genotypes for all quality parameters studied (Tables 1, 2). This significant genotypic difference implies the presence of variation between genotypes which is central to the study of quality traits in breeding.

Table no 1: Analysis of variance for thousand kernel weight, vitreousness and mean semolina yield for eight Tunisian durum wheat genotypes

Sources of variation	df	TKW	V	MSY
Genotype	7	117.97**	564.85**	88.33**
Error	16	0.04	0.03	0.05
CV (%)		11.18	128.78	7.29
R^2		0.99	1	0.99

TKW: thousand kernel weight (g); MSY: mean semolina yield (%); V: vitreousness (%); CV= coefficient of variation; R^2 = multiple correlation coefficient. *,** Significant at P <0.05 or 0.01, respectively (F-test).

Table no 2: Analysis of variance for protein content, moisture content, ash content and falling number for eight Tunisian durum wheat genotypes

Sources of variation	df	PR	M	AC	FN
Genotype	7	25216.61**	40.28**	0.43**	0.324**
Treatment	1	329014.08**	10.37**	5.42**	166.88**
G*T	7	26247.08**	0.792**	0.019**	0.81**
Error	32	5.64	0.066	0.003	0.025
CV (%)		23.23	15.51	24.15	14.9
R^2		1	0.99	0.98	0.99

AC: ash content (% DM); FN: falling number (s); PR: protein content (%DM); M: moisture content (%); CV= coefficient of variation; R^2 = multiple correlation coefficient.*,** Significant at P <0.05 or 0.01, respectively (F-test).

Thousand kernel weight

TKW between genotypes was highly significantly different (P<0.01) (Table 1) and TKW values varied between 39.35 g (Ouerd Bled) and 59.7 g (Arbi) (Table 3). According to Petrova [36], acceptable TKW for durum wheat is 30 to 35 g. Mohammed et al. [6] showed variation in TKW ranging from 35.4 to 48.8 g in 16 durum wheat genotypes tested at Sinana and Adabo, southeastern Ethiopia. Bakhella et al. [37] found a large range of TKW (30.9 to 65.6 g) in nine Moroccan durum wheat cultivars. The TKW ranged from 33.5 to 59.2 g recorded for Sicilian durum wheat collection. Interestingly, 48.14 % of landraces recorded significant TKW higher values, as compared to cv. Claudio, In addition, seven landraces also showed a higher TKW value than the modern cv. Simeto [38]. According these authors, these performances might be due to earlier flowering of modern wheat material. TKW is the trait most closely related to yield and was used to select high-yielding wheat cultivars [39]. It is an important trait in breeding, it is related to seedling growth and vigor and also milling quality [40]. Accoding to Taneva et al. [41], the estimated values of heritability were found for thousand kernel weight (TKW 72.4%) and test weight (TW 47.4%) indicated the possibility to conduct effective selection.

In this study, landraces, particularly Azizi (58.25g) and Arbi (59.7g), had a high TKW because of their kernel size [42]. These genotypes also had significantly higher mean semolina yield (75.2% and 75.06%, respectively) (Table 5). Similarly, Soriano et al. [43, 25] found that TWK is more important in western Mediterranean landraces than in modern durum wheat cultivars. High TKW did not affect the performance of milling as Ouerd Bled has the lowest TKW (39.35 g) and the highest mean semolina yield (76.07%).

Vitreousness

In durum wheat, the degree of vitreousness of the kernel is often used, in conjunction with kernel hardness, to predict crop quality. Non-vitreous kernels (starchy), characterized by an opaque area, have an important impact on the characteristics of kernels during milling, producing a detrimental effect to the end-use quality of durum wheat, and decreasing the semolina extract. The eight studied genotypes exhibited a wide range of vitreousness, from 1.04% in Azizi to 39.88% in Karim (Table 4). El-Khayat et al. [44] also found a high degree of variation in vitreousness within and between nine Syrian durum wheat genotypes, ranging from 50.4% to 93.6%. Pinheiro et al. [45] showed that vitreousness varied between 93.5% and 98.7%. The incidence of starchy kernels, recorded in Sisilian durum wheat collection ranges from 0 to 96% with landraces showing higher percentage compared to modern cultivars [38]. In recent research of Balkan et al. [46], the evaluation of 20 durum wheat landraces and 5 durum wheat cultivars from Turkey during two growing seasons showed that the grain vitreousness rate ranged from 78.42 to 95.08% and the highest value was obtained in Akbuğday landrace.

Table no 3: Means of thousand kernel weight (TKW), vitreousness (V), semolina yield (MSY), protein content (PR) on milled wheat and semolina, moisture content (M), ash content (AC) and falling number (FN) for eight Tunisian durum wheat genotypes

	Azizi	Mahmoudi	Ouerd bled	Arbi	Chili	Biskri	Karim	Razzek
TKW (g)	58.25c	55.6c	39.35 a	59.7c	53.5 b	52.9b	56.44c	52.65b
Vitreousness (%)	1.04a	4.02d	5.84e	1.8b	3.83d	3.22c	39.88g	22f
Mean semolina yield (%)	75.2e	60.28a	76.07f	75.06e	71.38d	73.88e	70.9c	66.2b
Milled durum wheat protein (% DM)	17.5c	18.2d	18.8d	17.18c	18.25d	18.9e	11.8a	13.13b
Semolina protein (% DM)	16.48cd	17.06de	16.19c	16.98de	17.32e	18.38f	11.2a	12.54b
Milled durum wheat (%)	11.41c	11.41c	11.31c	11.19bc	10.25a	10.72ab	10.7ab	11.1bc
Semolina (%)	14.93d	14.15a	14.41b	14.6bc	14.8cd	14.49b	15.67e	14.8cd
Milled durum wheat ash content (% DM)	2.5c	2.18b	2.22b	2.13b	2.26b	2.31b	1.66a	1.73a
Milled durum wheat (s)	473.5e	455.5d	452.5d	455d	417b	430.5c	428.5c	394.5a
Semolina ash content (% DM)	1.78g	1.72f	1.55d	1.36b	1.43c	1.61e	1.09a	1.08a
Semolina (s)	475b	461a	641f	853.5h	683g	633e	535c	550d

[a]Mean values represent average of three replicates.Means followed by different letters within each column for each genotype are significantly different based on Tukey's multiple range test ($P < 0.05$).

The highly significant difference (*P*< 0.01) between genotypes (Table 1), especially between landraces (mean: 3.29%) and improved genotypes (mean: 30.94%), could be explained by the degree of kernel compactness [47] or by the amount of protein and starch within a kernel [48], thus serving as the genetic basis of this parameter. Starchy kernels, in contrast to vitreous translucent ones, have a discontinuous endosperm with many air spaces and also have a white appearance. This is the case for Ouerd Bled, Karim and Razzek. During milling, starchy kernels are quickly reduced to fine particles (flour) [49, 50], which have a white appearance (Fig. 1C, 1G, 1H), explaining why lower endosperm vitreousness is used as an indicator of increased semolina production, and not flour [51]. Consequently, the degree of vitreousness should be taken into consideration because it has an important effect on milling quality (color and size particles of semolina) of durum wheat. According to Sandhu et al. [52], vitreous kernel content decreased about 23.6% after spikes exposed to 88% of humidity for 3 days. Takenobu et al. [53] showed that drying conditions are important for producing spaghetti with desired properties. Indeed, the percentage of vitreous kernels depends on cultivar, environment and nitrogen application, and grades of marketed durum wheat are generally based on the percentage of vitreous kernels [54].

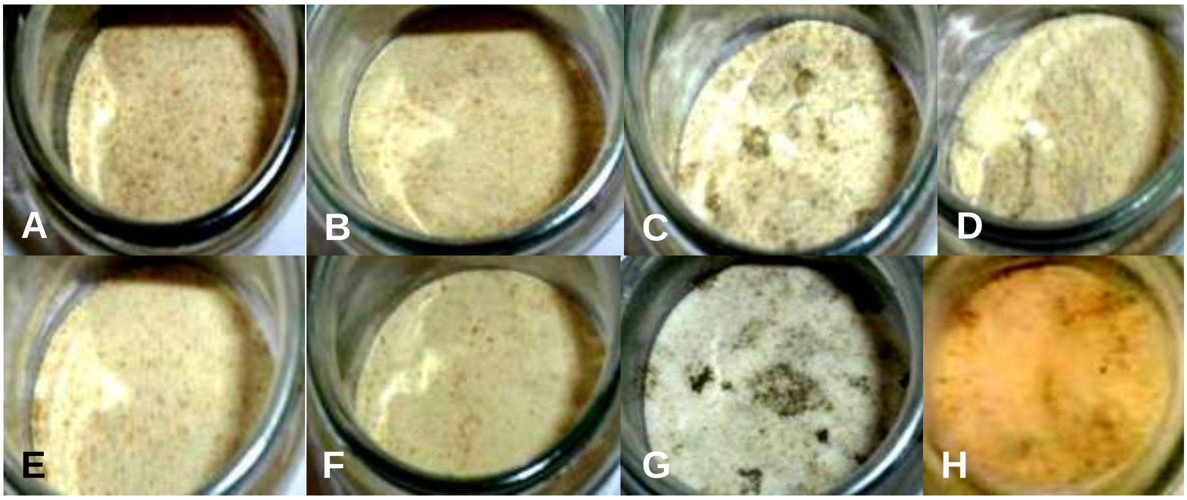

Figure 1: Durum wheat semolina of Azizi (A), Mahmoudi (B), Ouerd Bled (C), Arbi (D), Chili (E), Biskri (F), Karim (G) and Razzek (H). The images show the progress of fungal contamination of durum wheat semolina: advanced for Karim (G) and Ouerd Bled (D) and primary for Razzek (H) after two months of storage in the same conditions.

Mean semolina yield

Differences in MSY between genotypes were highly significant (*P*<0.01) (Table 1), ranging from 66.2% in Karim to 76.07% in Ouerd Bled (Table 3). Samaan et al. [55], who studied nine Syrian spring durum wheat genotypes, showed that extraction rates varied slightly between genotypes, from 62.7% to 65.5%. In this study, compared to improved genotypes, the majority of landraces had significantly higher MSY values (*P*<0.05).A high semolina extraction rate reduces the amount of smaller-sized durum wheat flour and optimizes use of kernel for pasta production [56]. Milling quality is influenced by the degree of vitreousness [57], which is strongly related to the yield and quality (brightness, granulation and purity) of semolina [45]. Marshall et al. [58] linked semolina yield to many factors such as test weight and TKW and thus indirectly to grain hardness.

Protein content

Variability in PC between genotypes was highly statistically different (*P*<0.01) (Table 2). In fact, a high level of variation (23.23%), ranging from 11.8% of dry weight (DW) in Karim to 18.8% DM in Ouerd Bled, was observed for milled durum wheat and from 11.2% DM in Karim to 18.38% DM in Biskri, for semolina (Table 3). Žilićet al. [59] reported 5.71% variation ranging from 11.04% to 12.40% DM when whole meals of four durum wheat genotypes (breeding lines and cultivars) were analyzed. Milled durum wheat is richer in protein than semolina and landraces had higher protein content than Karim and Razzek (Table 3). Protein content is among the most important useful indicator for characterizing durum wheat genotypes. Indeed, it is well-documented that the protein content composition has an important impact on the wheat processing quality. Indeed, high protein level in semolina will usually yield a product with uniform particle size, with a minimum number of starchy particles [38]. A significantly higher protein content (>16.0%) was observed in the six Sicilian landraces (bd3, sco4, reg1, cic1, gig1, and ing2) compared to the modern cultivars (<15%), whereas the lowest value (8.5%) was found in tri2, due to the high percentage of starchy kernels. The results of Kendal et al. [20] showed that majority of durum wheat landraces studied had high value of protein content that made a satisfactory pasta (= and >13%). Indeed, Gate [60] attributed the differences in PC between genotypes to their variable aptitude to absorb and remobilize nitrate. Water management and nitrogen application are important factors that determine wheat grain yield and protein quality: supplemental irrigation decreases the protein content of wheat grains [61]. Protein content is also strongly associated with high temperatures during the grain-filling stage [62].

According to Galterio et al. [63] and Mariani et al. [10], durum wheat with 13% of protein per DM can provide excellent products, whereas wheat with PC below 11% DM gives products of inferior quality. This is the case in this study of all studied landraces, particularly Biskri, Chili and Mahmoudi (Table 3). However, large differences in cooking pasta properties among genotypes of similar PC are problematic for a study of durum wheat quality. Previous studies conclusively demonstrated that cooking quality depends on both PC and gluten strength. While PC is the primary determinant of cooking quality, gluten strength has a direct effect on the rheology (viscoelasticity) and the properties of cooked pasta [64, 65]. The low PC of the improved genotypes could be explained by their high vitreousness (Table 3).

Moisture content

Moisture determination is a key parameter of quality tests, and is required for the precision of analytical results reported for DM and for the application of technological tests [31]. There were differences in MC in milled durum wheat and semolina between genotypes (Table 3), ranging on average between about 11% and 14%. Samman et al. [55] noted that MC exceeded 13.8% in Sham-1. MC, which is highly influenced by genotype (P<0.01; Table 2), must remain as low as possible because it influences the milling value of wheat, which is defined as the amount of extracted semolina with good technological properties [66, 67]. The tested milled wheat samples had MC that varied between 10.25% in Chili to 11.41% in Azizi and Mahmoudi and thus conform to commercialization norms established by the ISO, which require an MC lower than 14.5% [31]. The MC of semolina reached 14.8% in Razzek and 15.67% in Karim, exceeding the normative requirement (15% for semolina) as specified by ISO 712 [31]. After conserving for two months at the same conditions, only improved genotypes and Ouerd Bled were contaminated by fungus (Fig. 1C,1G, 1H). Thus, the evaluation of moisture has important health- and sanitation-related aspects. Similarly, Yağdı [68], the humidity was negative correlated with all the quality traits. The moisture content of grains is a key factor for storage and the stability of semolina quality. On an industrial scale, semolina is marketed only for a well-defined water content. The more moist a semolina is, the more quickly the constituents break down. High humidity might result in increased spike and kernel moisture and kernel size.

Ash content

AC is an economically important quality characteristic for durum wheat kernels as it influences pasta color. The faint color of semolina is caused by high AC, and may be due to high extraction rates [69]. Therefore, AC can be used as a relative measure of bran or mineral content in semolina and depends on kernel size, bran thickness and the efficiency of the milling process [67, 70]. A highly significant difference (P< 0.01) was observed in AC between durum wheat genotypes (Table 2).There was wide variation in AC (CV= 24.15%), ranging from 1.66% in Karim to 2.5% in Azizi for milled wheat, and between 1.08% in Razzek to 1.78% DM in Azizi for extracted semolina. The average AC of Tunisian milled wheat and semolina was 2.12% and 1.45%, respectively, values that lie within an acceptable range of 2.1 and 1.3% DM, respectively. El Khayatet al. [44] noted a range of AC between 1.45% and 1.74% DM for semolina extracted from nine durum wheat genotypes.
Grain AC is influenced by variety. Rodríguez et al. [71] showed differences (P<0.05) in mineral and trace elements between 19 landraces of *T.turgidum* and *Triticum aestivum*, even though that comparison was between wheat species and subspecies whose genetic differences significantly influenced the chemical composition of minerals and trace elements. Kling et al. [72] found relatively high varietal differences with respect to their ability to take up minerals into grain, and landraces were able to deposit more minerals than improved genotypes. Mineral content significantly decreased in modern cultivars and the highest level of iron and zinc could be found in landraces and low-yielding wheat genotypes [73, 74]. This may be due to the capacity of landraces and old varieties, which often mature later than modern cultivars, to uptake nitrogen (N), even in N-limited conditions. In these conditions, landraces and varieties with a taller growth habit and low harvest index absorb and translocate more N than modern cultivars [75]. Durum wheat usually contains 1.6 to 2.3% ash [76]. However, in this study, variation in AC not only existed between genotypes, but also between milled wheat and semolina (Table 3). Abecassis and Feillet [77] signaled that AC is irregularly distributed between the endosperm and peripheral parts.

Falling number

Wide variation in FN among the studied genotypes was observed (Table 3). For milling wheat's, FN ranged from 394.5s in Razzek to 473.5 s in Azizi, and from 475s in Azizi to 853.5s in Arbi for semolina. FN was highly influenced by genotype ($P<0.01$) (Table 2). This quality trait is associated with preharvest sprouting in the field under prolonged periods of moisture during harvest. Dexter et al. [78] and Petrova and Bojilov [79] demonstrated an adverse effect of preharvest sprouting in durum wheat. According to the California Wheat Council [76], a FN of 250-500sis acceptable while a FN of 300sand above is desirable. All tested genotypes showed FN values significantly higher than 400s, indicating sound grain with low α-amylase activities [80]. Thus, sprout damage is not a factor in Tunisian durum wheat, unlike in Bulgarian wheat [36]. El Kayat et al. [44] found that nine studied Syrian durum wheat genotypes had high FN values (433-579s). Similarly, Josephides [81] reported that durum wheat grown in Cyprus under dry and hot conditions generally had high FN (460 to 660s).FN is dependent on the genotype and environment [54].

Vitreousness

In durum wheat, the degree of vitreousness of the kernel is often used, in conjunction with kernel hardness, to predict crop quality. Non-vitreous kernels (starchy), characterized by an opaque area, have an important impact on the characteristics of kernels during milling, producing a detrimental effect to the end-use quality of durum wheat, and decreasing the semolina extract. The eight studied genotypes exhibited a wide range of vitreousness, from 1.04% in Azizi to 39.88%in Karim (Table 4). El-Khayat et al. [44] also found a high degree of variation in vitreousness within and between nine Syrian durum wheat genotypes, ranging from 50.4% to 93.6%. Pinheiro et al. [45] showed that vitreousness varied between 93.5% and 98.7%. The incidence of starchy kernels, recorded in Sisilian durum wheat collection ranges from 0 to 96% with landraces showing higher percentage compared to modern cultivars [38]. In recent research of Balkan et al.[46]the evaluation of 20 durum wheat landraces and 5 durum wheat cultivars from Turkey during two growing seasons showed that the grain vitreousness rate ranged from 78.42 to 95.08% and the highest value was obtained in Akbuğday landrace.

Correlations among traits

PCA was performed as an additional tool to confirm the effect of genotype on physico-chemical quality traits. The two principal component (PC) axes accounted for 68.94% of total variance: 51.7 and 17.24% for axes 1 and 2, respectively. The first PC axis (PC1) clearly separated semolina MC, vitreousness and TKW in its negative direction from AC, and PC and falling numbers in the positive direction. On the second PC axis (PC2), the observed variation was caused mainly by TKW in the negative direction with MSY (Fig. 2A). PCA classified the eight genotypes into three groups (Fig. 2B). The first group (Arbi, Biskri, Chili and Ouerd Bled) had the best quality characteristics with low amylolytic activity and high mean semolina yields. Genotypes of this group are rich in protein and AC. These genotypes might be used as good parents in durum wheat improvement programs. The second group (Azizi and Mahmoudi) is characterized by high AC and FN values. Genotypes of the third group (Karim and Razzek) had the highest level of vitreousness and moisture semolina (Table 3), therefore the worst quality attributes.

Table no 4: Correlation coefficients between physico-chemical quality traits for eight durum wheat genotypes

Quality measurement	TKW	V	MSY	PC1	MC1	AC1	FN1	PC2	MC2	AC2	FN2
TKW	1.00										
V	0.05	1.00									
MSY	-0.19	-0.21	1.00								
PC1	-0.27	-0.93**	0.23	1.00							
MC1	-0.06	-0.25	-0.11	0.13	1.00						
AC1	-0.04	-0.90**	0.36	0.89**	0.18	1.00					
FN1	0.10	-0.51*	0.29	0.50*	0.61	0.64	1.00				
PC2	-0.04	-0.94**	0.21	0.96**	0.04	0.88**	0.45	1.00			
MC2	0.31	0.77**	0.22	-0.76**	-0.43	-0.52*	-0.27	-0.72**	1.00		
AC2	-0.05	-0.80**	0.08	0.84**	0.39	0.91**	0.74**	0.80**	-0.61*	1.00	
FN2	-0.01	-0.29	0.52*	0.24	-0.28	0.07	-0.05	0.32	-0.13	-0.21	1.00

Level of significance: $P<0.05$=*; $P<0.01$=** (F-test); 1: milled wheat; 2: semolina; AC: ash content; FN: falling number; MSY: mean semolina yield; M: moisture content; PR: protein content; TKW: thousand kernel weight; V: vitreousness.

Grain physical quality of durum wheat, which depends on TKW and test weight (TW), influence semolina production [54]. As observed in Table 4, no significant correlation existed between TKW and mean semolina yield (r=–0.19).This result is in contrast with that by Pinheiro et al. [45], who reported that semolina yield was significantly correlated with TKW (r=0.32).This is probably due to the high level of vitreousness affecting kernel endosperm of the tested genotypes (Table 3).

Accordingly, Xie et al. [51] found that milled wheat with a high level of vitrousness more likely produced flour than semolina. Smaller particle-sized flour is less important for a miller than a high rate of semolina extraction [56]. Marshall et al. [58] linked factors such as TKW and TW to semolina yield and hence indirectly to grain hardness, which is a key determinant of milling performance for semolina production while TW is an important quality aspect used as a grading system to indicate grain soundness.

The influence of PC on physical properties was not as clear as vitreousness. A weak negative correlation was observed between TKW and PC (r=–0.04). Warechowska et al. [82] also showed a weak correlation between PC and TW (r=–0.39), but only for Eta variety. However, Rharrabti et al. [83] and Oguz et al. [84] found a highly significant and negative correlation (P<0.001) between TKW and PC and strongly negative correlation also existed between the degree of vitreousness and semolina PC (r=–0.94), but PC correlated positively with semolina extraction rate(r=0.21). El Khayat et al. [44] also indicated a positive relationship between TKW and PC (r=0.49). This is likely related to the relationship between PC and vitreousness. Non-vitreous (i.e., starchy) regions of the kernel have low PC [85] whereas vitreous kernels are usually harder and have a higher PC [86]. Thus, kernels with high PC are generally assumed to yield more semolina than either starchy or piebald kernels [87, 88].These results emphasize the role of kernel PC on the degree of vitreouness and in the performance of milling extraction.

Factors affecting semolina quality

AC showed a significant positive correlation with PC (r=0.84). Abecassis and Feillet [77], studying both the grain and flour of French and Italian durum varieties, showed highly significant correlations between PC and AC. Pyler [89] showed a similar relation in bread wheat. Oguz et al. [84] and El Khayat et al. [44] revealed a highly significantly negative correlation (P< 0.001) between AC and PC (r = –0.446 and –0.57, respectively). Semolina MC and PC showed a significantly negative correlation (r=–0.72). Turnbull [90] indicated that pasta with good potential has high PC semolina with good physical conditions and thus semolina with uniform particle size and minimum number of starchy semolina particles will hydrate evenly during mixing to produce strong and elastic pasta.

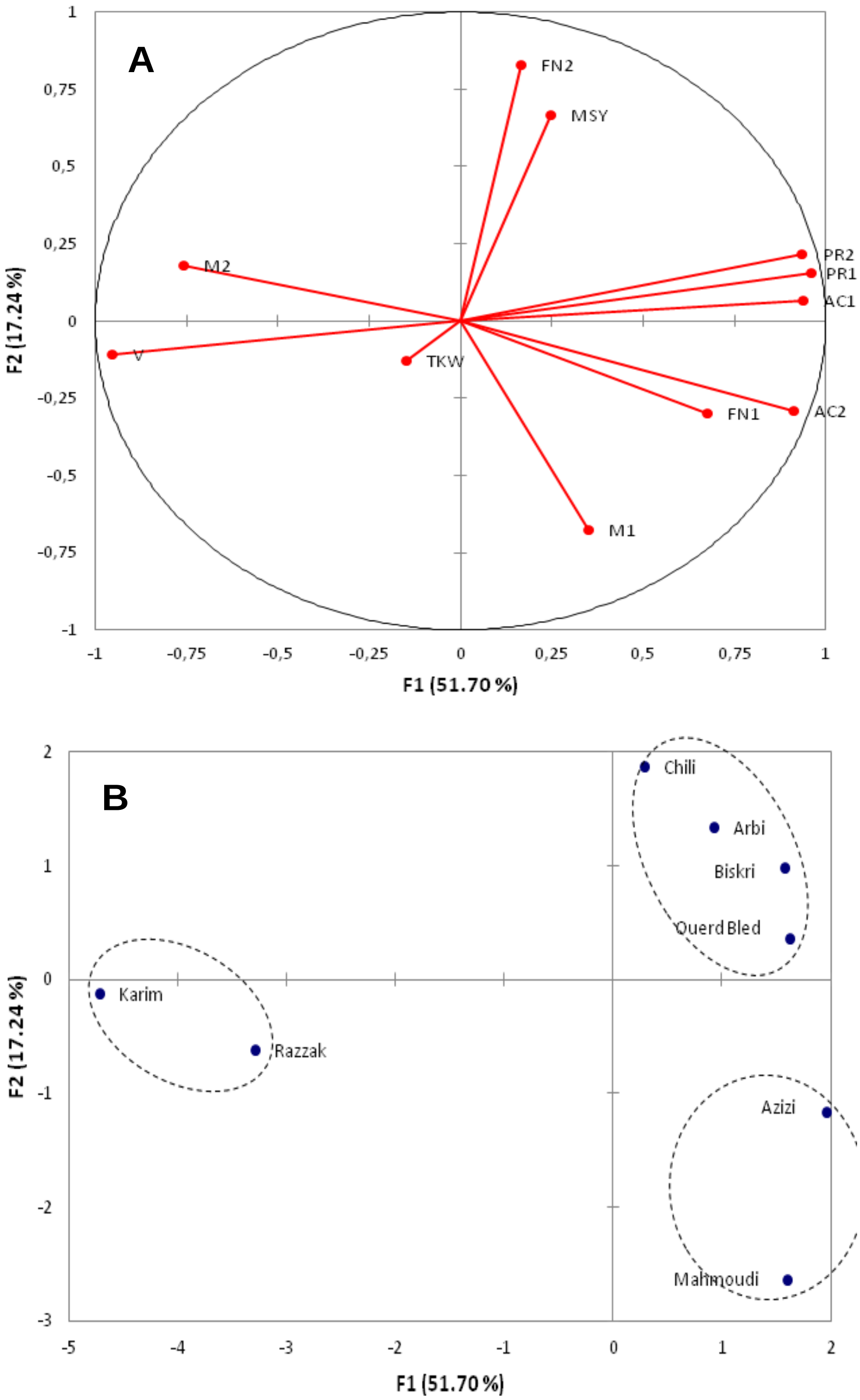

Figure 2: Principal component analysis showing the distribution of physico-chemical parameters tested (A) and the eight durum wheat genotypes (B) in axes 1 and 2. 1: Milled wheat; 2: Semolina; AC: ash content; FN: falling number; MSY: mean semolina yield; M: moisture; Pr: protein; TKW: thousand kernel weight; V: vitreousness.

IV. Conclusion

Our results depict wide and substantial variation among eight tested Tunisian durum wheat genotypes, and confirm the importance of ash and protein content, as well as falling number as possible physico-chemical markers with regards to good milling performance of durum wheat, namely the degree of kernel vitreousness and kernel weight. This provides an opportunity for breeders to improve these traits. The landraces tested particularly Arbi, Biskri, Chili and Ouerd Bled, relative to improved genotypes Karim and Razzek, showed higher ash and protein content, the best conservation and semolina extraction parameters. These genotypes can be used as parents to improve durum wheat and may constitute important germplasm to move towards sustainable agricultural development.

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