Evaluation of Technological Potential of New Developed Moroccan Hexaploid Oat Lines

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Abstract: - The objective of the current study was the evaluation of technological potential of new oat lines issued from interspecific crosses using Moroccan hexaploid oat cultivars of *A. sativa* and two wild accessions of tetraploid oat species *A. magna* and *A. murphyi,* respectively. The basic components as well as minor nutrients were determined such as the dry matter, ash, proteins, crude fibre, fat, available carbohydrates, minerals and energy value. Statistical analysis has revealed that there is a significant difference for the chemical composition between the studied samples. Results indicated the existence of a high significant difference (P<0.0001) in content of proteins (9,67-17,44%), fat (3,06-10,96%), crude fibre (9,15-23,99%) and carbohydrates (42,08-62,65%). Even more, groat protein content of the derivative lines was improved by 5 to 54% compared to that of their hexaploid parents. Phosphorus, potassium, and calcium were observed in high concentration compared to the total oat minerals. However, iron, manganese, and zinc are the dominant minor minerals. Overall, selected lines showed a good technological potential for further use for human consumption as well as feed for monogastric animals.

Key words:Oat grains, chemical composition, minerals, proteins, fats, crude fibre, carbohydrates, energy value.

INTRODUCTION:

Cereals are one of the most important components of our daily diet which affects positively human health. Among these cereals, the focus of nutritional experts was devoted to oat in particular due to its great nutritional value. Oats are characterised by the highest protein content ranging from 12,4% to 24,5% in the husked grain [1, 2, 5], exceptional protein composition due to their high amount of limiting amino acids [3, 4, 5, 6], a high lipid concentration ranging from 3,1 % to 10,9 %, mainly of essential unsaturated fatty acids [7, 8], and reputed to be exceptionally rich in dietary fibre relatively to the beta-glucans. Moreover, oat is a wonderful reservoir of valuable micronutrients such as minerals, vitamins, antioxidants, and phytochemicals [7, 10, 11].

Previous reports showed that the consumption of oats, as whole grains with good nutrients balance, provided both nutritional and health benefits [12]. It was noticed that oat has the ability to act on Coronary Heart Disease (CHD) on four keys : diabetes, obesity, hypertension and blood cholesterol; it also possesses various health benefits that go beyond its healing properties to direct protective effects and can be associated with its well-balance on fibres, antioxidants and a number of phytochemicals [13, 14]. Likewise, in the gastrointestinal tract, soluble dietary fibres can induce “prebiotic effects”, so they are proposed in dietary treatment and has been shown to provide symptomatic relief in the reduction of abdominal pain, reflux and has been linked with a reduced risk of colorectal cancer and adenomas, a condition that affects the quality of everyday life of many individuals [15, 16, 17, 46]. Therefore, beta-glucans can be regarded as the principal key factors in a health promoting diet [8, 12].

For that reason, numerous studies have attracted attention in the need of extending oat use as human health food and to find new ways to explore its constituent’s intake in oat based products such as wholegrain bread, oat milk, breakfast cereals and infant foods dealing with functional properties [14, 18]. Sanchez and Rasane (2010; 2013) have reported that oat proteins, antioxidants, and fibres improve the overall quality of foodstuffs due to their viscous, emulsifying and textural characteristics [19, 20]. Due to its high nutritional value, there is an increasing demand on oat by the consumer because of its awareness towards health benefits associated with this cereal.

Relatively to the socio-economic context of the Mediterranean region particularly in Morocco, bread can be deemed as the primary part of the diet, and therefore, breadmaking including oat products can thereby procure economical sources of biologically active substances.

Nonetheless, in Morocco, despite of all these evidences, oat is still mostly used for animal feeding only, so that information on Moroccan oat composition and technological quality is rather limited [43].
Taking all this into consideration, this study focussed on the technological evaluation of both major components as protein, fibres, and lipid and minor constituents of the grain (macroelements and microelements) which will provide composition data and particularities of the new developed oat lines and the studied cultivars. Therefore, the aims of the present study were:

- to assess the technological quality and the seed chemical characteristics of oat lines.
- to select the most suitable lines from nutritional point of view, for further exploitation and use for human consumption.

Material and methods:

1. PLANT MATERIAL

The used plant material concerned 6 Moroccan hexaploid oat cultivars (5 of *A. sativa L.* and one cultivar of *A.nuda*, all registered in the Moroccan Official Catalogue), in addition to 2 accessions of tetraploid oat *A. Magna*, 2 accessions of tetraploid oat *A. murphyi*, and 16 cutivars of improved hexaploid oat of *A. sativa*, derivative from interspecific crosses previously achieved between Moroccan hexaploid oat cultivars of *A. sativa* and wild accessions of tetraploid oat *A magna* Murphy and Terrell and *A. murphyi* Ladiz, respectively.
Samples were obtained from the National Institute for Agricultural Research (INRA), Rabat, Morocco, Research Unit of Plant Breeding, Conservation and Valorisation of Plant Genetic Resources.

2. REAGENTS AND STANDARDS

All used standards and chemical reagents were of analytical grade and obtained from Sigma-Aldrich.

3. CHEMICAL AND PHYSICOCHEMICAL ANALYSIS
4. SAMPLE PREPARATION AND MILLING PROCESS

Samples were the harvest of 2012/2013 growing season and were processed for pre-cleaning, drying and storage.
In order to perform the chemical analysis, seeds were ground using a mill MF 10 basic IKA WERKE, and sieved at 1 mm. Chemical results concerning components such as ash, protein, fat, crude fibre and micronutrients, were expressed on the basis of seed dry weight. The results were presented in g/100g and all analyses were carried out in two or three replications.

b. Physicochemical characteristics

Groat flour moisture

This parameter was determined by oven drying samples at 80 °C for 24 hr and confirmed by near infrared spectrometry (chopin infraneo-NIRS). Results are reported on a dry weight basis [9].

One thousand seed weight (TSW)

The determination of the weight of one thousand seeds (TSW) was carried out according to Doelehrt *et al*. (1999) and Hall *et al.* (2003) [44, 45]. For each line, 1000 seeds were counted with an automatic seed counter in three replications and weighted individually. Average weight was determined and expressed in grams.

Ash

Ash content of treated oat samples was determined using the AACC Method No. 08-01. In a dried and pre-weighed crucible, 3g of sample was ignited in muffle furnace at 550 °C during 6 hr to complete the burning of all organic matter. Samples were cooled, weighted and calculated as ash percent [22].

Crude protein

Crude protein (CP) was determined by the Kjeldahl method (Velp scientifica, DK 20-UDK 139), according to the procedure of AOAC No. 979.09 [21].

Crude fat

Total lipids (oil) from oat samples were determined using the Soxhlet method AACC No. 30-20 [22], when 20 g of oat flour were placed in cellulose thimbles, fitted into the extractor. The crude fat was extracted with ethyl ether; the obtained mixture was subjected to concentration under vacuum, by rotary evaporator. The extracted fat was weighed and expressed in percent (%).

Total fibre fractions: CF, NDF, ADF, and ADL

For each sample, Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL) and Crude Fibre (CF) were sequentially determined. Crude Fibre (CF) was determined according to AOAC method No.926.09 [21]. One gram of sample was digested with 100 ml of 1.25 % sulphuric acid in a beaker under reflux, for 30 min. The solution was then filtered through sintered glass crucible under vacuum. The residue was then washed with hot distilled water till being neutralised. The washed material was again transferred to a beaker and refluxed for 30 min with 100 ml of 1.25 % sodium hydroxide. Digested material was again filtered and washed with hot water until being neutralised. The washed material was dried at 130 ºC for 1 hr, cooled in a desiccator and weighted. The dried residue was ignited for 6 hr and reweighted. The NDF, ADF and ADL were determined according to the method described by Van Soest *et al*. (1991) [27]. Afterwards, hemicellulose was calculated according to the formula (NDF – ADF) and cellulose with the formula (ADF – ADL) [28].

Mineral determination

After incineration, mineral composition (Na+ and K+) was determined using flame photometer. Calcium (Ca^{2+})and magnesium (Mg^{2+}) were determined by complexometric titration. Oat grain phosphorus content was determined by the acidified solution reaction of ammonium molybdate containing ascorbic acid and antimony [38]. The phosphate contained in the grain reacted with the solution to form the ammonium molydiphosphate complex, which turned the solution to a blue colour because of the ascorbic acid effect. The amount of the absorbed light by the solution was measured at 825 nm with UV-visible spectrophotometer (Jenway 6405 uv/vis spectrometer) [38].

Trace elements, including iron, copper, manganese, zinc, and nickel were analysed by atomic absorption spectrometry [24] in a flame air-acetylene. The measured absorption was done at a specific wavelength of 248.3 nm to measure the concentration of Fe, Cu, Mn, Zn, and Ni in the sample solution.

Carbohydrates

Carbohydrates (CHO) were determined on the basis of the difference of all other basic components [29], weight (in grams) minus water, protein, fat, ash, and fibre content.

Energy value

The energy value was calculated from the approximate chemical composition data [29]. Energy value (Kcal) was calculated according to the formula:

$$E(Kcal) = CP \times 4 + CHO \times 4 + fat \times 9 \quad \textbf{(1)}$$

The values were expressed in Kcal/100 g.

5. STATISTICAL ANALYSIS

Data were expressed as the man values ± standard deviation (SD) for each measurement. All experiments were carried out using two or three replicates. The results were statistically analysed using one-way analysis of variance (ANOVA) by comparing mean values of the 26 cultivars. In case of significant difference between lines, means were compared by the Duncan multiple range test.

Results and Discussion:

In general, differences between the means of all parameters of the 26 cultivars were highly significant ($P<0,0001$) based on the used statistical method of analysis of variance.

Physiochemical characteristics

Moisture, weight of one thousand seeds, and ash are important parameters to explore when assessing grain and flour quality. The proportion of dry matter content of oat grains ranged between (87,26±0,28)% and (93,8±0,15)% for the derivative line mag*sat (F_{11-4}) and the tetraploid parent (P_{35-42}), respectively. Our values are, in some cases, higher than usual; the main reason for this difference may be associated to the humid climate of the Rabat region where were cultivated the studied oat lines. It was reported, before, that high moisture content affect the grains behaviour during storage and handling of oat products [37].

To appreciate the oat technological interest, weight of one thousand seeds (TSW) remains a key parameter to consider for determining the productivity of cereals. Cultivars, in comparison to their tetraploid and hexaploid parents have shown a large variability, lines presenting the high TSWare mur*sat (F_{10-4}) with (43,66±2,09)g exceeding the TSWof the tetraploid parents *A.murphyi* P_{35-42} and P_{50-52} with (41,84±3,33)g and (40,51±1,05)g, respectively. TSWvalues for mag*sat F_{11-4} and F_{11-8} were (22,89±1,96)g and (21,66±0,86)g, respectively. In comparison to their tetraploid and hexaploid parents, they have shown a large variability of this character, indicating that seed size was improved for some lines. The probable reason for our relatively high values, with regard to the mean values reported by Saidi and Brand (2003, 2013) [33, 42], may be due to the interspecific crosses acheived between tetraploid and hexaploid species.

Ash content values are given in Table 1. The Soualem variety (4,97±0)% is noteworthy as it showed the highest ash content compared to all the other analysed samples. The lowest value was observed for the line mur*sat F_{10-4} (1,98±0,24)%. Above results confirm what was reported by Duchonova (2013): high ash content is correlated with high mineral content and is associated with higher nutritional value [29].

Protein content

Grain protein content is an important component according to quality evaluation. This is why oat flour was appreciated by far for more better protein content of high biological value compared to wheat flour [32]. Analysis of our material has revealed that the highest mean value for groat protein content, for all assessed lines was exceptionally noticed for the lines mur*sat F_{10-1} (17,29±0,14)% and mag*sat F_{11-5} (13,32±0,14)%. Low values were observed for the lines mag*sat F_{11-8} (11,28±0,19)% and mur*sat F_{10-7} (11,01±0,005)%. In general, groat protein content in oat varies between 9 and 18%, depending on genetic make-up and on external factors associated with the crop [2]. Thus, obtained values for groat protein content fits within this range, but mostly on the higher side of the scale since groat protein content of the assessed lines ranged from 11 to 17%. We can conclude that groat protein content of allderivative lines of the crosses achieved between Moroccan hexaploid oat varieties and the tetraploid oat parents *A.magna* and *A.murphyi* was very important since it ranged from 11% to 17%. In comparison to their hexaploid parents, groat protein content was improved by 5 to 54% in the developed lines (Table 1).

Table1a: Chemical Composition Of Moroccan Oat Varieties And Tetrapoid Parents.

Elements	Tetraploid parents				Hexaploid parents					
	P_{35-42}	P_{50-52}	P_{1-1}	P_{1-6}	Tissir	Zahri	Soualem	Amlal	Ghali	Bonejemate
Moisture (%)	6,2±0,15	7,49±0,09	8,78±0,13	8,07±0,01	8,41±0,01	9,58±0,08	8,22±0,1	7,9±0,01	8,95±0,02	8,41±0,04
Ash (%)	3,12±0,19	4,36±0,11	3,13±0,06	3,82±0,13	4,39±0,04	2,47±0,11	4,97±0	4,38±0,25	4,43±0,57	2,71±0,2
Fat (%)	5,96±0,38	4,97±0,58	5,07±0,58	5,15±0,38	4,65±0,59	6,69±0,4	7,33±0,44	7,99±0,4	5,76±0,5	9,43±0,31
TSW (g)	41,84±3,33	40,51±1,05	23,19±0,83	29,82±1,2	24,08±1,92	27,68±1,17	28,00±2,05	26,49±1,34	31,52±2,13	28,64±0,39
Protein (%)	14,7±0,28	11,82±0,09	16,5±0,07	9,67±0,64	13,85±0,08	11,37±0,1	11,88±0,03	10,46±0,12	13,96±0,03	10,10±0,01
Carbohydrate (%)	54,24±0,97	57,38±3,95	54,37±1,04	56,59±2,32	53,54±4,47	55,08±0,74	48,5±2,33	52,96±3,75	53,84±2,03	55,91±0,89
Energy (Kcal/100 g)	315,77±3,3	316,76±4,17	301,32±5,23	309,08±4,77	305,73±4,31	327,51±4,64	304,79±2,9	320,89±1,37	320,85±1,98	354,15±1,86

Table1b: Chemical Composition Of Moroccan Improved Oat Cultivars

Elements	Mag*sat						
	F_{11-1}	F_{11-2}	F_{11-3}	F_{11-4}	F_{11-5}	F_{11-7}	F_{11-8}
Moisture (%)	8,12±0,05	10,98±0,23	8,73±0,15	12,74±0,28	10,53±0,09	7,88±0,035	9,95±0,04
Ash (%)	3,97±0,52	3,98±0,03	2,56±0,04	4,36±0,24	3,68±0,04	4,21±0,11	2,88±0,09
Fat (%)	5,03±0,67	6,00±0,61	3,8±0,6	3,72±0,58	7,3±0,6	4,91±0,58	9,13±0,58
TSW (g)	25,31±1,06	24,95±1,31	24,54±2,61	22,89±1,96	26,23±1,24	23,08±0,41	21,66±0,86
Protein (%)	13,02±0,15	12,04±0,25	12,34±0,29	12,91±0,44	13,32±0,14	11,74±0,62	11,28±0,19
Carbohydrate (%)	54,49±4,63	46,90±1,58	58,98±0,86	46,88±5,00	51,73±1,73	50,84±1,82	47,59±1,54
Energy value (Kcal/100g)	310,04±3,7	288,77±2,7	320,28±2,3	266,49±4,3	324,67±2,21	293,00±4,9	317,01±1,9

Table1c: Chemical Composition Of Moroccan Improved Oat Cultivars

Elements	Mur*sat								
	F_{10-1}	F_{10-2}	F_{10-3}	F_{10-4}	F_{10-5}	F_{10-6}	F_{10-7}	F_{10-8}	F_{10-9}
Moisture (%)	10,39±0,12	9,34±0,05	9,58±0,16	9,82±0,25	7,64±0,08	7,85±0,04	7,12±0,02	9,38±0,05	6,87±0,04
Ash (%)	2,99±0,04	4,25±0,32	3,16±0,12	1,98±0,24	2,58±0,11	4,19±0,1	3,14±0,05	3,8±0,14	4,49±0,1
Fat (%)	4,51±0,57	7,27±0,6	6,28±0,58	6,85±0,05	9,19±0,63	6,52±0,46	6,04±0,3	5,44±0,53	4,08±0,38
TSW (g)	32,24±2,01	23,23±2,77	25,69±0,48	43,66±2,09	37,03±0,45	39,24±0,36	24,07±1,29	23,64±1,31	31,13±0,96
Protein (%)	17,29±0,14	13,09±0,06	11,8±0,03	12,42±0,05	13,12±0,26	12,3±0,15	11,01±0,005	13,17±0,12	12,72±0,38
Carbohydrate (%)	43,75±1,19	45,29±4,19	45,98±2,11	47,47±3,88	52,8±0,96	47,98±2,44	60,72±1,67	54,94±1,48	54,61±2,92
Energy value (Kcal/100g)	284,72±1,3	293,64±2,4	286,06±0,4	298,38±5,7	346,89±3,29	297,32±0,41	344,17±4,19	320,65±1,87	302,64±0,96

These results confirm that high groat protein content of the tetraploid parents was transferred to the derivative lines of mag*sat and mur*sat. The obtained results are in agreement with that recently reported by Saidi et al. (2013) [33].

Fat content

The fat contents are shown in Table 1. The lipid content of the collection investigated in this study, ranged from 3,8 to 9,43 %, the most probable reason for the variability of the obtained values may be due to genetic and environmental factors. Highest mean total fat content is present in Bonejemate variety, mur*sat (F_{10-5}), and mag*sat (F_{11-8}) with (9,43±0,31)%, (9,19±0,63)% and (9,13±0,58)%, respectively. Regarding total fat content, oats contain about twice that of the other cereals [29]. The lipid fraction of oat grain has a significant impact on its nutritional quality; it determines, in a large measure, the energy content and fatty acid composition of oat flour [34].

Micronutrient composition

Cereals could provide a large amount of our mineral intake, noting that the mineral deficiency is a major nutritional problem throughout the world [35]. Data regarding micronutrient composition, especially those abundantly present in plants [36], are presented in Table 2.

We noticed that trace or minor elements have shown greater variations in term of concentration between assessed samples. All samples had lower amounts of calcium and sodium compared to the other measured minerals (P, K and Mg) but higher than what was reported by Welch et al [39]. In general, phosphorus content ranged from 295,8 to 775,45 mg/100g forthe assessed material. In one hand, the lowest phosphorus content value was noticed for Amlal and, in the other hand, the highest value was detected in the line mag*sat (F_{11-5}). In contrast, potassium content was higher for all analysed lines and similar to what has been reported by Welch et al[39], bearing in mind the presence of a substantial variation between samples. Although magnesium content varied substantially between samples, the lowest value was observed in mag*sat (F_{11-4}) with (0,15±0,01)% and the highest in mur*sat (F_{10-2}) with (0,31±0)%.

With respect to microelements (Zn, Fe, Cu, Mn, and Ni), high concentrations were reached for most elements for most of studied samples (Table 2).

Contents are broadly similar to the mean levels found in whole grain of oat [39, 40] and even if the material was tested in the same location, samples have shown a large variation.

Despite the high content of minerals in oat groat, the presence of phytic acid and phytate salts may render phosphorus and other minerals nutritionally unavailable [39, 41].Nowadays, throughout the world, especially in less developed countries, the population is afflicted with micronutrient deficiency, and all adverse associated disturbances, leading to poor health, sickness, etc. [41]. In this trait, it is interesting to note that the most commonly consumed cereals in Morocco is wheat; however, its flour does not contain the essential nutrient elements in significant amounts. Therefore, oat grains can complement, to a certain extent, our daily dietary intake (DDI) of essential trace elements if included in a mixed diet.

Fibre

The analysis of total fibre fractions (NDF, ADF, ADL, and CF), has revealed the presence of a huge variations between analysed samples. The mean NDF values of all cultivars varied between (25,39±0,52) and (44,47±0,62)% (Table 3). The lowest concentrations were obtained with mag*sat (F_{11-1}) and cv. Bounejmate (naked oat) with (25,39±0,52)% and (27,18±0,39)%, respectively.

The mean ADF values of all cultivars ranged from (5,76±0,9)% for cv. Bounejmate to (27,7±0,77)% for tetraploid parent (P_{1-1}). The ADF followed the same tendency as the NDF and hence a considerable variation in ADF content was observed within cultivars.

Higher fibre fractions reflect the proportion of present hulls which is one of the main reasons of the higher fibre content whereas both NDF and ADF contents havea negative impact on the energy values (Tables 1 and 3).

Table 2a: Mineral Composition Of Moroccan Oat Varieties And Tetrapoid Parents

Elements		Tetraploid parents				Hexaploid parents					
		P_{35-42}	P_{50-52}	P_{1-1}	P_{1-6}	Tissir	Zahri	Soualem	Amlal	Ghali	Bonejemate
Minerals (mg/100g D.W)	P	0,36±0,01	0,32±0,01	0,34±0,01	0,31±0,01	0,38±0	0,29±0	0,36±0,01	0,34±0	0,36±0,005	0,49±0,01
	Na	0,11±0	0,09±0	0,07±0	0,09±0	0,07±0	0,09±0	0,09±0	0,07±0	0,066±0	0,07±0
	K	0,38±0	0,44±0	0,36±0	0,42±0	0,33±0	0,33±0,01	0,4±0	0,32±0	0,33±0,01	0,32±0
	Ca	0,16±0,04	0,24±0,04	0,16±0	0,28±0,04	0,22±0,02	0,16±0	0,2±0,04	0,32±0,04	0,32±0	0,32±0,04
	Mg	0,24±0,02	0,28±0,02	0,24	0,19±0,02	0,27±0,03	0,19±0,02	0,25±0,01	0,24±0,02	0,31±0,02	0,26±0,12
Trace elements (mg/100g D.W)	Fe	7,25±0,15	6,1±0,1	7,1±0	8,55±0,15	7,25±0,25	8,6±0,4	9,1±0,1	6,4±0,2	20,2±1	5,7±0
	Zn	3,9±0,1	4±0,1	3,1±0	2,85±0,05	2,85±0,05	2,9±0,1	3,6±0,1	3,1±0,2	3,7±0,2	3±0,1
	Cu	0,85±0,05	0,6±0	0,7±0	0,7±0	0,85±0,05	0,75±0,05	0,65±0,05	0,55±0,05	0,75±0,05	0,55±0,05
	Mn	4,2±0,1	6,05±0,05	5,3±0	4,45±0,15	5,25±0,25	3,7±0,1	3,65±0,05	4,6±0,1	6±0,1	5,45±0,15
	Ni	0,6±0	0,5±0	0,6±0	0,8±0	0,8±0	0,6±0	0,55±0,05	0,55±0,05	0,75±0,05	0,5±0

Table 2b: Mineral Composition Of Moroccan Improved Oat Cultivars.

Elements		Mag*sat						
		F_{11-1}	F_{11-2}	F_{11-3}	F_{11-4}	F_{11-5}	F_{11-7}	F_{11-8}
Minerals (mg/100g D.W)	P	0,35±0	0,32±0	0,34±0	0,36±0,01	0,75±0	0,35±0	0,31±0
	Na	0,07±0	0,07±0	0,07±0	0,09±0	0,09±0,01	0,13±0	0,11±0,01
	K	0,33±0	0,33±0	0,33±0	0,43±0,01	0,43±0,08	0,45±0,02	0,61±0,03
	Ca	0,3±0,02	0,36±0	0,24±0,04	0,16±0,04	0,22±0,02	0,26±0,02	0,2±0,08
	Mg	0,23±0,01	0,2±0,08	0,29±0	0,15±0,01	0,22±0,03	0,2±0,08	0,18±0,04
Trace elements (mg/100g D.W)	Fe	7,85±0,05	7,35±0,15	7,6±0,1	9,45±0,25	9,35±0,15	20±0,3	7,25±0,15
	Zn	2,8±0,1	2,7±0,1	3,35±0,15	2,95±0,15	4,8±0,1	8,4±0,1	2,5±0,1
	Cu	0,75±0,05	0,65±0,05	0,75±0,05	0,85±0,05	0,95±0,05	1,2±0	0,85±0,05
	Mn	4,85±0,05	4,7±0,1	4,3±0,1	4,65±0,15	4±0,1	5,2±0,1	4,15±0,15
	Ni	0,7±0	0,7±0	0,7±0	0,65±0,05	0,6±0	0,9±0	0,5±0,1

Table 2c: Mineral Composition Of Moroccan Improved Oat Cultivars

Elements		Mur*sat								
		F_{10-1}	F_{10-2}	F_{10-3}	F_{10-4}	F_{10-5}	F_{10-6}	F_{10-7}	F_{10-8}	F_{10-9}
Minerals (mg/100g D.W)	P	0,52±0,01	0,35±0,01	0,38±0	0,36±0	0,32±0	0,36±0	0,34±0,01	0,35±0	0,5±0,01
	Na	0,11±0	0,07±0	0,1±0	0,08±0,005	0,15±0	0,1±0	0,07±0	0,07±0	0,12±0,01
	K	0,53±0,01	0,31±0	0,45±0,02	0,38±0	0,35±0	0,39±0,01	0,33±0,005	0,32±0	0,58±0,09
	Ca	0,18±0,02	0,3±0,02	0,18±0,02	0,2±0	0,14±0,02	0,16±0	0,28±0,12	0,28±0	0,18±0,06
	Mg	0,25±0,01	0,31±0	0,24±0,1	0,23±0,01	0,26±0,02	0,24±0	0,2±0,03	0,21±0,04	0,28±0,06
Trace elements (mg/100g D.W)	Fe	7±0,1	6, 4±0,2	6,1±0,1	6,85±0,05	12,4±1	8,3±0	8,45±0,25	10,55±0,15	7,6±0,2
	Zn	2,45±0,05	3,45±0,05	2,65±0,05	2,45±0,05	5,6±0,2	3,9±0	4,35±0,05	3,25±0,15	3,15±0,15
	Cu	0,65±0,05	0,65±0,05	0,55±0,05	0,65±0,05	0,85±0,05	0,7±0	0,75±0,05	0,8±0,1	0,7±0
	Mn	5,1±0,1	4±0,1	3,95±0,05	3,9±0,1	6,55±0,25	5,5±0	4,95±0,15	4,55±0,05	5,8±0,1
	Ni	0,7±0	0,8±0	0,55±0,05	0,5±0	0,6±0	0,6±0	0,65±0,05	0,6±0	0,6±0

Based on the statistical analysis, a high correlation between CF and energy value (r = -0,80**) was observed and this was broadly in line with the obtained results.

The correlation coefficient determined among different variables other than cell wall fractions, had little biological meaning.

Table 3a: Content Of Fiber Fractions Of Moroccan Oat Varieties And Tetraploid Parents

Elements	Tetraploid parents				Hexaploid parents					
	P_{35-42}	P_{50-52}	P_{1-1}	P_{1-6}	Tissir	Zahri	Soualem	Amlal	Ghali	Bonejmate
Dry weight (g)	93,8±0,15	92,51±0,09	91,21±0,13	91,93±0,01	91,58±0,01	90,41±0,08	91,77±0,1	92,1±0,01	91,05	91,59±0,04
CF (%)	19,93±0,99	15,04±1,6	20,2±2,29	17,68±0,7	16,29±1,98	15,31±1,3	20,41±0,94	17,51±1,11	14,39±0,44	13,57±0,89
NDF (%)	44,47±0,62	44,23±0,38	40,71±0,81	35,61±0,91	41,52±0,01	34,2±0,26	36,31±1,96	41,78±0,42	35,92±0,73	27,18±0,39
ADF (%)	20,74±0,23	24,67±0,13	27,7±0,77	12,65±0,93	17,79±0,41	15,83±0,82	12,45±0,19	20±0,85	9,9±0,85	5,76±0,9
ADL (%)	5,58±1	15,81±0,46	7,27±0,44	6,81±0,1	11,79±0,59	3,49±0,9	13,34±0,45	4,14±0,21	3,82±0,02	4,53±0,41
Cellulose (%)	38,89±0,38	28,42±0,08	33,44±1,25	28,8±0,82	29,73±0,58	30,72±1,17	22,97±1,51	37,64±0,21	32,1±0,71	22,65±0,02
Hemicellulose (%)	23,73±0,86	19,56±0,25	13±0,04	22,96±1,85	23,73±0,42	18,36±0,55	23,86±2,16	21,78±1,26	26,01±1,58	21,41±1,29

Table 3b: Content Of Fiber Fractions Of Moroccan Improved Oat Cultivars.

Elements	Mag*sat						
	F_{11-1}	F_{11-2}	F_{11-3}	F_{11-4}	F_{11-5}	F_{11-7}	F_{11-8}
Dry weight (g)	91,88±0,05	89,02±0,23	91,26±0,15	87,26±0,28	89,47±0,09	92,11±0,03	90,05±0,04
CF (%)	16,17±1,84	21,06±1,09	14,07±0,89	20,42±1,72	14,33±0,59	21,43±1,47	19,82±0,35
NDF (%)	25,39±0,52	41,39±0,39	41,83±1,07	42,33±1,09	39,73±0,37	35,83±0,42	41,5±0,52
ADF (%)	11,81±0,86	12,88±0,88	23,54±0,25	14,6±0,86	20,67±0,18	17,89±0,49	16,25±0,3
ADL (%)	7,76±0,72	8,59±0,68	6,07±0,64	6,11±0,23	3,27±0,68	4,97±0,68	1,64±0,02
Cellulose (%)	17,63±0,19	32,8±0,28	35,75±0,42	36,21±1,32	36,46±1,05	30,86±0,26	39,85±0,5
Hemicellulose (%)	13,58±0,34	28,51±1,19	18,29±1,33	27,73±1,95	19,06±0,56	17,93±0,91	25,25±0,22

Table 3c: Content Of Fiber Fractions Of Moroccan Improved Oat Cultivars.

Elements	Mur*sat								
	F_{10-1}	F_{10-2}	F_{10-3}	F_{10-4}	F_{10-5}	F_{10-6}	F_{10-7}	F_{10-8}	F_{10-9}
Dry weight (g)	89,6±0,12	90,65±0,05	90,41±0,16	90,17±0,25	92,35±0,08	92,15±0,04	92,88±0,02	90,62±0,05	93,13±0,04
CF (%)	21,71±0,46	21,94±1,83	23,86±0	21,64±2,34	15,22±0,91	22,17±0,03	12,65±2,61	14,14±0,95	18,35±0,33
NDF (%)	33,79±0,01	37,76±0,86	29,73±0,62	36,62±0,05	32,34±0,14	34,92±1,84	31,42±1,33	43,22±0,11	33,16±0,98
ADF (%)	16,68±0,39	10,54±0,47	15,14±0,24	12,67±0,24	15,81±0,31	11,31±0,29	11,43±0,49	20,78±0,32	16,22±0,85
ADL (%)	5,26±0,89	6,39±0,01	4,64±0,16	8,03±0,66	4,46±0,27	3,14±0,47	4,48±0,09	9,96±0,04	8,33±0,45
Cellulose (%)	28,52±0,9	31,37±0,87	25,09±0,77	28,58±0,61	27,87±0,4	31,78±2,31	26,94±1,41	33,27±0,08	24,82±0,53
Hemicellulose (%)	17,11±0,38	27,22±1,33	14,59±0,37	23,95±0,19	16,52±0,44	23,31±2,13	19,9±0,83	22,44±0,21	16,94±0,13

Low correlation coefficients were found between the following parameters: NDF, CF, protein content, and TSW. This could be mainly related to the environmental factors, genotype, test weight, groat percentage, groat weight,.... while others reported either negative, positive or no correlation with grain yield [2, 25, 26, 31].

Carbohydrates and energy value

In oat, as in the other cereals, carbohydrates are the chemical group present in a greater amount.

The carbohydratescontent was found to be between 43,75 and 60,72 %, close to the values mentioned by Welch et al [39].

A cursory look at the obtained results of energy value indicated a considerable variation in energy valuebetween samples within cultivars for all the grains. Mean energy values of the tested cultivars presented in Table 1 varied between (266,49±4,31)Kcal in mag*sat (F_{11-4}) and (354,15±1,86)Kcal in Bounejmate variety (hulled oat), as expected hulling had a negative effect on the amount of ash, CF, ADF, ADL and NDF contents of the grains. Contrariwise, it increases the fat content.

Among cereals, oat is likely to have the higher energy content, due probably to its higher fat content and its higher fibre content and this can have a significant effect on animal performance and explain its use at high levels in diets of ruminants [42, 30]. Cultivation conditions might affect the chemical composition of oats [25, 26]; however, environmental differences could be considered as minor source of variation between the samples in this study, since they were all grown under well-defined conditions within the same site.

In all, the results showed that the studied samples were observed nutritionally rich and may be useful for different purposes. Variations in physical characteristics, chemical composition and energy values noted between individual samples of oat in this study, were higher with reference to previous literature documented in Morocco. Therefore, the results presented in the current work may be valuable, especially when the promising new developed lines were the subject of this experiment. F_{10-1}, F_{10-8} and F_{11-5} had the highest content of protein content, crude fibre and minerals and would be privileged in diet formulation. F_{11-4} and F_{10-7} were superior in energy content, NDF and lower in ADL and would be favoured in animal feed while F_{11-8} and F_{10-5},with high levels of fat and protein, form an excellent basis or candidate for cosmetic use.

CONCLUSION

The results obtained in this research, according to the chemical composition and nutritional values of the newly developed oat lines, could stimulate the public awareness regarding the consumption of this unconventional cereal in Morocco, and then, would be considered as reference data of the Moroccan oats.

Relatively to the data compiled with that reported in the previous research and in order to explore the oat grain technological potential, we are willing that the breeding efforts will be directed towards three main objectives: cultivar selection for industry (bran, β-glucan and starch characteristics), human consumption of whole oat grain (fibre, oil content and composition) and animal feed (NDF, crude proteins, starch and oil content and composition). Also, additional information on these cultivars, such as phytochemicals and fatty acid profile constitute an important research topic in our future work.

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