Original article
UDC 633.13;577
DOI: 10.30901/2227-8834-2023-1-128-136

Variation of some physical and chemical quality traits of Moroccan domesticated tetraploid oat lines of *Avena murphyi* Ladiz.

Rajae Manzali[1, 2], Mohamed Bouksaim[2], Ahmed Douaik[2], Gideon Ladizinsky[3], Nezha Saidi[2]

[1] *Hassan First University, Settat, Morocco*

[2] *National Institute for Agricultural Research, Regional Centre for Agricultural Research of Rabat, Rabat, Morocco*

[3] *retired from the United States Agency for International Development, Washington DC, USA*

Corresponding author: Nezha Saidi, nezha.saidi@inra.ma

A potential in improving nutrition and health is the consumption of high balanced whole grains. A breeding program was launched by the National Institute for Agricultural Research (INRA-Morocco), aiming to develop new domesticated tetraploid oat lines of *Avena murphyi* Ladiz., with high nutritional benefits. A sequence-based diversity study was conducted on ten tetraploid oat lines of *A. murphyi* to shed light not only on the importance of domesticating wild oat species for crop improvement but also to highlight the nutritional traits of those oat lines. In this study, we assessed the lines for some grain nutritional traits, such as groat contents of proteins and lipids as well as ash, fiber fractions, carbohydrates, and minerals.
The obtained results showed a wide range of chemical contents among lines. The results revealed a high significant difference ($P < 0.001$) in the groat contents of proteins (11.46–15.12%), fat (4.14–10.14%), carbohydrates (48.68–57.38%), and ash (2.71–5.18%). Analysis of total fiber fractions (NDF, ADF, ADL and CF), showed the presence of significant differences between the assessed lines. The lines *A. murphyi* 8 and 9, recorded the highest groat protein contents of 15.12% and 13.66%, with an interesting macroelement profile, mainly magnesium and phosphorus, and iron and manganese as minor mineral profile.
Due to their biochemical composition, Moroccan domesticated tetraploid oat lines of *A. murphyi* offer many opportunities to improve oat cultivation in Morocco and serve as an excellent raw material for foodstuffs formulation.

Keywords: domesticated lines, oat groat, chemical composition, minerals, proteins, fats, carbohydrates, energy value

Acknowledgments: this work was partially financed by USAID, Project No. TAMOU 97-053, Washington, DC 20523, U.S.A, under the supervision of the project principal investigator Prof. Gideon Ladizinsky.
The authors thank the referees for their contribution to the peer review of this work.

For citation: Manzali R., Bouksaim M., Douaik A., Ladizinsky G., Saidi N. Variation of some physical and chemical quality traits of Moroccan domesticated tetraploid oat lines of *Avena murphyi* Ladiz. *Proceedings on Applied Botany, Genetics and Breeding*. 2023;184(1):128-136. DOI: 10.30901/2227-8834-2023-1-128-136

ГЕНЕТИКА КУЛЬТУРНЫХ РАСТЕНИЙ И ИХ ДИКИХ РОДИЧЕЙ

Научная статья
DOI: 10.30901/2227-8834-2023-1-128-136

Изменчивость некоторых технологических и биохимических признаков качества марокканских тетраплоидных культурных линий овса *Avena murphyi* Ladiz.

Р. Манзали[1, 2], М. Буксаим[2], А. Дуаик[2], Г. Ладизинский[3], Н. Саиди[2]

[1] Университет Хассана Первого, Сеттат, Марокко

[2] Национальный институт сельскохозяйственных исследований, Рабатский региональный центр сельскохозяйственных исследований, Рабат, Марокко

[3] до выхода в отставку: Агентство США по международному развитию, Вашингтон, округ Колумбия, США

Автор, ответственный за переписку: Нежа Саиди, nezha.saidi@inra.ma

Потенциал улучшения продуктов питания и здоровья человека заключается в потреблении высокосбалансированных цельных зерен. Национальный институт сельскохозяйственных исследований (INRA-Марокко) запустил селекционную программу, направленную на создание новых культурных линий тетраплоидного овса *Avena murphyi* Ladiz. с высокими питательными свойствами. Исследование различных показателей было проведено на десяти линиях тетраплоидного овса *A. murphyi*, чтобы показать не только важность одомашнивания диких видов овса для повышения урожайности, но и выявить питательные свойства этих линий. В этом исследовании мы оценили линии по некоторым биохимическим свойствам зерна, таким как содержание в зерновке белка и липидов, а также зольности, фракций клетчатки, углеводов и микроэлементов.
Полученные результаты показали широкий диапазон биохимического состава линий. У проанализированных зерновок различных линий выявлены высокие достоверные различия ($P < 0,001$) по содержанию белка (11,46–15.12%), жиров (4,14–10,14%), углеводов (48,68–57,38%) и зольности (2,71–5.18%). Анализ общих фракций клетчатки (NDF, ADF, ADL и CF) показал наличие достоверных различий между оцениваемыми линиями. В зерновках линий 8 и 9 зафиксировано самое высокое содержание белка (15,12% и 13,66%) с повышенным содержанием фосфора и некоторых микроэлементов: магния, железа и марганца.
Благодаря своему биохимическому составу культурные марокканские линии тетраплоидного овса *A. murphyi* открывают много возможностей для расширения возделывания овса в Марокко и служат отличным потенциальным сырьем для производства пищевых продуктов.

Ключевые слова: зерновки, химический состав, минеральные вещества, белки, жиры, углеводы, энергетическая ценность

Благодарности: эта работа частично финансировалась Агентством США по международному развитию, проект № TAMOU 97-053, Вашингтон, округ Колумбия, США, под руководством главного исследователя проекта профессора Гидеона Ладизинского.
Авторы благодарят рецензентов за их вклад в экспертную оценку этой работы.

Для цитирования: Манзали Р., Буксаим М., Дуаик А., Ладизинский Г., Саиди Н. Изменчивость некоторых технологических и биохимических признаков качества марокканских тетраплоидных культурных линий овса *Avena murphyi* Ladiz. *Труды по прикладной ботанике, генетике и селекции*. 2023;184(1):128-136. DOI: 10.30901/2227-8834-2023-1-128-136

Introduction

Oat is one of the most versatile cereal crops, it has been used through centuries for animal feed, human consumption and to produce a wide range of added-value products (Bayram, 2017). The popularity of this crop has increased due to its consumption as a functional food with a wide range of health beneficial effects (Ramzan, 2020). It is regarded as a nutrient-dense grain, consisting of good-quality proteins, phytochemicals and dietary fibers, mainly *β*-glucan, which has positive human health implications (Soycan, 2019). Oat is nutritionally very rich in carbohydrate mainly starch (70–80% of dry matter), proteins (11–55%) and lipids (3.1–10.9%). Total dietary fiber in oat grains ranges from 12–38%, of which around 30–50% are water soluble (Singh, 2018). Oats are rich in tocopherols and contain about 2.3 mg tocopherols/100 g grain (Lásztity, 1998). Oat grains are commonly processed as whole grain, because its groat is softer compared to that of the other grains, which make it difficult to separate the different parts of the grain (germ, endosperm and bran), thus oats is suggested to be a promising grain in the whole-grains landscape (Don, 2019).

Due to its high spectrum of bioactive molecules, there is an increased demand of oat for different applications. This appeal challenges oat growth under different environmental conditions and geographical locations. Oat breeding and improvement key to meeting the quality requirements and oat adaptability for different end uses. As a result, the release of new oat varieties is continually required in order to remain competitive in terms of agronomics and disease resistance while maintaining appropriate quality. Genetic diversity aims to incorporate new feasible sources in plant breeding to continue increasing the grain yield, plant height and quality.

In contrast, since the time of first domestication, the genetic diversity of cereal crops has been continuously eroded. Thus, it is imperative that their gene pools be expanded by incorporating new resistance genes into breeding programs. In this regard, the wild relatives of oat and barley offer diverse sources of unique alleles for cultivated cereal improvement (Steffenson, 2007). For this purpose, a breeding program was launched by the National Institute for Agricultural Research (INRA-Morocco), aiming the development of new domesticated tetraploid oat lines of *Avena murphyi* Ladiz., having a high nutritive value conceived for a multiplicity of use.

In Morocco, yet only the research program conducted by INRA-Morocco has been advanced to introgress domesticated tetraploid oat lines, and to promote their exploration on a broad scale. In our survey, we have investigated the genetic variability of the main quantitative traits for ten selected domesticated tetraploid oat lines of *A. murphyi* (2n = 4x = 28) versus the nutritional composition of a hexaploid oat cultivar of *Avena sativa* L. ('Amlal') (2n = 6x = 42).

Material and methods

Abbreviations:

ADF, acid detergent fiber; **ADL**, acid detergent lignin; **CF**, crude fiber; **NDF**, neutral detergent fiber; **DM**, dry matter.

Сокращения:

ADF – кислотно-детергентное волокно; **ADL** – кислотно-детергентный лигнин; **CF** – сырая клетчатка; **NDF** – нейтральное детергентное волокно; **DM** –сухое вещество.

1. Plant material

Ten domesticated tetraploid oat lines of *A. murphyi* released by the National Institute for Agricultural Research (INRA) of Morocco, two accessions of the tetraploid parent *A. murphyi* P45-55 and P50-52, collected in 1985 from South of Spain and Northern region of Morocco, and handed by US-AID within the framework of a collaborative project, respectively, and a Moroccan cultivar of hexaploid oat *A. sativa* ('Amlal'), were used in this study. The domesticated lines are derivatives of four hybridization cycles involving both tetraploid accessions and the hexaploid parents respectively, and were maintained after pedigree selection due to their good agronomic performance.

2. Reagents and standards

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

3. Chemical and physicochemical analysis

a. Sample preparation and milling process

Samples were harvested and processed for pre-cleaning, drying, and storage.

In order to perform the chemical analysis, seeds were grounded using a mill MF 10 basic IKA WERKE, and sieved at 1 mm. Chemical results concerning components, such as ash, proteins, fat, crude fiber, and micronutrients, were expressed on the basis of seed dry weight. The results were presented in g/100 g and all analyses were carried out in two or three replications.

Physicochemical characteristics

- **Groat flour moisture**

This parameter was determined by oven-drying samples at 80°C for 24 hrs and confirmed by near infrared spectrometry (Chopin Infraneo-NIRS). Results are reported on a dry weight basis (Brunner, Freed, 1994).

- **Ash**

Ash content of treated oat samples was determined using the AACC Method No. 08-01. In a dried and pre-weighed crucible, 3 g of a sample was ignited in muffle furnace at 550°C during 6 hrs to complete the burning of all organic matter. Samples were cooled, weighted, and calculated as ash percent (AACC, 1983).

- **Crude proteins**

Crude proteins (CP) were determined using the conventional Kjeldahl method (Velp Scientifica, DK 20-UDK 139), according to AOAC No. 979.09 procedure (AOAC, 1993).

- **Crude fat**

Total lipids (oil) from oat samples were determined using the Soxhlet method AACC No. 30-20, 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 (%) (AACC, 1983).

- **Total fiber fractions: CF, NDF, ADF, and ADL**

For each sample, Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL), and Crude Fiber (CF) were sequentially determined. CF was determined according to AOAC method No. 926.09 (AOAC, 1997). One gram of a sample was digested with 100 ml of 1.25% sulfuric 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 neutralized and then was transferred to a beaker to be refluxed for 30 min with 100 ml of 1.25% sodium hydroxide. Digested material was filtered and washed with hot water in order to be neutralized. The washed material was dried at 130ºC 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). Afterwards, hemicellulose was calculated according to the formula (NDF – ADF) and cellulose with the formula (ADF – ADL) (Rinne et al., 1997).

- **Mineral content determination**

After incineration, mineral composition (Na+ and K+) was determined using a 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 (Chapman, 1978). The grain phosphate reacted with the solution to form the ammonium molydiphosphate complex, which turned the solution to a blue color because of the effect of ascorbic acid. The amount of the absorbed light by the solution was measured at 825 nm with a UV-visible spectrophotometer (Jenway 6405 uv/vis spectrometer) (Chapman, 1978).

Trace elements, including iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), and nickel (Ni), were analyzed by atomic absorption spectrometry (Pinta 1971) in a flame air-acetylene. The measured absorption was realized at a specific wavelength of 248.3 nm to measure the concentrations 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 (Duchoňová et al., 2013), weight (in grams) minus water, proteins, fat, ash, and fiber contents.

- **Energy value**

The energy value was calculated from the approximate chemical composition data (Duchoňová et al., 2013). Energy value (Kcal) was calculated according to the formula:

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

The values were expressed in Kcal/100 g.

4. Statistical analysis

Data were expressed as the mean values ± standard deviation (SD) for each measurement. All experiments were carried out using two or three replicates. The results were statistically analyzed using one-way analysis of variance (ANOVA) by comparing mean values of the 9 cultivars. In case of significant difference between lines, means were compared by the Duncan multiple range test.

Results and discussion

Chemical composition

As shown by Table 1, the analysis of protein contents among the investigated tetraploid oat cultivars of *A. murphyi* showed important levels of protein contents, ranging from 10.54 ± 0.27% to 115.2 ± 1.16% for the lines *A. murphyi* 1 and 9. The line *A. murphyi* 8 and 9 with 13.66 ± 0.93 and 15.12 ± 1.16, respectively, presented the highest contents. In comparison with the previous studies performed on the tetraploid oat lines collected from Morocco, the recorded contents were about 10–35% higher than the ones reported by H. Saidi et al. (2013) and R. Manzali et al. (2018).

Owing to the valuable fatty acid composition of its grain fat, oat has a high nutritional potential. Oat genotypes usually include more fat than the other small cereal grains (Mut et al., 2018). The total concentration of fat in the analyzed lines varied between 3.93 ± 0.64% and 10.14 ± 0.75%. The assisted variations in terms of fat contents among samples are a good indicator of gene diversity. Furthermore, knowing the complexity of oat processing for the grains with high fat content (Decker, 2014), this variability can be seen as a valuable feature for oat valorization. Thus, suggesting oriented uses, according to the nutrient content or properties.

Among the studied *A. murphyi* domesticated tetraploid oat lines, line 1 had significantly higher thousand-seed weight (TSW = 54.66 g) than both the other lines and the control cultivar of hexaploid oat *A. sativa* (cv. ‘Amlal’). Test weight, TSW and chemical composition are the common traits used to characterize and define oat grain quality. Thousand-seed weight was reported to be one of the most important grain yield indicators for cereals. Oat cultivars with higher values of this parameter are generally considered to be of higher quality than those with low values (Mut et al., 2018).

According to the result of mean comparison, the maximum of ash concentration (5.18 ± 0.2%) was obtained for *A. murphyi* line 3 and the minimum of 2.71 ± 0.26% was registered for *A. murphyi* line 6. Mainly all the tetraploid lines presented interesting concentration of ash reflecting their good mineral contents.

We also noted, based on the used statistical method of analysis of variance, high significant differences ($P < 0.0001$) between the means of the moisture content, ash content and TSW. Concerning the energy value, it ranged from 293.59 ± 1.59 Kcal to 356.37 ± 5.28 Kcal, a variation mainly due to fat content differences between the assessed lines.

Micronutrient composition

The content of abundant minerals and trace elements in oat tetraploid lines grains are summarized in Table 2. Concentrations of macroelements K, Ca, Na, P, and Mg were assessed; they tended to be similar to the obtained values for the tetraploid parents of *A. murphyi* P_{45-55} and P_{50-52}. Meanwhile, the analysis of the tested samples indicated a slight improvement for both magnesium and calcium contents in *A. murphyi* line 6 (0.34 ± 0.02 mg/100 g) and *A. murphyi* line 9 (0.36 ± 0.12 mg/100 g), respectively, which corresponded to the research by Doehlert et al. (2013) on macro elements Mg, P, K and Ca, as the most abundant minerals in oats.

While for microelements, especially Fe, Cu and Mn, the concentrations were relevant for the tetraploid lines compared to their tetraploid parents P_{45-55} and P_{50-52}. The highest values for Fe, Cu and Mn were obtained in the *A. murphyi* line 7 (13.1 ± 1.9 mg/100 g), *A. murphyi* line 5 (1.5 mg/100 g) and *A. murphyi* line 9 (6.55 ± 0.15 mg/100 g), respectively. For Zinc and Nickel contents, they were broadly narrow to the levels recorded for the tetraploid parents P_{45-55} and P_{50-52}, ranging from 2.7 mg/100 g to 5.65 mg/100 g, and 0.6 mg/100 g to 0.9 mg/100 g respectively.

The identified cultivars showed relatively important contents for all the trace minerals. Nevertheless, Fe, Cu and Mn showed more phenotypic variability among the tested lines. The average contents reported by Bityutskii et al., (2017) for Fe, Zn and Mn in oat cultivars were relatively lower than the ones measured for our material.

From the nutritional point of view, some of the trace elements, including Fe, Mg, Zn and Co, are essential micronutrients for biochemical functions in all living organisms, and have a tremendous impact on human health and wellbeing (Jakobsone et al., 2019).

For instance, in Morocco, mineral and vitamin deficiencies continue to impact a great share of the population. As the re-

Table 1. Chemical composition of new domesticated Moroccan tetraploid oat lines of *Avena murphyi* Ladiz.
Таблица 1. Химический состав новых культурных марокканских тетраплоидных линий овса *Avena murphyi* Ladiz.

Lines	Content of elements						
	Moisture (%)	Ash (%)	Fat (%)	TSW (g)	Protein (%)	Carbohydrate (%)	Energy (Kcal/100 g)
A. murphyi 1	7.14 ± 0.01	3.54 ± 0.25	4.14 ± 0.77	54.66 ± 0.42	12.03 ± 0.01	53.64 ± 2.8	296.87 ± 3.14
A. murphyi 2	6.8 ± 0	5.05 ± 0.2	6.02 ± 0.6	33.45 ± 1.17	10.54 ± 0.27	56.56 ± 3.31	318.17 ± 3.36
A. murphyi 3	6.69 ± 0.02	5.18 ± 0.2	5.81 ± 0.57	40.24 ± 1.26	12.01 ± 0.07	52.19 ± 3.38	304.7 ± 1.42
A. murphyi 4	7.45 ± 0.12	3.53 ± 0.11	5.69 ± 0.32	32.11 ± 1.37	10.59 ± 0.1	53.66 ± 1.48	305.96 ± 2.30
A. murphyi 5	8.28 ± 0.03	2.84 ± 0.05	8.19 ± 0.61	31.57 ± 0.64	12.6 ± 0.23	49.64 ± 1.4	322.38 ± 3.32
A. murphyi 6	7 ± 0.07	2.71 ± 0.26	6.09 ± 0.6	31.94 ± 1.79	12.34 ± 0.02	51.88 ± 2.68	309.65 ± 1.95
A. murphyi 7	7.22 ± 0.07	3.3 ± 0.31	10.14 ± 0.75	33.18 ± 0.73	12.19 ± 0.12	52.15 ± 1.91	356.37 ± 5.28
A. murphyi 8	8.23 ± 0.05	4.0 ± 0.1	8.82 ± 0.16	37.59 ± 1.96	13.66 ± 0.93	48.68 ± 3.75	321.97 ± 2.49
A. murphyi 9	8.33 ± 0.02	4.73 ± 0.17	5.6 ± 0.46	39.15 ± 2.00	15.12 ± 1.16	50.91 ± 4.17	307.00 ± 5.74
A. murphyi 10	7.99 ± 0.02	4.47 ± 0.11	3.93 ± 0.64	39.41 ± 1.16	11.68 ± 0.07	53.38 ± 2.02	293.59 ± 1.59
P45-55	6.2 ± 0.15	3.12 ± 0.19	5.96 ± 0.38	41.84 ± 3.33	14.7 ± 0.28	54.24 ± 0.97	315.77 ± 3.30
P50-52	7.49 ± 0.09	4.36 ± 0.11	4.97 ± 0.58	40.51 ± 1.05	11.82 ± 0.09	57.38 ± 3.95	316.76 ± 4.17
Amlal	7.9 ± 0.01	4.38 ± 0.25	7.99 ± 0.4	26.49 ± 1.34	10.46 ±0.12	52.96 ± 3.75	320.89 ± 1.37

Table 2. Mineral composition of new domesticated Moroccan tetraploid oat lines of *Avena murphyi* Ladiz.
Таблица 2. Минеральный состав новых культурных марокканских тетраплоидных линий овса *Avena murphyi* Ladiz.

Lines	Content of elements (mg/100 g DW)									
	P	Na	K	Ca	Mg	Fe	Zn	Cu	Mn	Ni
A. murphyi 1	0.31 ± 0.01	0.07 ± 0	0.34 ± 0	0.18 ± 0.02	0.2 ± 0.06	5.65 ± 0.05	2.7 ± 0	1.15 ± 0.05	4.9 ± 0.1	0.8 ± 0
A. murphyi 2	0.28 ± 0.01	0.09 ± 0	0.33 ± 0.01	0.2 ± 0.04	0.18 ± 0.04	6.45 ± 0.05	3.25 ± 0.15	1.15 ± 0.05	5.2 ± 0.1	0.9 ± 0
A. murphyi 3	0.29 ± 0	0.07 ± 0	0.34 ± 0.02	0.22 ± 0.02	0.24 ± 0.02	6.35 ± 0.15	3.45 ± 0.05	1.25 ± 0.05	5.3 ± 0.2	0.75 ± 0.05
A. murphyi 4	0.31 ± 0	0.08 ± 0	0.33 ± 0	0.16 ± 0.04	0.19 ± 0.02	7.05 ± 0.25	4.25 ± 0.15	0.95 ± 0.05	5.2 ± 0	0.7 ± 0
A. murphyi 5	0.3 ± 0.02	0.1 ± 0	0.35 ± 0	0.2 ± 0	0.2 ± 0.01	10.95 ± 0.45	4.75 ± 0.15	1.5 ± 0	6.25 ± 0.35	0.7 ± 0
A. murphyi 6	0.31 ± 0.01	0.07 ± 0	0.32 ± 0	0.34 ± 0.02	0.25 ± 0.03	6.65 ± 0.25	4.05 ± 0.15	0.85 ± 0.05	6.25 ± 0.15	0.6 ± 0
A. murphyi 7	0.31 ± 0.01	0.07 ± 0	0.32 ± 0	0.26 ± 0.06	0.15 ± 0.1	13.1 ± 1.9	4.05 ± 0.05	1 ± 0.1	6.25 ± 0.05	0.8 ± 0
A. murphyi 8	0.29 ± 0	0.09 ± 0	0.34 ± 0.01	0.14 ± 0.02	0.25 ± 0.01	6.15 ± 0.05	3 ± 0.1	1 ± 0.1	5.1 ± 0.1	0.8 ± 0
A. murphyi 9	0.32 ± 0.02	0.08 ± 0	0.32 ± 0	0.2 ± 0.04	0.36 ± 0.12	6.55 ± 0.15	5.65 ± 0.15	0.75 ± 0.05	6.55 ± 0.15	0.9 ± 0.1
A. murphyi 10	0.36 ± 0	0.09 ± 0	0.37 ± 0	0.16 ± 0	0.31 ± 0.02	7.25 ± 0.15	4.5 ± 0.1	0.85 ± 0.05	6.05 ± 0.15	0.9 ± 0
P45-55	0.36 ± 0.01	0.11 ± 0	0.38 ± 0	0.16 ± 0.04	0.24 ± 0.02	7.25 ± 0.15	3.9 ± 0.1	0.85 ± 0.05	4.2 ± 0.1	0.8 ± 0
P50-52	0.32 ± 0.01	0.09 ± 0	0.44 ± 0	0.24 ± 0.04	0.28 ± 0.02	6.1 ± 0.1	4 ± 0.1	0.6 ± 0	6.05 ± 0.05	0.5 ± 0.0
Amlal	0.34 ± 0	0.07 ± 0	0.32±0	0.32 ± 0.04	0.24 ± 0.02	6.4 ± 0.2	3.1 ± 0.2	0.55 ± 0.05	4.6 ± 0.1	0.55 ± 0.05

sults had promising outcomes for micronutrient contents, these lines could be used for human consumption as well as crossing parents in breeding programs targeting at high microelement contents.

Fiber fractions composition

According to the average of the distribution of fiber fractions ratios, the means for ADF and NDF ranged from 10.21 to 24.17% and 31.69 to 41.76%, respectively. The lowest recorded ADF and NDF values were obtained for the lines *A. murphyi* 4 and *A. murphyi* 8. The levels of NDF and ADF within tetraploid lines were slightly higher than the ranges previously reported by Mut et al., (2018). This study showed that cellulose content varied from 24.05% (*A. murphyi* 2) to 36.17% (*A. murphyi* 7), with an average of 31.18%. Concerning hemicellulose content, seven lines lied in higher range, exceeding 20.34%, and remaining lines had medium content (11.32 to 17.59%) (Table 3).

It is designed to grow under marginal and unfertile-arid lands, while offering high-dense grains. Present findings point out that the selected tetraploid lines provide interesting nutritional profiles and quality traits. Besides, plant breeders have long been working to develop high-yielding and consistent good-quality cultivars. The assessed tetraploid lines present good combination of proteins, fat, fiber fractions and micronutrients. In addition, being domesticated tetraploid lines, they are natural genetic sources, providing many opportunities to explore in breeding programs and improve oat cultivation at both national and international levels.

These genotypes are now being grown in different locations and further being tested for abovementioned parameters and yield characteristics in order to select the best genotype; they may be explored in breeding programs for the inclusion of desirable characters into elite breeding lines to develop high-yielding cultivars possessing better nutritional quality traits.

Table 3: Content of fiber fractions in new domesticated Moroccan tetraploid oat lines of *Avena murphyi* Ladiz.

Таблица 3: Содержание фракций клетчатки в новых культурных марокканских линиях тетраплоидного овса *Avena murphyi* Ladiz.

Lines	Content of elements (%)						
	DM	CF	NDF	ADF	ADL	Cellulose	Hemicellulose
A. murphyi 1	92.85 ± 0.01	20.42 ± 0.54	41.76 ± 0.45	24.17 ± 0.76	9.87 ± 0.82	31.89 ± 1.27	17.59 ± 1.21
A. murphyi 2	93.2 ± 0	16.44 ± 0.97	32.28 ± 0.24	20.96 ± 0.81	8.22 ± 0.4	24.05 ± 0.64	11.32 ± 1.05
A. murphyi 3	93.3 ± 0.02	19.44 ± 0.37	35.7 ± 2.47	11.91 ± 0.72	8.42 ± 0.67	27.29 ± 1.8	23.8 ± 3.19
A. murphyi 4	92.54 ± 0.12	20.04 ± 0.89	37.47 ± 0.26	10.21 ± 0.19	6.98 ± 0.26	30.48 ± 0	27.26 ± 0.45
A. murphyi 5	91.72 ± 0.03	19.03 ± 0.71	40.45 ± 1.24	12.57 ± 0.77	5.21 ± 0.58	35.23 ± 1.82	27.87 ± 0.47
A. murphyi 6	92.99 ± 0.07	20.45 ± 1.02	38 ± 0.75	16.3 ± 0.5	4.57 ± 0.41	33.43 ± 1.17	21.7 ± 0.25
A. murphyi 7	92.77 ± 0.07	14.65 ± 0.43	39.69 ± 0.95	11.04 ± 0.22	3.53 ± 0.11	36.17 ± 0.84	28.65 ± 1.17
A. murphyi 8	91.76 ± 0.05	17.77 ± 0.36	31.69 ± 0.09	16.19 ± 0.85	4.55 ± 0.09	27.14 ± 0	15.49 ± 0.76
A. murphyi 9	91.67 ± 0.02	16.82 ± 0.07	36.77 ± 0.11	16.42 ± 0.33	2.04 ± 0.19	34.72 ± 0.3	20.34 ± 0.22
A. murphyi 10	92 ± 0.06	19.72 ± 0.34	36.49 ± 0.24	13.77 ± 0.76	5.02 ± 0.31	31.44 ± 0.06	22.72 ± 1
P45-55	93.8 ± 0.15	19.93 ± 0.99	44.47 ± 0.62	20.74 ± 0.23	5.58 ± 1	38.89 ± 0.38	23.73 ± 0.86
P50-52	92.51 ± 0.09	15.04 ± 1.6	44.23 ± 0.38	24.67 ± 0.13	15.81 ± 0.46	28.42 ± 0.08	19.56 ± 0.25
Amlal	92.1 ± 0.01	17.51 ± 1.11	41.78 ± 0.42	20 ± 0.85	4.14 ± 0.21	37.64 ± 0.21	21.78 ± 1.26

The present investigation showed that lignin content varied from 2.04 to 9.87%, with an average of 5.84%. Six lines possessed medium amount of lignin (2.04 to 5.21%) compared to the tetraploid parents of *A. murphyi* P_{45-55} (5.58 ± 1%) and P_{50-52} (15.81 ± 0.46%) (see Table 3). Many reports advanced an inverse correlation between lignin content and digestibility (Vivekanand et al., 2014; Prates et al., 2018) and thus, the lines *A. murphyi* 6, 7, 8 and 9 with moderate levels of ADL may present good digestibility.

In the current context of climate change constraints, oat is considered one of the most suitable cereal for growing.

Conclusion

The results of the performed characterization lead to conclude that the new developed tetraploid oat lines are of a good nutritional value, rich in biochemical substances and their utilization in oat breeding and human diet is beneficial for human wellbeing. Selected lines can be considered as a release of new plant material with high-production and good-quality grain, thus contributing traits and good adaptation to climate.

These lines will increase the diversity among cultivated oat as rich sources of resistance genes, against various pathogens and pests, and can broaden the germplasm resources of oat. Additional research is warranted to exploit the genetic diversity and the valuable traits of these accessions.

References / Литература

AACC – American Association of Cereal Chemists. Approved Methods. 8th ed. St. Paul, MN; 1983.

AOAC – Association of Official Analytical Chemists. Methods of analysis for nutrition labeling. Arlington, TX; 1993.

AOAC – Association of Official Analytical Chemists. Official Methods of Analysis of the Association of Official Analytical Chemists, 16th ed., Washington DC; USA; 1997.

Bayram C., Ayan İ. Determination the effects of nitrogen doses on hay yield and quality characteristics of some oat cultivars/lines. In: *VIII International Scientific Agriculture Symposium, "Agrosym 2017", Jahorina, Bosnia and Herzegovina, October 2017. Book of Proceedings*. Sarajevo: University of East Sarajevo; 2017. p.744-749.

Bityutskii N., Yakkonen K., Loskutov I. Content of iron, zinc and manganese in grains of *Triticum aestivum, Secale cereale, Hordeum vulgare* and *Avena sativa* cultivars registered in Russia. *Genetic Resources and Crop Evolution*. 2017;64(8):1955-1961. DOI: 10.1007/s10722-016-0486-9

Brunner B.R., Freed R.D. Oat grain β-glucan content as affected by nitrogen level, location, and year. *Crop Science*. 1994;34(2):473-476. DOI: 10.2135/cropsci1994.0011183X003400020031x

Chapman H.D., Pratt P.F. Methods of analysis for soils, plants and waters. Oakland, CA: University of California; 1978.

Decker E.A., Rose D.J., Stewart D. Processing of oats and the impact of processing operations on nutrition and health benefits. *The British Journal of Nutrition*. 2014;112(Suppl 2):58-64. DOI: 10.1017/S000711451400227X.

Doehlert D.C., Thavarajah D., Thavarajah P., Ohm J.B. Detailed composition analyses of diverse oat genotype kernels grown in different environments in North Dakota. *Cereal Chemistry.* 2013;90(6):572-578. DOI: 10.1094/CCHEM-09-12-0111-R

Dong J.L., Yang M., Shen R.L., Zhai Y.F., Yu X., Wang Z. Effects of thermal processing on the structural and functional properties of soluble dietary fiber from whole grain oats. *Food Science and Technology International.* 2019;25(4):282-294. DOI: 10.1177/1082013218817705

Duchoňová L., Polakovičová P., Rakická M., Šturdik E. Characterization and selection of cereals for preparation and utilization of fermented fiber-betaglucan product. *The Journal of Microbiology, Biotechnology and Food Sciences*. 2013:2(2):2187.

Jakobsone I., Zute S.,Bleidere M., Kantane I., Ece L., Bartkevics V. Macro and trace elements in oat cultivars bred in Latvia. *Zemdirbyste = Agriculture*. 2019;106(1):21-28. DOI: 10.13080/z-a.2019.106.003

Lásztity R. Oat grain – a wonderful reservoir of natural nutrients and biologically active substances. *Food Reviews International*. 1998;14(1):99-119. DOI: 10.1080/87559129809541150

Manzali R., Douaik A., Bouksaim M., Ladizinsky G., Saidi N. Assessment of important technological parameters of new Moroccan domesticated tetraploid oat lines of *Avena magna*. *Proceedings on Applied Botany, Genetics and Breeding*. 2018;179(1):32-42. DOI: 10.30901/2227-8834-2018-1-32-42

Mut Z., Akay H., Doğanay Ö., Köse E. Grain yield, quality traits and grain yield stability of local oat cultivars. *Journal of Soil Science and Plant Nutrition*. 2018;18(1):269-281. DOI: 10.4067/S0718-95162018005001001

Pinta M. (ed.). Spectrométrie d'absorption atomique. Tome II, Application à l'analyse chimique. Paris: Masson et Co. ;ORSTOM; 1971. [in French]

Prates L.L., Refat B., Lei Y., Prates M.L., Yu P. Relationship of carbohydrates and lignin molecular structure spectral profiles to nutrient profile in newly developed oats cultivars and barley grain. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2018;188:495-506. DOI: 10.1016/j.saa.2017.07.042

Ramzan S. Oat: a novel therapeutic ingredient for food applications. *Journal of Microbiology, Biotechnology and Food Sciences*. 2020;9(4):756-760. DOI: 10.15414/jmbfs.2020.9.4.756-760

Rinne M., Huhtanen P., Jaakkola S. Grass maturity effects on cattle fed silage-based diets. 2. Cell wall digestibility, digestion and passage kinetics. *Animal Feed Science and Technology*. 1997;67(1):19-35. DOI: 10.1016/S0377-8401(96)01142-X

Saidi N., Saidi S., Hilali A., Benchekroun M., Al Faiz C., Bouksaim M. et al. Improvement of oat hexaploid lines's groat nutritive value *via* hybridisation with tetraploid oat *A. magna*. *American Journal of Research Communication*. 2013;1(9):126-135.

Singh S., Kaur M., Sogi D.S. A comparative study on chemical composition, color, and functional characteristics of flours and protein concentrates from different oat cultivars. *International Journal of Recent Scientific Research*. 2018;9(5):2666-26671. DOI: 10.24327/ijrsr.2018.0905.2100

Soycan G., Schär M.Y., Kristek A., Boberska J., Alsharif S.N.S., Corona G. et al. Composition and content of phenolic acids and avenanthramides in commercial oat products: Are oats an important polyphenol source for consumers? *Food chemistry: X*. 2019;3:100047. DOI: 10.1016/j.fochx.2019.100047

Steffenson B.J., Olivera P., Roy J.K., Jin Y., Smith K.P., Muehlbauer G. A walk on the wild side: mining wild wheat and barley collections for rust resistance genes. *Australian Journal of Agricultural Research*. 2007;58(6):532-544. DOI: 10.1071/AR07123

Van Soest P.J., Robertson J.B., Lewis B.A. Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*. 1991;74(10):3583-3597. DOI: 10.3168/jds.S0022-0302(91)78551-2

Vivekanand V., Chawade A., Larsson M., Larsson A., Olsson O. Identification and qualitative characterization of high and low lignin lines from an oat TILLING population. *Industrial Crops and Products*. 2014;59:1-8. DOI: 10.1016/j.indcrop.2014.04.019

Information about the authors

Rajae Manzali, PhD, Department of Applied Biology and Food Processing, Faculty of Sciences and Techniques, Hassan First University, P.O. Box 577, Settat 26000, Morocco, National Institute for Agricultural Research, Regional Centre for Agricultural Research of Rabat, P.O. Box 6570, Rabat Institutes, Rabat 10101, Morocco, raja.manz@live.fr, https://orcid.org/0000-0001-8746-1229

Mohamed Bouksaim, PhD, National Institute for Agricultural Research, Regional Centre for Agricultural Research of Rabat, P.O. Box 6356, Rabat Institutes, Rabat 10101, Morocco, mbouksaim@hotmail.com, https://orcid.org/0000-0002-2369-1284

Ahmed Douaik, PhD, National Institute for Agricultural Research, Regional Centre for Agricultural Research of Rabat, P.O. Box 6356, Rabat Institutes, Rabat 10101, Morocco, ahmed.douaik@inra.ma, https://orcid.org/0000-0001-7374-4674

Gideon Ladizinsky, Professor, Ex Principal Investigator, United States Agency for International Development, Project No. TAMOU 97-053, Washington DC 20523, USA, ladizins@agri.huji.ac.il, https://orcid.org/0000-0001-5454-4095

Nezha Saidi, PhD, National Institute for Agricultural Research, Regional Centre for Agricultural Research of Rabat, P.O. Box 6356, Rabat Institutes, Rabat 10101, Morocco, nezha.saidi@inra.ma, https://orcid.org/0000-0002-2665-3574

Информация об авторах

Радже Манзали, доктор философии, кафедра прикладной биологии и производства продуктов питания, научно-технический факультет, Университет Хассана Первого, 26000 Марокко, Сеттат, п/я 577, Национальный институт сельскохозяйственных исследований, Рабатский региональный центр сельскохозяйственных исследований, 10101 Марокко, Рабат, Институты Рабата, п/я 6570, raja.manz@live.fr, https://orcid.org/0000-0001-8746-1229

Мохамед Буксаим, доктор философии, Национальный институт сельскохозяйственных исследований, Рабатский региональный центр сельскохозяйственных исследований, 10101 Марокко, Рабат, Институты Рабата, п/я 6356, mbouksaim@hotmail.com, https://orcid.org/0000-0002-2369-1284

Ахмед Дуаик, доктор философии, Национальный институт сельскохозяйственных исследований, Рабатский региональный центр сельскохозяйственных исследований, 10101 Марокко, Рабат, Институты Рабата, п/я 6356, ahmed.douaik@inra.ma, https://orcid.org/0000-0001-7374-4674

Гидеон Ладизинский, профессор, бывший главный исследователь, Агентство США по международному развитию, 20523 США, Вашингтон, округ Колумбия, проект № TAMOU 97-053, ladizins@agri.huji.ac.il, https://orcid.org/0000-0001-5454-4095

Нежа Саиди, доктор философии, Национальный институт сельскохозяйственных исследований, Рабатский региональный центр сельскохозяйственных исследований, 10101 Марокко, Рабат, Институты Рабата, п/я 6356, nezha.saidi@inra.ma, https://orcid.org/0000-0002-2665-3574

Contribution of the authors: the authors contributed equally to this article.
Вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.

Conflict of interests: the authors declare no conflicts of interests.
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

The article was submitted on 21.09.2022; approved after reviewing on 19.12.2022; accepted for publication on 02.03.2023.
Статья поступила в редакцию 21.09.2022; одобрена после рецензирования 19.12.2022; принята к публикации 02.03.2023.