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RESEARCH ARTICLE

Physicochemical and antioxidant characterization of quinoa (*Chenopodium quinoa Willd*) seeds cultivated in Béni Mellal, Morocco

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Abstract

Quinoa (*Chenopodium quinoa Willd*) is a highly nutritious pseudo cereal originating from the Andes, notable for its resilience in diverse soil types and climatic conditions. It contains high levels of protein, fats, dietary fiber, micronutrients and essential amino acids. Despite limited consumption due to high import costs and low public awareness, quinoa is increasingly drawing interest from researchers and consumers alike. Morocco faces growing water scarcity, exacerbated by global climate change, irregular rainfall and successive years of drought. These challenges are particularly acute in arid and semi-arid regions such as Béni Mellal, where high temperatures and limited water availability place increasing pressure on agricultural systems. In this context, quinoa stands out as a resilient crop due to its ability to tolerate heat and thrive under water-limited conditions, making it a strong candidate for climate resilient agriculture. This study aims to assess the physicochemical, biochemical and morphological characteristics of quinoa grown for the first time in Morocco's Béni Mellal region, to evaluate its suitability and agronomic potential under local environmental conditions. A comparison was made between quinoa seeds cultivated in the Béni Mellal region and those grown in another region of Morocco (Settat). A morphological and nutritional analysis was conducted, focusing on weight, thickness, diameter, coloration, dry matter, ash, fat, protein, fiber and sugar content. The seeds were analyzed for their content of phenolic compounds, including flavonoid derivatives and condensed tannins. Their antioxidant potential was also assessed through multiple evaluation methods. The analysis revealed that the quinoa seeds cultivated in the Béni Mellal region exhibited notably elevated levels ($p \leq 0.05$) of phenolic content, reaching 1512.16 (mg GAE/100 g DW). These seeds also demonstrated a strong antioxidant potential, with a total antioxidant capacity (TAC) value of 467.52. In addition, they contained higher proportions of protein (19.13 %) and dietary fiber (12.55 %) compared to typical reference values. These results highlight quinoa's potential not only to thrive under agro-climatic stress but also to contribute to nutritional security and drought-adaptive farming systems. Incorporating quinoa into Moroccan agriculture could enhance crop diversification, reduce vulnerability to climate extremes and support sustainable development in arid and semi-arid regions.

Keywords: antioxidant activity; morphological analysis; proximate analysis; quinoa (*Chenopodium quinoa Willd*); total phenolic content

Introduction

Quinoa (*Chenopodium quinoa* Willd.) is an annual dicotyledonous herbaceous plant originally cultivated in the Andean highlands, where it has been grown for 5000-7000 years (1). It's currently grown in Bolivia, Peru, United States, Ecuador and Canada as a food crop (2). The quinoa seeds, which are consumable, are tiny, circular and slightly flattened. Seed colors can range from white to grey and black, or can be yellow and red (3). Today, quinoa is known for its high protein content and quality, a balanced amino acid spectrum with high contents of lysine and methionine (1). It contains a considerable amount of fiber and minerals, such as calcium and iron (4). Moreover, quinoa is considered gluten-free and, therefore, suitable for celiac patients as well as people who have wheat allergy (5-7). In recent years, quinoa has garnered significant attention due to its outstanding nutritional profile and potential health benefits. Both quinoa and its derivatives are not only abundant in macronutrients like protein, carbohydrates and fats, but also rich in micronutrients such as polyphenols, vitamins and minerals (8-11). Given its exceptional nutritional composition and resilience to harsh environmental conditions, quinoa represents a promising crop for improving food and nutritional security in arid and semi-arid regions. Its cultivation could provide local populations particularly in areas like Béni Mellal with access to a nutritious,

climate-resilient food source, thereby contributing to better health outcomes and greater agricultural sustainability (12). In under two decades, global demand for quinoa surged significantly, prompting a threefold increase in the area dedicated to its cultivation in the Andes. Furthermore, the plant's resilience and adaptability are being leveraged to expand its cultivation beyond the Andean region. As a result, the number of countries growing quinoa has increased rapidly since the 1980s, with over 95 countries now cultivating or experimenting with quinoa as a crop. In the early 1990s, quinoa began to be cultivated in Europe and the crop has been successfully tested in several Mediterranean countries, such as Greece, Morocco, Spain and Italy (13). Quinoa was initially brought to Morocco under an IAV initiative in the 1990. More recently, it has been cultivated in the Rhamna region, where it has shown excellent adaptation to the climate, but unfortunately, limited research has been conducted on these seeds in Morocco. This lack of studies inspired us to carry out the present research (14).

Considering the potential of cultivating quinoa in the Béni Mellal region, we hypothesized that quinoa grown under the specific climatic conditions of this region would adapt well and tolerate these environmental stresses. Thus, the objective of this study is to describe the quinoa grains cultivated in Béni Mellal by assessing their morphological, nutritional and biochemical properties, including their composition, phenolic content and antioxidant activity. This will help determine the quinoa's potential adaptation and quality in this new agro ecological context.

Materials and Methods

Culture the seeds

Quinoa seeds were cultivated at two different regions of Morocco: Béni Mellal (E1) and Settat (E2). The seedlings were initially sown in trays during the last week of January 2022 and moved to a previously prepared area after 40 days. Transplanting was done with 0.6 cm between rows and 0.2 cm between seedlings. This trial used 60 units of potash, 50 units of phosphorus and 100 units of nitrogen as fertilizer. The crop received a total of 280 mm of water, divided into four 50-mm doses, of which 200 mm came from irrigation and 80 mm from rainfall. The first week of June marked the start of the harvest.

Preparation of seed extract

The grains of the cultivated quinoa, treated, are crushed in the grinder. 30 g of the flour was measured and dissolved in 300 mL of 90 % ethanol, then maintained under agitation for 2 hr. The mixture was centrifuged for 15 min at 6000 rpm, followed by filtration through filter paper. After filtration, the sample underwent vacuum drying. The obtained extract was diluted in 6 mL of 90 % ethanol. The extract is ready for analysis of antioxidant activity and phenolic content (15).

Morphological analysis

Traditional morphological markers were assessed under natural conditions, including grain diameter (mm), thickness (mm), grain weight (mm) and color. Measurements were recorded for 30 sample seeds (16).

Proximate analysis

The analyses of quinoa flour determined several components. The dry matter content was measured by heating 3 g of quinoa flour at 105 °C until a constant weight was achieved (17). Ash content was evaluated by incinerating the samples in a muffle furnace at 550 °C for 12 hr (18). Protein content was determined using the Macro-Kjeldahl method with a conversion factor of 6.25 for quinoa flour (19). Crude fat was measured using a Soxhlet apparatus (20). Fiber content was assessed by acid/alkaline hydrolysis of insoluble residues (21). Total sugars were extracted with 80 % ethanol by centrifugation, followed by a colorimetric assay using phenol and sulfuric acid and quantified by measuring absorbance at 485 nm, based on a glucose standard curve (22). Reducing sugars were measured using the Somogyi-Nelson method, where a reaction with specific reagents allowed absorbance to be measured at 540 nm, with results expressed according to a D-glucose standard curve (23).

Determination of phenolic content

The number of polyphenols was assessed using The Folin-Ciocalteu technique. To 1 mL of Folin-Ciocalteu reagent, 400 µL of the sample extract was introduced, stirred for 5 min and then 5 mL of Na_2CO_3 was incorporated. The solution was left to incubate for 60 min at room temperature, away from light and absorbance was analyzed at 750 nm. Results are expressed in milligrams of gallic acid equivalent (24). Flavonoids were determined using a method in which 1 mL of 2 % $AlCl_3$ was added to 1 mL of extract, followed by incubation for 15 min. The absorbance was recorded at 430 nm, with measurements presented as rutin equivalents per 100 g of dry matter (g ER/100 g DM) (25). Condensed tannins were quantified using the method (26), where 500 µL of the extract (500 µg/mL) was combined with 3 mL of a 4 % vanillin-methanol solution, followed by the addition of 1.5 mL of 37 % hydrochloric acid. After mixing and incubating for 15 min in the dark, the absorbance was recorded at 500 nm. The results are expressed as milligrams of catechin in equivalents per gram.

Antioxidant activity

Diphenyl-1-picrylhydrazil free radical scavenging assay

The antioxidant capacity of quinoa seeds extract was determined through a modified DPPH method based on previously established procedures (27–29). For the preparation of the DPPH-methanol solution, 2 mg of DPPH was dissolved in 100 mL of methanol. A series of extract solutions at concentrations ranging from 5 to 500 µg/mL was then prepared. Subsequently, 2.5 mL of the DPPH solution was added to each sample and the final volume was adjusted to 3 mL. The mixtures were left to react at room temperature for 30 min. Absorbance was then recorded at 517 nm using a blank as reference. The percentage of DPPH free radical scavenging activity was calculated using the following equation:

$$\text{Free Radical Scavenging (\%)} = \left[\left(\frac{A_{\text{blank}} - A_{\text{sample}}}{A_{\text{blank}}}\right)\right] \times 100$$

(Eqn. 1)

The absorbance of the control solution containing all reagents except the extract was designated as a blank**,** while the absorbance of the test solutions with varying extract

concentrations was referred to as a sample. The IC_{50} value, representing the concentration required to inhibit 50 % of the DPPH radicals, was calculated by plotting the percentage of inhibition against the corresponding extract concentrations. Ascorbic acid was used as a reference antioxidant (positive control).

ABTS scavenging activity assay

The ABTS radical scavenging activity of quinoa seed extracts was assessed using a modified version of a previously described procedure (30). To generate the $ABTS^{\bullet+}$ radical cation, ABTS solution was mixed with 2.45 mM potassium per sulfate and left to react in the dark at room temperature for 16-18 hr. The resulting solution was then diluted with ethanol to reach an absorbance of 0.70 ± 0.02 at 750 nm. L-ascorbic acid was used as a standard reference compound.

For the assay, 20 µL of the extract was added to 200 µL of the pre-diluted $ABTS^{\bullet+}$ solution, followed by incubation in the dark for 10 min at room temperature. Absorbance was measured at 734 nm using a micro plate reader. The percentage of ABTS radical scavenging was calculated using a formula similar to that applied in the DPPH method.

Total antioxidant capacity (TAC)

The antioxidant capacity of the sample was evaluated using the phosphomolybdenum assay, as previously outlined (31). In this method. The extract or standard solution was combined with a reagent mixture composed of 0.6 M sulfuric acid, 28 mM sodium phosphate and 4 mM ammonium molybdate. The resulting mixture was incubated at 95 °C for 90 min, then allowed to cool naturally to ambient temperature. Absorbance was measured at 695 nm. The antioxidant activity was expressed in terms of ascorbic acid equivalents, based on a calibration curve constructed using ascorbic acid standards. A control solution containing all reagents except the sample was also prepared. Each experiment was repeated in triplicate to ensure accuracy and reproducibility.

Carotene bleaching assay

The antioxidant activity of quinoa seed extracts was assessed using the β-carotene bleaching assay, following modified protocols (27, 28). An emulsion was prepared from β-carotene, linoleic acid, Tween 80 and distilled water, then incubated with the samples in a 96 well plate. Absorbance was measured at 470 nm at t_0 and t_1 (after 2 hr) and compared to a blank; BHA was used as a positive control. The percentage of residual color was calculated using the following equation:

$$\text{Residual color (\%)} = \left[\left(\frac{\text{Initial OD} - \text{Sample OD}}{\text{Initial OD}}\right)\right] \times 100 \quad \text{(Eqn. 2)}$$

Statistical analysis

Data analysis was performed using a one-way multivariate ANOVA, followed by a Tukey test, with a significance threshold set at 0.05. The statistical analysis was carried out using Minitab statistical software, version 18 (Minitab, Inc.)

Results and Discussion

Morphological analysis

The morphological characteristics of quinoa seeds from Béni Mellal (E1) and Settat (E2) are summarized in Table 1.

The seeds from Béni Mellal exhibited an average diameter of 1.8 mm, a thickness of 0.99 mm and a weight of 0.003 g, whereas those from Settat showed a diameter of 1.53 mm, a thickness of 0.64 mm and a weight of 0.002 g. These results indicate slight, yet statistically non-significant, differences between the two locations ($p \leq 0.05$).

Seed color was assessed using the colorimetric parameters a*, b* and c*, allowing for the calculation of hue angle (h*). Both varieties exhibited similar values: 80.93 for Béni Mellal and 83.01 for Settat, corresponding to a yellow hue. These findings are consistent with previous literature, which reports a wide variability in quinoa seed coloration, ranging from white to black, including cream, beige, yellow, red and brown hues (32).

The slight differences in seed size and weight between the two sites may indeed be linked to agro-climatic factors such as soil fertility, temperature and precipitation regimes; several studies have shown that these parameters influence seed morphology in quinoa, particularly size, mass and the content of secondary metabolites. For instance, adequate nitrogen nutrition can promote better seed filling, while water or heat stress may result in smaller, less dense seeds (33-35).

These findings align with general ranges reported in the literature. Average quinoa seed diameters and widths have been cited as 2.05 mm and 1.07 mm, respectively, with a thousand seed weight of approximately 2.68 g (36). Earlier studies have also reported seed diameters between 2 and 2.5 mm and widths ranging from 1.2 to 1.6 mm, depending on genotype and environmental conditions (33-35). The slight differences observed in samples, particularly in terms of thickness and weight, may be attributed to eco-climatic variations between Morocco and other quinoa-producing regions, seed size is also influenced by developmental stage and nutritional status, which affect embryo formation and reserve accumulation (33, 34). Our findings support these observations and reflect the natural morphological and colorimetric variability inherent in quinoa seeds.

Table 1. Morphological parameters of cultivated quinoa seeds (E1 and E2) from Morocco

	d	t	w	l*	a*	b*	c*	h
Quinoa seeds cultivated in Béni mellal (E1)	1.83 ± 0.16^a	0.99 ± 0.12^a	0.003 ± 0.0006^a	56.25 ± 13.58^a	4.88 ± 2.06^a	32.5 ± 5.73^a	45.90 ± 8.64^a	80.93 ± 5.08^a
Quinoa seeds cultivated in Settat (E2)	1.53 ±0.12^a	0.64 ± 0.14^b	0.001 ±0.0002^b	53.14 ± 10.21^a	4.22 ± 1.58^a	31.04 ± 6.81^a	48.78 ± 5.74^a	83.01 ± 6.26^a

d: diameter (mm); t: thickness (mm); w: weight (g); l* = lightness 0 (black) to 100 (white) a* = (- a) redness to (+ a) greenness b* = (- b) yellowness to (+) blueness c* = color intensity calculated as c = (a 2 + b 2) ½ h = Hue, calculated using the formula hue = tan - 1 (b/a) H* = 0–360 (red-violet), h* = 90 (yellow), h* = 180 (green) and h* = 270 (blue). The data are presented as Mean ± SD, with all experiments conducted in triplicate (n = 3). Statistical analysis was performed using a one-way ANOVA, followed by Tukey's post-hoc test at a 5 % significance level. Means in the same column that are followed by different letters are significantly different (p < 0.05).

Proximate analysis

Table 2 present the results of moisture, ash, Total fiber, Overall sugar content, Total reducible sugar, total protein content and crude fat contents of cultivated quinoa seeds (E1 and E2) from Morocco.

The data presented in Table 2 indicate significant variations ($p \leq 0.05$) in the nutritional composition of the quinoa samples. (Quinoa seeds cultivated in Béni mellal E1 and Quinoa seeds cultivated in Settat E2): E1 contains 6.44 % ash, 12.55 % crude fiber, 41.20 g/100 g DW of total sugars, 12.80 g/100 g DW of reducing sugars, 18.91 g/100 g DW of protein and 4.54 g/100 g DW of crude fat. In contrast, E2 has 5.89 % ash, 10.31 % crude fiber, 40.44 g/100 g DW of total sugars, 9.92 g/100 g DW of reducing sugars, 19.13 g/100 g DW of protein and 4.01 g/100 g DW of crude fat.

The crude fiber content in quinoa ranges from 7.0 % to 14.1 % and our results fall within this range (37). Regarding protein content, a variation between 13.81 % and 21.9 % has been reported and our findings are consistent with this range (14). Other studies have observed protein levels ranging from 12.9 % to 16.5 % (38-40). In terms of fat content, although the values obtained in this study are lower than the 6.09 g/100 g DM reported in previous research (41), hey are consistent with the 4.88 g/100 g DM noted in another study (14) and fall within the general range of 4.0 % to 7.6 % (37).

The variability observed in the proximate composition of quinoa remains only partially addressed in the literature (42). These differences are likely attributed to multiple factors, such as genetic diversity among quinoa varieties, the analytical techniques employed and differing environmental conditions (41, 42). Despite these variations, the comparison of physicochemical properties between quinoa cultivated in Béni Mellal and Settat highlights its notable nutritional quality. Rich in dietary fiber, quinoa contributes to natural detoxification by aiding the elimination of toxins and metabolic waste. Furthermore, its substantial protein content makes it a valuable plant-based protein source in human nutrition. Quinoa's protein quality, particularly due to its exceptional amino acid profile, makes it more beneficial than many common vegetables (41, 42). Furthermore, the oil fraction of quinoa seeds, especially rich in linoleic acid, adds to its overall nutritional value.

In addition to its macronutrient composition, quinoa contains a wide range of secondary metabolites, particularly phenolic compounds, which have been linked to various health promoting effects. The following section investigates the phenolic profile of quinoa seeds cultivated in Béni Mellal and Settat.

Phenolic content

Table 3 presents the content of phenolic compounds, including flavones, flavanols and condensed tannins in cultivated quinoa seeds (E1 and E2) from Morocco.

As shown in Table 3, the total polyphenol, flavonoid and condensed tannin contents are expressed, respectively, in mg of gallic acid, rutin and catechin equivalents per 100 g of dry weight (mg GAE/100 g DW, mg RE/100 g DW and mg CE/100 g DW). The results reveal a significant difference between the samples ($p \leq 0.05$).

The amount of phenolic compounds in quinoa seed extracts varies substantially. The highest content was found in E1 (1512.16 ± 9.21 mg GAE/100 g DW), followed by E2 (1433.51 ± 9.21 mg GAE/100 g DW). These values are lower than those reported by a study conducted in Morocco, which found 20.63 ± 0.51 mg GAE/g DW (14). but higher than the results of other studies, which reported 71.7 ± 5.5 mg GAE/100 g DW and 3.75 ± 0.05 mg GAE/g DW, respectively (43, 44). However, these results disagree with those of another study, which reported total phenolic content ranging between 873-994, 410-1152 and 623-1131 mg GAE/100 g DW for red, white and black quinoa, respectively (45). The flavonoid content of E1 (397.78 ± 8.05 (mg RE/100 g DW) are higher than of E2 (310.18 ± 6.33 (mg RE/100 g DW), this result is lower than obtained of (14) search who fond 10.86 ± 1.80 mg RE/g DW. For the tannins there is no significant difference between two quinoa seeds cultivated; we found a 21.14 ± 0.91 (mg CE/100 DW) of E1 and 26.79 ± 1.01 (mg CE/100 DW) of E2. They are present in quinoa seeds in small amounts, So far, there are no data available on the presence of tannins in quinoa seeds (37). Generally speaking, the results found differ from one study to another, this difference could be attributed to the different solvents and extraction procedures used, the reactivity of the Folin-Ciolcateu reagent with other non-phenolic compounds (e.g. vitamins, amino acids and proteins),

Table 2. Physicochemical caracterisation of cultivated quinoa seeds (E1 and E2) from Morocco

	***Quinoa* seeds cultivated in Béni mellal (E1)**	***Quinoa* seeds cultivated in Settat (E2)**
Moisture	9.34 ± 0.71^{b}	11.34 ± 0.14^{a}
Ash	6.44 ± 0.09^{a}	5.89 ± 0.11^{b}
Total fiber	12.55 ± 0.24^{a}	10.31 ± 0.06^{b}
Total sugar	41.20 ± 0.32^{a}	40.44 ± 1.05^{b}
Reducing sugar	12.80 ± 0.49^{a}	9.92 ± 0.27^{b}
Protein	19.13 ± 0.09^{a}	18.91 ± 0.12^{b}
Fat	4.54 ± 0.22^{a}	4.01 ± 0.14^{b}

Moisture (%), ash (%), crude fiber (%), total sugar content (g/100 g DW), total reducing sugar (g/100 g DW), total protein content (g/100 g DW), crude fat (g/100 g DW). The data are presented as Mean ± SD, with all experiments conducted in triplicate ($n = 3$). Statistical analysis was performed using a one-way ANOVA, followed by Tukey's post-hoc test at a 5 % significance level. Means in the same column that are followed by different letters are significantly different ($p < 0.05$).

Table 3. Phenolic compounds, flavone and flavonol and condensed tannins contents in cultivated quinoa seeds (E1 and E2) from Morocco

Extracts	**Phenolic compounds (mg GAE/100 g dw)**	**Flavone and flavonol (mg RE/100 g dw)**	**Condensed tannins (mg CE/100 dw)**
C. quinoa seeds cultivated in Béni mellal	1512.16 ± 9.21^{a}	397.78 ± 8.05^{a}	21.14 ± 0.91^{a}
C. quinoa seeds cultivated in Settat	1433.51 ± 9.21^{b}	310.18 ± 6.33^{b}	26.79 ± 1.01^{a}

*dw: dry weight; GAE: gallic acid equivalents; RE: rutin equivalents; CE: catechin equivalents. Data presented as Mean ± SD and experiments were done in triplicates ($n = 3$). Ordinary one-way ANOVA using post hoc testing (Tukey's test) at the 5 % threshold. Means followed by a different letter in the same column are significantly different ($p < 0.05$).

the climatic conditions of cultivation and genotype (variety and cultivar), as reported by previous studies (41).

In summary, environmental, methodological and genetic factors likely account for the variation in phenolic compound measurements across studies.

Antioxidant capacity and free radical inhibition in quinoa seed cultivated

Table 4 displays the free radical scavenging activity and antioxidant capacity in Chenopodium quinoa seed extracts (E1 and E2).

As shown in Table 4, the results of DPPH scavenging capacity IC_{50} of seeds of quinoa produced in Béni mellal and quinoa seeds cultivated in Settat are 134.81 ± 3.04 and 189.14 ± 2.72 (µg/mL), respectively, these results are higher than ascorbic acid standard 91.33 ± 2.32 (µg/mL) but there are close to this one. It appears from these results that E1 presents significant antioxidant activity compared to that cultivated in Settat. These results are close to those of a previous study, which reported a QM value of 345.89 ± 16.34 µg/mL (14). For the ABTS Scavenging test revealed a notable disparity between the two samples. The values for E1 were 74.36 ± 1.30 (TE µmol/mL) and for E2 were 103.18 ± 0.90 (TE µmol/mL). Both values far exceed the reference of 7.81 ± 0.29 (TE µmol/mL) while maintaining the highest activity for Béni Mellal quinoa (44). Concerning the results of the β-carotene bleaching assay show no significant difference: 112.58 ± 6.71 (µg/mL) for E1 and 115.33 ± 2.19 (µg/mL) for E2. Both the results are higher than the reference BHT 34.98 ± 7.81 (µg/mL), demonstrating high antioxidant activity in both samples. According to this study, the total antioxidant capacity of quinoa seeds cultivated in Béni Mellal was 467.52 ± 3.12 and for those cultivated in Settat, it was 418.24 ± 1.99. Quinoa seeds cultivated in Béni Mellal have shown to have a fair amount of antioxidant capacity.

Moreover, several studies have reported a strong correlation between DPPH radical scavenging activity and the phenolic content in quinoa, supporting the hypothesis that these compounds play a central role in its antioxidant properties (46). This implies that quinoa grown in different geographical regions may exhibit distinct bioactive profiles. These findings underscore the influence of geographic origin on quinoa's phytochemical composition and confirm its relevance as a valuable source of natural antioxidants for nutritional and therapeutic applications.

Conclusion

This study confirms the strong potential of quinoa cultivated in the Béni Mellal region as a nutritious and resilient crop. It demonstrated higher levels of polyphenols, proteins and fibers along with superior antioxidant capacity compared to samples from Settat. These findings highlight its value in strengthening local food systems and promoting agricultural diversification in climate stressed regions. Its successful cultivation under drought-prone conditions positions quinoa as a strategic crop for Morocco and similar environments.

However, further research is needed to explore the long-term agronomic performance and nutritional stability of quinoa under varying environmental stresses, as well as its potential impacts on local biodiversity. Such studies would support the development of optimized cultivation practices and reinforce quinoa's role in sustainable agriculture.

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Authors' contributions

NA conceived the research, designed the study, collected the data and wrote the manuscript. NA, ZH and SL contributed to the concept and design, as well as the data analysis and interpretation. NA, OA and MO participated in the visualization and supervision of the study. NA, MB, FK, KB and KF carried out the critical revision and gave final approval of the article. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflicts of interest related to this article.

Ethical issues: None

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Table 4. Antioxidant capacity and Free radical inhibition in *Chenopodium quinoa* seed extracts (E1 and E2)

Extracts/Reference	DPPH scavenging capacity IC_{50} (µg/mL)	β-Carotene bleaching assay (µg/mL)	ABTS scavenging (TE µmol/mL)	Total antioxidant capacity
C. quinoa seeds cultivated in Béni mellal	134.81 ± 3.04^{b}	112.58 ± 6.71^{b}	74.36 ± 1.30^{b}	467.52 ± 3.12^{a}
C. quinoa seeds cultivated in Settat	189.14 ± 2.72^{c}	115.33 ± 2.19^{b}	103.18 ± 0.90^{c}	418.24 ± 1.99^{b}
Ascorbic acid (AA)	91.33 ± 2.32^{a}	-	7.81 ± 0.29^{a}	-
Butylated hydroxytoluene (BHT)	-	34.98 ± 7.81^{a}	-	-

*Total antioxidant capacity reported as µg ascorbic acid equivalents per milligram of extract. TE: Trolox equivalent. Data presented as Mean ± SD and experiments were done in triplicates (n = 3). Ordinary one-way ANOVA using post hoc testing (Tukey's test) at the 5 % threshold. Means followed by a different letter in the same column are significantly different (p < 0.05).

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