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MAPPING SPATIAL VARIABILITY OF ECOLOGICAL FOOTPRINTS IN OLIVE (*OLEA EUROPAEA* L.) FRUITS, OIL, AND SOILS THROUGH ELEMENTAL PROFILING

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ABSTRACT

This study explored how spatial variation in ecological conditions influences the elemental composition of olive (*Olea europaea* L.) cultivars and their associated soils. Fruits of Leccino, Coratina, Koroneiki, Frantoio, Arbequina, Arbasona, and Suri from Quetta, Loralai, and Khuzdar sites of Balochistan, Pakistan, were collected and analyzed. Twenty-one elements in soil and fruit and six in oil were quantified by CHNS-O and ICP-OES. Soil analysis revealed high Calcium (Ca), Magnesium (Mg), Phosphorus (P), Iron (Fe), Aluminum (Al), Manganese (Mn), Nickel (Ni), Titanium (Ti), and Zirconium (Zr) in Quetta; elevated Carbon (C), Nitrogen (N), Potassium (K), Sodium (Na), and Boron (B) levels in Loralai, and increased Sulfur (S), Copper (Cu), Barium (Ba), Chromium (Cr), Strontium (Sr) and Zinc (Zn) in Khuzdar. In olive fruits, notable findings included high C in Arbequina, Hydrogen (H) in Suri (Loralai), N, Mg, and Ca in Arbequina and Frantoio (Loralai), and K, P and S in Leccino. Olive oil analysis revealed Ca in Arbequina (Quetta), Fe in Coratina (Loralai), K in Leccino (Loralai), Mn in Frantoio (Loralai), and Zn in Koroneiki (Khuzdar). Moderate to high Ca, K, Mg, P, S, Na, B, Mn, Titanium (Ti), and Zn levels in soil may not directly translate to plant uptake, as confirmed by fruit analysis. Essential elements (Ca, K, Mg, P, Cu, Zn, Na, Al, Mn, Fe, Ba, Cr) were within optimal ranges, and non-essential elements Sr and Ti remained within safe limits. Elemental interactions in soil influenced varietal accumulation potential. Among fruits, Arbequina and Suri were notable for elemental accumulation, while Coratina (Loralai) was a mineral-rich oil source with high Ca, Mg, Fe, and Zn. These findings provide baseline data for establishing permissible limits in olives and their products, supporting sustainable agriculture and regulatory guidelines.

Key Words: *Balochistan; Elemental composition; Olive cultivars; Olive fruits and oil; Soil*

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INTRODUCTION

The olive tree, an anciently cultivated fruit-bearing tree, has historically held profound socioeconomic significance. The olive tree, scientifically classified as *Olea europaea* L., subsp. *europaea* is a member of the Oleaceae family. Globally, cultivation spans over 11 million hectares, yielding more than 20 million metric tons of olives annually (Cuevas *et al*., 2019). Its primary cultivation is concentrated in Mediterranean nations such as Spain, Italy, Greece, Tunisia, Turkey, Morocco, Syria, Egypt, and Algeria. Over recent decades, cultivation has extended to regions like the West Coast of the USA, Argentina, Chile, Australia, Peru, and China, establishing these countries as principal contributors to global olive production (Cuevas *et al*., 2010). Aside from being a significant source of olive oils, esteemed for their health-promoting properties as the healthiest form of vegetable fats, the olive tree also yields table oils, renowned as popular condiments for various culinary preparations. Olive fruits are rich in nutrients and minerals and provide essential health benefits, including cardiovascular support, antioxidant protection, and overall wellness. The mineral composition in various plant parts, particularly fruit, is a critical parameter for detecting nutrient deficiencies, excesses, or imbalances in crops. The nutritional condition of fruit trees significantly influences crop yield, as evidenced by research (Casero *et al*., 2004). In the context of olive trees, leaf nutrient analysis is commonly utilized to evaluate the nutritional status of trees, playing a crucial role in determining future fertilization needs (Fernandez-Escobar *et al*., 2006). Scientists have investigated the correlations between minerals and flower bud development in diverse fruit species, including olive trees (Ulger *et al*., 2004). Noteworthy findings from studies on olive trees reveal elevated levels of macro minerals, particularly calcium, and micro minerals, specifically iron. During the differentiation stage (when floral organs form and mature), the levels of Na, Ca, Fe, Mn, Zn, and Cu were the highest. Potassium (K) reached its peak during the induction stage (when vegetative buds begin to convert into reproductive buds), while Phosphorus (P) was highest during the initiation stage (when the first floral structures start to form) (Fabbri & Benelli, 2000). In leaves, the highest concentrations were recorded for N, Ca, Fe, Mn, Zn, and Cu. In fruits, P showed the highest levels, while in nodes, K was the most abundant. The elemental composition of fresh olive fruits is influenced by multiple factors, such as cultivar, geographic location, environmental conditions, packaging materials, agricultural chemicals, production methods, and ripening stages (Fernandez-Hernandez *et al*., 2010; Soares *et al*., 2006). Regarding fruit ripening, researchers observed a non-uniform evolution of mineral elements. K showed consistent increases throughout development and ripening, whereas other minerals exhibited fewer variations, highlighting disparities in the limited studies available (Soyergin *et al*., 2002; Nergiz & Engez, 2000). These differences were attributed to factors such as olive cultivar variations, soil mineral distribution, and environmental conditions prevalent during the sampling periods. There is an increasing focus on investigating mineral element concentrations in fruit trees, driven by their influence on fruit quality and, notably, on olive oil quality (Hidalgo *et al.,* 2018). Studies on various fruit trees, including oranges (Storey & Treeby, 2000), apples (Raese & Drake, 1997), peaches (Tagliavini *et al*., 2000) and mangoes (Nguyen *et al*., 2004) have illustrated correlations between mineral element concentrations and fruit quality. In studies involving olive trees, specific mineral concentrations have been found to correlate with distinct quality parameters. The researchers (Cruz *et al.,* 2016) observed a positive relationship between the levels of nitrogen (N), phosphorus (P), and potassium (K) and the fat content of olives. Meanwhile, the researcher identified associations between fruit weight and the concentrations of phosphorus (P) and boron (B). Conversely, significant negative correlations were observed between fruit weight and fat content with calcium (Ca) and linoleic acid levels, as well as between magnesium (Mg), manganese (Mn), zinc (Zn), and oleic acid levels (Symanowicz *et al*., 2015). Numerous studies have explored the elemental composition of olive fruit, focusing on essential nutrients, trace elements, and potentially harmful substances. Essential nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium are essential for olive tree growth, fruit development, and oil quality. These nutrients are often supplemented through fertilization to maintain optimal levels in the soil and support healthy fruit production. Trace elements such as iron, zinc, copper, manganese, and boron are also vital for olive tree metabolism and overall health (Erel *et al*., 2013). However, excessive accumulation of certain trace elements can lead to toxicity issues and affect fruit quality. Therefore, monitoring trace element levels in both soil and olive fruit is critical for preventing nutritional imbalances and ensuring food safety. Studies have also investigated the presence of potentially harmful elements in olive fruit, such as heavy metals (e.g., cadmium, lead) and metalloids (e.g., arsenic). These elements can originate from soil contamination, irrigation water, or atmospheric deposition, posing risks to human health if present in elevated concentrations (Al-Habahbeh *et al*., 2021). These findings highlighted the critical importance of maintaining optimal nutrition for olive trees. This study was therefore designed to comprehend the mineral composition of olive fruits.

The aim was to evaluate elemental variations in olive fruits, oils, and their associated soil samples collected from three locations with differential ecological characteristics to understand the impact of different modes on fruit and oil quality in terms of elemental composition. The data may further help to explore the total elemental reservoirs of the sampling areas and to identify phytoaccumulation potentials of the olive cultivars under different modes. The outcomes of the present study may also serve as baseline data to select and tailor suitable cultivation sites for olive growth and development with a known yet balanced nutrient supply in nexus to other physicochemical properties.

MATERIALS AND METHODS

Study Sites: The study area includes three distinct locations in Balochistan, Pakistan: Quetta (Balochistan Agricultural Research and Development Center BARDC Quetta), Loralai (Balochistan Agriculture Research Institute BARI, Loralai), and Khuzdar (Balochistan Horticulture Research Institute, Baghbana). Quetta, the provincial capital of Balochistan, Pakistan, lies at an elevation of about 1,680 meters (5,510 feet) and covers an area of roughly 2,653 square kilometers (1,024 square miles). Known for its cool summers and cold winters, Quetta occasionally experiences snowfall during winter. The soil here is primarily loamy, consisting of a blend of sand, silt, and clay. Loralai, located at an elevation of around 1,993 meters (6,539 feet), covers approximately 3,621 square kilometers (1,398 square miles). It features a semi-arid climate with hot summers and cold winters, with sparse rainfall occurring mainly during the monsoon season. The soil here is also loamy, consisting of sand, silt, and clay. Khuzdar, situated at an altitude of approximately 1,237 meters (4,058 feet), spans an area of about 7,295 square kilometers (2,818 square miles). Its climate ranges from arid to semi-arid, characterized by hot summers and mild winters, with rainfall also sporadic and primarily during the monsoon season. The soil in Khuzdar varies but generally includes sandy to loamy textures composed of sand, silt, and clay, often with gravel and rocky outcrops in certain areas.

Soil samples collection and processing: The study areas *viz.,* Quetta (Balochistan Agricultural Research and Development Center BARDC Quetta), Loralai (Balochistan Agriculture Research Institute BARI, Loralai) and Khuzdar (Balochistan Horticulture Research Institute, Baghbana) were subdivided into 5 distinct strata, using the stratified random sampling technique. Soil samples were collected at a depth of 0-10 cm from each stratum using clean scientific tools. Five sampling cores were taken from each stratum at all sites. These samples were then mixed to create representative composite samples for each site. The composite soil samples underwent processing to remove plant debris, stones, and other non-soil materials. Afterwards, they were air-dried at room temperature. To avoid metal contamination, the dried soil samples were passed through a 2 mm diameter plastic sieve. They were then stored in cleaned bottles until further analysis.

Olive fruit collection and processing: Seven olive cultivars - Leccino, Frantoio, Koroneiki, Coratina, Arbosana, Arbequina and Suri were selected from three districts (Quetta, Loralai and Khuzdar) of Balochistan. Fruit samples were carefully gathered from each stratum of every site using a random sampling technique during the last week of October 2023. Approximately 20 samples of each olive cultivar were collected from each stratum of each district. Mature and healthy fruits were hand-plucked and washed thoroughly with tap water and then with distilled water to eliminate any dust or contaminants. After washing, the fruit samples of each variety were mixed to create a representative sample for each site, thus obtaining 7 samples from each district. These samples were promptly oven-dried at 60°C for 48 hours to remove moisture. To prevent metal contamination, the dried fruit samples were manually ground into fine powder using a ceramic pestle and mortar, and stored in clean containers. The laboratory analyses were conducted at the Analytical Chemistry Division, Pakistan Institute of Nuclear Science and Technology (PINSTECH), Islamabad.

Extraction of virgin olive oil: The extraction of virgin olive oil commenced with the harvesting of ripe olives, which were subsequently washed to eliminate extraneous materials. The olives were then subjected to crushing, producing a paste that underwent malaxation to facilitate the coalescence of oil droplets. Following this, the oil was separated from the solid residue and aqueous phase using centrifuge methods. The extracted oil was filtered to improve clarity and was stored in dark containers to safeguard against photodegradation and oxidative deterioration.

Organic elemental profiling of soil and olive fruit samples via CHNS-O analyzer: Organic elements such as C, H and N, were analyzed using a CHNS-O analyzer (Flash 2000, Thermo Scientific). Each sample, weighing 10 mg, was placed in tin capsules and subjected to complete oxidation at 950°C, producing elemental gases (CO_2, H_2O, N_2, and SO_2). Throughout the process, excess oxygen was carefully regulated. The resulting combustion products were homogenized mechanically in a controlled gas environment and separated using a gas chromatographic column. Eluted gases were then passed through a thermal conductivity detector to quantify the amounts of N, H, and C present. High-purity helium and oxygen (99.99%) served as carrier gases and for oxidation, ensuring precise analysis of the elemental composition of the samples.

Elemental profiling of soil, olive fruits and oil samples via ICP-OES: Soil samples (1g) were digested using concentrated HNO_3 and HCl (aqua regia) on a hotplate at 120–150°C until clear solutions were obtained. The digested samples were diluted to a known volume (50 mL) with deionized water and filtered to remove particulates. Olive Fruit samples (2 g each) were placed into platinum crucibles and dried to a constant weight in a conventional oven at 80°C. The dried samples were then finely ground using an agate mortar and pestle. Subsequent digestion and mineralization were performed in closed Teflon tubes utilizing sub-boiling grade HNO_3 and 30% (V/V) ultrapure H_2O_2 at a temperature of 220°C for 8 hours. The mineralized samples were quantitatively transferred to 10 mL volumetric flasks, with the final volume adjusted to 2% (V/V) HNO_3 in ultrapure water, followed by filtration through 0.45 µm pore filters. Whereas olive oil samples (1 g) were also digested with concentrated HNO_3 (5 mL) and H_2O_2 (2 mL) using a microwave digestion system at 180–200°C for 20 minutes. The digested samples were diluted to 25–50 mL with distilled water and filtered through a 0.45 µm membrane. Elemental concentrations were analyzed using an Agilent 7500cx inductively coupled plasma optical emission spectrometer (ICP-OES) (PerkinElmer, USA), adhering to previously established analytical protocols. All ICP-OES measurements employed the element's internal standards, and a comprehensive quantitative analysis was conducted against calibration standards for each respective element.

Statistical analysis: The data for soil, olive fruits, and olive oil samples from selected cultivars were analyzed in triplicates. Statistix 8 software was applied to analyze the data. Normality of data was confirmed using the Shapiro Wilk test on residuals and homogeneity of variance was verified via residual plots (no funnel) and variance ratio (< 4 for macro nutrients and < 10 for trace elements). Two-way ANOVA was employed to examine the effects of cultivar and growing location as fixed factors. Mean differences were compared using the Tukey test at 5% probability level ($P < 0.05$). The following mathematical model was assumed for the analysis $Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \epsilon_{ijk}$. where Y_{ijk} = observed value of the dependent variable, μ = overall mean, A_i = effect of the cultivar, B_j = effect of the location, AB_{ij} = interaction effect between cultivar and location, ϵ_{ijk} = random error term associated with each observation

RESULTS AND DISCUSSION

The earth is a reservoir of 92 elements, with approximately 82 elements being accessible to many plant species (Reimann *et al*., 2001). Edaphic and ecological factors influence the availability of elements to plants, thereby depicting variation even among the same species growing under different environmental conditions. In this study, Fruits and oil samples of seven olive cultivars (Leccino, Coratina, Koroneiki, Frantoio, Arbequina, Arbasona, and Suri) and their associated soil samples were examined exclusively for their elemental composition (21 elements were quantified in soil samples, 21 in olive fruit samples, and 6 in olive oil samples) collected from Quetta, Loralai and Khuzdar districts of Balochistan. The study revealed significant variation in elemental concentrations in three districts, as well as among different olive cultivars.

Elemental composition of Soil collected from study sites: In this study, the elemental composition of soil samples was categorized into several groups. Organic elements included Carbon (C), Hydrogen (H), and Nitrogen (N), while macronutrients consisted of Calcium (Ca), Potassium (K), Magnesium (Mg), Phosphorus (P), and Sulfur (S). Beneficial elements comprised Aluminum (Al) and Sodium (Na), and micronutrients included Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni), and Zinc (Zn). Trace elements analyzed were Barium (Ba), Chromium (Cr), Strontium (Sr), Titanium (Ti), and Zirconium (Zr). The concentrations of various components in soil samples from three locations Quetta, Loralai, and Khuzdar are presented in Table 2. The data indicated notable variations in elemental concentrations across the collection sites. The variations in soil element concentrations among Quetta, Loralai, and Khuzdar highlighted the influence of local geological and environmental factors on soil elemental reservoirs.

Organic Elements: Carbon (C) plays a vital role in the soil by improving its structure, water-holding capacity, and nutrient availability (Gomez *et al*., 2022). In this study soil carbon levels varied across the three sites. Loralai exhibited the highest percentage (5.40%) and Khuzdar the lowest (4.45%). The relatively high carbon content in these soils might reflect the carbon sequestration potential of olive orchards which contributed organic matter over time (Torrús-Castillo *et al*., 2023). Hydrogen (H) an essential element was below detectable limits in all sites. This might be because it exists in forms not easily measured by standard analytical methods. Nitrogen (N) is a vital nutrient that supports plant growth through its role in protein and nucleic acid synthesis. In the present study soil nitrogen levels varied among the three sites. Quetta exhibited the lowest N concentration (0.32%) which might restrict olive growth and fruit yield. This indicated a need for additional fertilization to support the nutrient needs of olive trees (Ferreira *et al*., 2020). Loralai recorded a moderate level (0.37%) and Khuzdar exhibited the highest N content (0.40%). Both locations reflected favorable soil conditions for vigorous growth and productivity (Rodrigues *et al*., 2019). The balanced carbon-to-nitrogen (C: N) ratio was observed in Loralai soils. The enhanced C and N levels supports efficient nutrient cycling.

Macro elements: Soil nutrient analysis revealed notable spatial variations among the three study sites. Calcium (Ca) concentrations were highest in Quetta (157720 µg/g), followed by Loralai (140186 µg/g) and Khuzdar (122632 µg/g)). This suggested differences in soil mineral reserves which influence nutrient management strategies. Potassium (K) levels showed the opposite trend, with Loralai recording the highest concentration (13,185 µg/g) might be due to soil type, land use, and fertilizer application patterns. Magnesium (Mg) concentrations were relatively similar across sites but remained highest (15,240 µg/g) in Quetta. This reflected its geological composition and greater nutrient retention capacity. Phosphorus (P) levels were also elevated (15,240 µg/g) in Quetta. This indicated potential enrichment from soil composition and past fertilization practices. Sulfur (S) concentrations varied notably across the sites. Khuzdar showed the highest levels (613.0 µg/g), followed by Loralai (472.0 µg/g) and Quetta (284.0 µg/g). The elevated S in Khuzdar reflected differences in soil composition and farming practices that enhanced sulfur availability. The lower levels in Quetta suggested limited sulfur retention and possible nutrient depletion. The assessment of key macronutrients (Ca, K, Mg, P, and S) indicated that soils across the study areas showed optimal nutrient supply capacity and may serve as a bioavailable reserve of elements to plants over time.

Beneficial elements: The soil analysis showed noticeable differences in aluminum (Al) levels among the three sites. Quetta had the highest Al concentration (69,13 µg/g**)**, followed closely by Loralai **(**68,67 µg/g**)**, while Khuzdar had the lowest (59,84 µg/g**)**. The overall Al content was not high enough to cause toxicity, since excess Al can restrict root development and nutrient absorption. Sodium (Na) levels also varied, with Loralai showing the highest concentration (8,332.00 µg/g). Quetta and Khuzdar also showed fairly high Na levels. This suggested that all sites support conditions where sodium is naturally present. Sodium is beneficial for maintaining soil balance and plant water regulation but its high level may pose risks if sodium adsorption ratios increase beyond safe limits.

Microelements: Boron (B) levels varied widely among the sites. Loralai exhibited the highest level (11,119 µg/g) possibly due to saline-alkaline soil conditions that might influence plant growth and necessitate careful nutrient management. Copper (Cu) concentrations rose gradually from Quetta (23.55 µg/g) to Khuzdar (31.38 µg/g) reflecting regional variations in soil composition. Cu is vital for plant metabolism but excessive amounts could lead to toxicity. Iron (Fe) was most abundant in Quetta (27,760 µg/g), suggesting mineral-rich soils though its bioavailability might depend on soil pH and organic matter. Manganese (Mn) concentrations showed a mild decline from Quetta (609 µg/g) to Khuzdar (526 µg/g), which could affect plant enzymatic activity. Nickel (Ni) levels were relatively low and consistent across sites. This indicated limited toxicity risk. Zinc (Zn) concentrations were highest (125.00 µg/g) in Khuzdar and lowest (73.92 µg/g) in Quetta. This might be due to soil type, land use history, and agricultural input, underscoring the key role of zinc as an essential micronutrient for plant health and productivity.

Trace elements: Barium (Ba) concentrations were comparable among sites, with slightly higher levels in Khuzdar (523 µg/g). This indicated minor geological variation without environmental concern. Strontium (Sr) showed an increasing trend from Quetta (483 µg/g) to Khuzdar (1017 µg/g) This suggested regional differences affect soil chemistry and plant uptake. Titanium (Ti) remained relatively uniform across sites which reflect stable geological conditions. Zirconium (Zr) levels varied slightly. This might be due to differences in parent material and land use among the study regions. Only the exchangeable fraction of soil minerals is available for plant uptake which influence growth, yield, and oil quality. In this study total mineral concentrations were assessed to evaluate long-term nutrient reserves and soil mineral status. Soils exhibited moderate to high total levels of Ca, K, Mg, P, S, Na, B, Mn, Ti, and Zn across all sites. The results provided insights into potential nutrient release, contamination risks, and the phytoaccumulation capacity of olive cultivars under soil conditions of Balochistan.

Elemental analysis of Olive fruit: The elemental profiling of all seven olive cultivars revealed the presence of C, Ca, H, K, Mg, N, P, S, B, Cu, Fe, Mn, Ni, Zn, Al, Na, Ba, Cr, Sr, Ti, and Zr. These findings underscore the importance of all olive cultivars in all three districts of Balochistan. Overall, the results demonstrated significant variations in the concentrations of all studied elements in the fruits of all seven olive cultivars (Table 3).

Organic Elements: The critical role of carbon (C) assimilation in plant growth is underscored by its central function in photosynthesis. The carbon content in olive fruits exhibited notable differences across varieties and collection areas. Arbequina grown in Quetta showed the highest C content (90.21%), suggesting optimal nutrient uptake and fruit quality, likely supported by favorable environmental and soil conditions (Torrús-Castillo *et al*., 2023). Suri grown in Khuzdar displayed the lowest C content (53.01%), indicating potential stress or nutrient deficiency which might affect fruit development or quality (Conde *et al*., 2008). Higher soil C concentrations coincided with optimal C supply in the fruit. Hydrogen (H) is another important element crucial for various biochemical processes, and its absence may hinder nutrient uptake (Tzika *et al.,* 2008). Despite the lack of H in the soil, the hydrogen content in the olive fruits from different varieties showed notable variability. Suri grown in Loralai exhibited the highest H content (18.22%), suggesting that other soil or environmental factors might influence its uptake, potentially leading to enhanced fruit quality (Mousavi *et al*., 2022). Frantoio in Quetta showed the lowest H content (12.72 %), which might reflect limited nutrient uptake due to suboptimal growing conditions (Casademont *et al*., 2018). The variations in H content among different olive varieties indicated that certain varieties could adapt better to low soil H conditions. For example, Leccino and Koroneiki showed consistent H levels across different locations, indicating resilience in nutrient uptake (Eroglu, 2004). Nitrogen (N) is the most vital element due to its fundamental role as a major constituent of nearly all amino acids, coenzymes and proteins. Arbequina grown in Loralai had the highest N content (1.81%), indicating excellent nutrient uptake and fruit quality. Frantoio from Quetta showed the lowest nitrogen content (0.70 %), which might reflect the limited nitrogen availability in that area and could lead to reduced fruit quality (Fernandez-Escobar, 2011). The results indicated a clear correlation between soil N levels and the nitrogen content in olive fruits. Olive varieties grown in Khuzdar, where N availability is greatest, show consistently higher N content. Overall data highlighted Arbequina as a significant variety with a strong affinity for C and N accumulation.

Macro elements: Calcium (Ca) plays a vital role in plant physiology, contributing to membrane stability and numerous metabolic processes. The study revealed that both cultivar type and geographical location significantly affected Ca concentrations in olive fruits. Frantoio stood out as the most calcium-rich cultivar across all locations, particularly in Loralai (3057.0 µg/g). This adaptability might be due to specific soil and climatic conditions that favor mineral accumulation (Fernandez-Hernandez *et al*., 2010). Leccino and Arbequina displayed substantial variability, especially in Loralai, indicating potential stress factors or differences in nutrient uptake efficiency (Ataollahi Eshkour *et al*., 2023). The lowest Ca concentrations were observed in the Loralai site, suggesting some limitations in the phytoaccumulation capacity of the cultivar under certain physicochemical properties of the soil of that particular site. Koroneiki exhibited higher Ca levels in Khuzdar, indicating its unique genetic traits that might enhance nutrient accumulation potential under local soil conditions (Manolikaki *et al*., 2022). A general trend of decreasing Ca levels from Quetta to Loralai and Khuzdar was noted for most cultivars. This trend might reflect differences in soil composition, climatic factors, or agricultural practices between the regions, emphasizing the importance of site selection in olive cultivation (Chatzistathis *et al*., 2010; Ataollahi Eshkour *et al*., 2023). Potassium (K) is vital for plant growth because it regulates enzyme activation, water uptake, nutrient transport, and stress resilience, thus promoting optimal health and productivity. The analysis revealed significant K-level variability across olive cultivars and locations (Table 3). The highest K concentration was observed in the Leccino cultivar from Loralai (29543 µg/g), while the lowest was noted in the Koroneiki cultivar collected from Quetta (15328 µg/g). The cultivars Leccino, Frantoio, Coratina and Arbequina exhibited consistent K levels across all three locations (Table 3). This suggested their adaptability and accumulation potential under varying levels of total K content in soil. This finding was consistent with previous research highlighting the genetic variability among olive cultivars in nutrient uptake (Haberman *et al*., 2019; Rosati *et al*., 2015. The results were aligned with findings by Erel *et al.*, (2008) and Ibrahimi & Gaddas, (2015) which emphasized the importance of selecting appropriate cultivars based on soil nutrient profiles to optimize yield. Magnesium (Mg) is essential for olive plants as a key component of chlorophyll and for enzyme activation and nutrient uptake. Results showed significant variation in Mg levels among cultivars and locations (Table 3). The highest Mg concentration was founded in Arbequina at Loralai (753.0 µg/g), while the lowest was in Suri at Loralai (307.0 µg/g). Arbequina's high Mg content suggested strong adaptability and efficient nutrient uptake. This aligned with findings from Chatzistathis *et al*., (2010), indicating that certain cultivars demonstrate enhanced nutrient uptake capabilities, which might contribute to better growth and yield. In contrast, Suri's low Mg levels indicated possible nutrient deficiency. This is consistent with studies by Marcelo *et al.,* (2002), which emphasized the importance of cultivar selection based on nutrient profiles to ensure optimal growth conditions Overall, the study highlighted that location significantly influences Mg availability, emphasizing the need for site-specific agronomic practices to enhance nutrient availability in less fertile locations (Stateras & Moustakas, 2017). Phosphorus (P) is crucial for olive plants as it supports energy transfer, root development, and the synthesis of nucleic acids and ATP, promoting overall plant vigor and productivity. The highest P content was observed in the Leccino (2372 µg/g) cultivar at the Loralai site, while the lowest was found in the Suri (415 µg/g) cultivar at the Quetta site. Despite Quetta having the highest soil P concentration, the P content in olive fruits across the seven cultivars did not significantly differ from those grown in Loralai and Khuzdar. These results suggested that total P levels might not directly translate into P accumulation in the olive fruits however it's the exchangeable elemental percentages available to plant roots. Research indicated that different olive varieties exhibited distinct root systems and nutrient absorption capabilities, which could influence their ability to assimilate P from the soil (Iqbal *et al*., 2022). Additionally, pH and organic matter, could also affect P availability and uptake. It is possible that the higher P levels in Quetta's soil did not sufficiently enhance fruit P concentrations due to competing nutrient interactions or suboptimal soil conditions affecting root health (Chatzistathis *et al*., 2020). Moreover, the physiological state of the olive trees and environmental stresses might also play a critical role in nutrient uptake efficiency. Even with adequate soil nutrients, drought or disease could hinder the plant's ability to absorb certain elements effectively (Erel *et al.,* 2008; Silva *et al*., 2023). Sulfur (S), as a macronutrient, is a key component of amino acids such as methionine, cysteine, and cystine, and is essential for the normal growth and development of plants. The data indicated a clear trend in S availability between the three study locations. Khuzdar, with the highest soil sulfur concentration (613.0 µg/g), also produced the highest S content in the olive varieties, notably in Leccino (910.0 µg/g) and Arbequina (623.0 µg/g). This suggested a positive correlation between available S levels in soil and S accumulation in olive fruits. Conversely, Quetta, which had the lowest S concentration in soil (284.0 µg/g), exhibited an optimal S content in olive fruits across most varieties, with Suri yielding 332.0 µg/g (Table 3). This finding aligned with previous research indicating that soil nutrient levels might impact nutrient uptake by plants ultimately affecting crop quality and yield (Danyaei *et al*., 2017). Loralai showed intermediate results, with moderate to high sulfur (S) concentrations in both soil and olive fruits. While adequate S is essential for growth and enzyme activity, excessive amounts may negatively affect fruit quality and metabolic balance, possibly due to local environmental conditions (Marcelic *et al*., 2022). Overall, macro minerals such as Ca, K, Mg, and P were present at optimal levels across all cultivars and locations, indicating that the selected olive varieties are nutrient-rich. However, higher S levels in Khuzdar and Loralai suggest increased S uptake from soils with higher exchangeable S content. These findings emphasize the need for regular soil nutrient monitoring to maintain optimal fruit quality and yield across regions.

Beneficial Elements: Sodium (Na) a micronutrient can play a role in certain physiological processes, such as maintaining osmotic balance and influencing enzyme activity. The Leccino variety demonstrated the highest Na concentration in Quetta (2355.0 µg/g) but a significant drop in Loralai (211.0 µg/g) (Table 3). This variation suggested a strong dependence on soil Na levels and might indicate adaptive responses to localized soil conditions (Chartzoulakis, 2005). Frantoio exhibited a pronounced increase in Na concentration in Loralai (2437.0 µg/g), highlighting potential soil salinity issues in that area. The significantly lower concentration in Khuzdar (410.0 µg/g) indicated environmental factors influencing ion uptake (Benlloch *et al*., 1994). Koroneiki results showed substantial Na concentrations across all locations, suggesting the variety's high sensitivity to soil salinity levels, which could affect overall growth and fruit quality (Fernandez-Hernandez *et al*., 2010; Vanderlinden *et al*., 2022). Coratina demonstrated very low Na levels in Loralai (17.07 µg/g), which could indicate the variety's ability to thrive in lower salinity conditions. In contrast, Arbequina showed moderate concentrations across locations, suggesting a balanced ion uptake strategy (Cresti *et al*., 1994). Suri had high Na concentrations in Quetta (2334.0 µg/g) and a moderate level in Khuzdar (1942.0 µg/g), which might have indicated a tolerance mechanism or a reliance on specific soil characteristics that promote Na absorption. Aluminum (Al) can be important for olive plants in low concentrations as it may enhance root growth and nutrient uptake, although its role and optimal levels are not fully understood. Leccino showed a higher uptake of Al in Loralai (28.50 µg/g) compared to Quetta and Khuzdar sites, indicating potential soil-plant interaction variability in Al absorption. The Frantoio demonstrated the lowest concentrations of Al across all locations, with a notable absence in Khuzdar, suggesting lower susceptibility to Al toxicity, likely due to genetic factors and soil conditions (Luka & Akun, 2019). In Loralai, Koroneiki had an exceptionally low Al concentration (0.96 µg/g), which might indicate a specific adaptation to the local soil conditions, resulting in reduced Al uptake. Selected olive varieties showed elevated levels of Al in Quetta, particularly Coratina with 28.85 µg/g, and Arbequina with 29.63 µg/g. This suggested that these varieties might be more sensitive to higher soil Al concentrations, which could affect their growth and fruit quality (Sahan & Basoglu, 2008). Overall, Quetta consistently produced higher Al concentrations in olive fruits across most varieties, correlating with the soil Al content. This emphasized the importance of monitoring soil conditions in agricultural practices, particularly in areas with known high Al levels, as it directly affects plant health and fruit quality (Silva *et al.*, 2023).

Microelements: Boron (B) is vital for olive plants because it facilitates cell wall formation, aids in reproductive development, and enhances nutrient uptake, all of which are critical for optimal growth and fruit production. In the present study, total soil B levels were very high in the Loralai region indicating an excess availability to the vegetation but olive fruits collected from all seven cultivars showed an optimal range of B (29.44 to 16.25 µg/g) which might be attributed to lower available B ratios in soil or may be due to selective transport mechanism of plant root. This suggested that exchangeable soil B levels might influence the plant's nutrient absorption capacity (Tsadilas *et al*., 1994), which is crucial for overall growth and fruit quality (Vera-Maldonado *et al*., 2024). Among all other cultivars across all selected sites, Koroneiki exhibited the highest B levels in Quetta (37.87 µg/g). This suggested that Koroneiki under certain physicochemical environments might thrive better in soils with higher B availability, impacting overall health and yield (Arrobas *et al*., 2023). Further results highlighted a consistency in B levels in Leccino, Arbequina, Arbosana and Suri across all three selected sites (Table 3). This could indicate adaptability or nutrient accumulation capacity to varying soil B levels, essential for sustaining growth in diverse environment (Delgado *et al*., 1994). The overall data also suggested a potential resilience of different cultivars to varying B availability, imperative for maintaining consistent fruit production across locations (Ferreira *et al*., 2019). Copper (Cu) is involved in numerous photosynthetic enzymes in plants, yet its precise function remains unclear. Cu is an essential micronutrient for plants but can become toxic at high concentrations (Soares *et al*., 2006). The study identified varying concentrations of Cu in soils across three different areas. These findings suggested spatial variability in Cu concentrations, influenced by agricultural practices and natural soil composition (Gürel & Başar, 2014). The data on olive fruits collected from three selected sites also demonstrated differential uptake and distribution patterns among cultivars. Three cultivars viz., Frantoio, Arbequina and Suri showed consistency in Cu accumulation highlighting genetic differences in Cu uptake and accumulation mechanisms among olive cultivars. In addition, several other factors were identified as influencing Cu uptake in olive trees, including soil pH, organic matter content, and the physiological characteristics of each cultivar. Higher soil pH generally decreases Cu availability for plant uptake, while organic matter can bind with copper ions, reducing bioavailability. Cultivar-specific traits such as root morphology and metal transporters also play crucial roles in Cu uptake and accumulation (Yucel & Kılıcoglu, 2019). Iron (Fe) is another essential micronutrient critical for various metabolic processes in plants, including photosynthesis and respiration. The data in the present study revealed significant variability Iron (Fe) levels across different olive cultivars and locations (Table 3). The highest Fe concentration was observed in the Arbequina cultivar at Khuzdar (32.57 µg/g), while the lowest was noted in the Frantoio cultivar at Quetta (1.45 µg/g). Among all cultivars Arbosana and Suri showed a consistent Fe accumulation across all three sites. The Arbequina cultivar also consistently exhibited the highest Fe levels (32.57 µg/g, 20.87 µg/g and 17.13 µg/g) across all three locations (Table 3), suggesting their adaptability and ability to accumulate available Fe content regardless of its total levels in soils of the selected site. This finding was in line with previous research highlighting the genetic variability among olive cultivars in nutrient uptake (Chatzistathis *et al.*, 2017; Chatzistathis *et al*., 2010). Conversely, Fe was not detected in the Leccino from Quetta, Frantoio from Loralai and Khuzdar Koroneiki cultivar from Khuzdar, indicating potential deficiencies in its growth environment. This aligned with findings by Nedjimi, (2020) that the majority of nutrient elements taken up by the plants reached the fruits, except for Fe and Mn which were retained in leaves. Manganese (Mn) plays several crucial roles in the plant growth and development of olive trees. Mn is essential for activating several enzymes involved in photosynthesis, respiration, and nitrogen metabolism. It participates in antioxidant reactions, helping plants to cope with oxidative stress caused by environmental factors such as drought, light intensity etc. In olive trees specifically, Mn deficiency can manifest as chlorosis (yellowing of leaves), reduced growth, and overall poor vigor. On the other hand, excess Mn can be toxic and lead to physiological disorders (Vidovic *et al*., 2021). From the data obtained among cultivars, a consistent pattern in Mn accumulation was observed in cultivars such as Leccino, Frantoio, Arbequina, Arbosana and Suri across all three sites. Whereas the maximum level of Mn content was found in Coratina (7.32 µg/g) from Loralai whereas the minimum level was also detected in fruit samples of Suri (2.87 µg/g) from Loralai (Table 3). This difference in accumulation potential of different cultivars growing in similar edaphic conditions or the same cultivars growing in different edaphic conditions manifest the expression of genes related to nutrient uptake and metabolism can lead to differences in Mn accumulation among cultivars or different cultivars might exhibit varying efficiencies in absorbing Mn ions from the soil. These results were in agreement with the Mn concentration range previously reported (Sabouni, 2023; Manolikaki *et al*., 2022; Bonyanpour *et al*., 2017). Nickel (Ni) is acknowledged as the seventeenth essential micronutrient for plant growth and development. Ni serves as a critical micronutrient for plants, particularly in the activation of the urease enzyme, which is vital for nitrogen metabolism. Nonetheless, its dual character implies that while small amounts can be advantageous, elevated concentrations can prove harmful (Aghabarati *et al*., 2008). Comparatively higher Ni concentrations (0.88 µg/g) were observed in Arbequina from Quetta while the lowest concentration (0.44 µg/g) was recorded in Frantoio from Khuzdar (Table 3). Despite the high Ni content in associated soils, Ni was detected in low concentrations in all selected olive cultivars in the optimal range to support olive fruit quality, suggesting that the nutrient uptake is regulated by the plant's mineral accumulation mechanisms under varying environmental and edaphic factors. These results were in agreement with the Ni concentration range previously reported (Khan *et al*., 2015; Yucel & Kılıçoglu, 2019). Zinc (Zn) is crucial for olive plants as it supports enzyme function, aids protein synthesis, and promotes proper growth and development. Variations in Zn accumulation across olive varieties were evident, highlighting the influence of the phytoaccumulation potential of olive cultivars along with the bioavailability of Zn under different environmental and edaphic conditions. Optimal levels of Zn in almost all selected cultivars from the Quetta site along with Arbequina exhibited the highest Zn levels (14.10 µg/g), proposed genetic predisposition of cultivars and bioavailability of Zn under favorable soil conditions (Zipori *et al*., 2018). Suri variety consistently showed lower Zn accumulation across all three sites, indicating limited phytoaccumulation potential of cultivar under certain edaphic or environmental conditions hindering Zn absorption (Fernandez-Escobar, 2019). The observed differences in Zn concentrations among olive varieties underscore the importance of genetic diversity and environmental and edaphic factors in determining nutrient uptake and accumulation. Varieties with optimal Zn content may offer enhanced nutritional benefits, particularly in regions with adequate soil zinc availability (Ramezani & Shekafandeh, 2012). The significant variability in Zn concentrations across areas highlighted the need for localized agricultural practices to optimize nutrient uptake and ensure consistent fruit quality. Understanding these dynamics could inform agricultural strategies aimed at enhancing the nutritional value of olive products.

Trace elements: Barium (Ba) is considered as 14th most abundant element in the earth's crust, which is typically found in the soil in different concentrations. The concentration of Ba present in the soil of three distinct areas could be attributed to natural geological formations or anthropogenic activities specific to each location

(Cappuyns, 2018). Despite the highest Ba levels in the Khuzdar site, the accumulation in all selected cultivars in that region was low, highlighting the lower levels of Ba bioavailability in soil. Other olive cultivars, also showed a low concentration of Ba across the other two selected sites. The highest concentration (2.17 µg/g) was observed in Frantoio grown in Quetta and the lowest (0.55 µg/g) in Suri grown in Loralai (Table 3). This finding suggested that olive trees in these regions accumulated a low concentration of Ba from the soil into their fruits. The low concentration in olive fruits aligned with previous studies (Nasr *et al*., 2021; (Nergiz & Engez, 2000). Chromium (Cr) contamination in soil is a significant environmental concern due to its toxic effects on plants and potential risks to human health through food chain contamination. The previous findings indicated localized variability in Cr contamination, influenced by regional industrial activities and soil management practices (Gurel & Başar, 2014). Seven selected olive cultivars were analyzed for Cr accumulation in their fruits and Cr was not detected in many varieties of olive fruits grown in these three areas and those with Cr accumulation depicted a very low concentration such as Koroneiki, Coratina, Arbequina, Arbosana and Suri (Table 3). This finding suggested that olive trees in these regions did not accumulate Cr from the soil into their fruits or had low levels. The absence and low concentration of Cr in olive fruits aligned with the previous studies (Aghabarati *et al*., 2008). Higher soil pH generally correlated with increased Cr availability for plant uptake, while organic matter acted as a buffer, reducing bioavailability (Blazquez *et al*., 2009). Cultivar-specific traits such as root morphology and ion transport mechanisms also played crucial roles in Cr accumulation. Strontium (Sr) is quite common in nature it is the 15th most abundant element in Earth's crust. Sr is primarily taken up and stored in the cell wall, with more than 50% accumulating there. Once inside the cell, Sr can substitute Ca, disrupting cellular function. Consequently, elevated concentrations of strontium adversely affect plant growth. Among the different olive cultivars studied, significant variation in Sr concentrations was observed. The highest concentration of Sr (76.0 µg/g) was found in the Arbequina cultivar grown in Khuzdar, while the lowest concentration (12.22 µg/g) was detected in the Leccino cultivar grown in Loralai (Table 3). These findings underscored the impact of both geographical location and cultivar type on Sr accumulation in olive plants. The higher Sr concentrations observed in Khuzdar could reflect the elevated Sr levels in the local soil, potentially influenced by geological factors or human activities specific to that region. Conversely, lower concentrations in other areas might indicate different soil compositions or management practices affecting Sr availability (Nasr *et al*., 2022; Techer *et al.,* 2017). Titanium (Ti) is recognized as a valuable element that promotes plant growth (Lyu *et al.*, 2017). The indicated variations in Ti content across different geographical locations could be attributed to natural geological formations or anthropogenic activities specific to each location (Damak *et al*., 2021). In contrast, Ti was not detected in many varieties of olive fruits grown in these three areas. Very low concentrations of Ti were observed in Koroneiki, Coratina, Arbequina, Arbosana and Suri of these three areas (Table 3). The absence and low concentration of Ti in olive fruits aligned with previous studies (Pucci *et al*., 2022). The Zirconium (Zr) was not detected in any variety of olive fruits grown in these three areas (Table 5). This finding suggested that olive trees in these regions do not accumulate Zr from the soil into their fruits, or the levels are below detectable limits for the analytical methods employed. The absence or low concentration of Zr in olive fruits aligns with previous studies (Pucci *et al*., 2022; López-López *et al*., 2008). The analysis of beneficial, micro, and trace elements in seven olive cultivars from three locations showed that these olives are rich in essential minerals such as Cu, Zn, Na, Al, Mn, Fe, Ba, and Cr, all within optimal ranges, while non-essential elements like Sr and Ti remained within safe limits. Among all cultivars, Arbequina and Suri stood out for their strong ability to accumulate minerals across sites. The study concluded that the mineral content in olive fruits is not solely determined by total soil element levels, but rather by the bioavailability of nutrients in the soil and each cultivar's capacity to absorb and store them.

Elemental Analysis of olive oil: Analysis of essential elements in olive oil is inevitable to understand the nutritional benefits and quality of different cultivars. This study aimed to quantify the concentrations of some important elements viz., calcium (Ca), potassium (K), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn) in oil samples of seven selected olive cultivars grown across three distinct study sites viz., Quetta, Loralai and Khuzdar of Balochistan. The overall data analysis showed significant differences ($P < 0.05$) in elemental concentrations among olive cultivars and locations (Table 4). Among some important essential elements, calcium (Ca) may enhance olive oil's nutritional value, supports bone health, and influence the oil's stability and flavor. The data showed significant variability in Ca content among oil samples of olive cultivars collected from three study sites. A Ca content in oil samples in the range of 9.96-2.15mg/L in Quetta, 9.00-4.27mg/L in Loralai and 9.01-4.03 in Khuzdar cultivars were quantified. Suri cultivar exhibited a constant and high Ca concentration in oil samples across all three selected sites, Arbequina also demonstrated relatively high levels with location variation indicating a strong binding affinity of Ca to lipophilic compounds. These findings underscored the impact of genetic and environmental factors on Ca content, suggesting that

Table 1: Meteorological data of collection sites viz., Quetta (Q), Loralai (L), Khuzdar (K) for the years 2022 and 2023

Months	AREA	2022					2023				
		Temperature			Rainfall	Humidity	Temperature			Rainfall	Humidity
		Max	Min	Average	Total mean (mm)	Total mean (%)	Max	Min	Average	Total mean (mm)	Total mean (%)
JAN	Q	9	1	4	75.1	63	6	-2	1	16.4	53
	L	20	11	15	0	41	21	9	14	0.7	20
	K	15	4	9	59.6	45	14	2	7	2.3	35
FAB	Q	14	3	8	2.7	41	17	6	11	2.3	35
	L	27	14	20	0	23	30	16	22	0.1	17
	K	20	7	13	4.5	28	23	9	16	0.18	25
MAR	Q	23	11	16	4.1	31	19	8	13	24.99	45
	L	36	22	29	4.2	20	33	22	27	30.2	29
	K	29	14	21	5	22	24	13	18	8.67	36
APR	Q	29	16	22	0.3	14	24	11	17	24.2	30
	L	43	34	25	0.3	7	37	23	30	4.5	19
	K	34	18	26	2.2	13	28	15	22	14.45	25
MAY	Q	32	19	25	0.1	13	30	17	23	6.2	22
	L	46	29	38	1.8	8	41	27	35	22.1	18
	K	37	22	29	0.5	12	35	20	27	29.4	23
JUN	Q	35	20	27	0	18	36	20	27	1.1	29
	L	45	30	38	6.5	20	44	32	38	4.5	28
	K	38	22	30	6.2	23	38	23	30	73.15	35
JULY	Q	32	22	26	72.3	52	35	21	28	36.4	38
	L	38	31	34	123.32	47	41	32	37	137.2	38
	K	31	23	26	178.08	60	35	24	29	99.3	44
AUGUST	Q	29	19	23	254.92	53	34	22	28	0	20
	L	35	29	32	281.61	54	43	32	37	0.6	30
	K	28	21	24	231.7	62	37	23	30	4	27
SEPTEM	Q	30	18	23	0	24	30	17	23	0	20
	L	29	28	33	0.6	34	42	31	36	5.24	24
	K	33	20	26	2.6	36	35	21	27	0.9	27
OCTO	Q	25	12	18	0	16	24	12	17	4.57	25
	L	36	22	29	0	16	37	25	31	0.18	18
	K	30	14	22	0	19	30	17	23	4.88	24
NOV	Q	17	7	12	3	34	17	8	12	18.47	37
	L	30	17	23	2.9	22	30	20	25	0.84	22
	K	23	11	17	8	28	21	12	17	0.62	29
DEC	Q	12	3	7	10.7	43	14	3	7	4.19	33
	L	25	12	18	4	21	25	15	19	0	22

	K	18	5	11	4.6	31	18	7	12	0	25
	Q	1,680 meters (5,510 feet)									
	L	1,993 meters (6,539 feet)									
	K	1,237 meters (4,058 feet)									
Latitude Longitude	Q	30.1 N and 66.95 E									
	L	30°22′N 68°36′E									
	K	27°48′N 66°37′E									

Table 2: Elemental composition of soil samples collected from three districts of Balochistan.

S.N0	Elements	Concentration		
		Quetta	Loralai	Khuzdar
	Organic elements			
1	C (%)	5.13± 0.02^{b}	5.40 ± 0.10^{a}	4.45 ± 1.00^{c}
2	H (%)	ND	ND	ND
3	N(%)	0.32± 0.01^{b}	0.37 ± 0.02^{a}	0.40 ± 0.01^{a}
	Macro elements			
4	Ca (µg/g)	157720±0.00^{a}	140186 ± 2.00^{b}	122632 ±3.00^{c}
5	K (µg/g)	12310 ± 0.00 ^{c}	13185 ± 2.00 ^{a}	12597 ± 2.00 ^{b}
6	Mg (µg/g)	15240± 1.00 ^{a}	15063 ± 1.00 ^{b}	12562 ± 2.00 ^{c}
7	P (µg/g)	1170.00± 1.00 ^{a}	1042.00 ±2.00 ^{b}	1044.00 ± 1.00 ^{b}
8	S(µg/g)	284.00± 2.00 ^{c}	472.00 ± 1.00 ^{b}	613.00 ± 2.00 ^{a}
Beneficial elements				
9	Al (µg/g)	69136± 3.00^{a}	68675 ±2.00^{b}	59841± 1.52^{c}
10	Na (µg/g)	8024.00±2.00^{b}	8332.00±1.00^{a}	7452.00±1.00^{c}
	Microelements			
11	B(µg/g)	3420.00±1.00^{b}	11119 ±1.00^{a}	2394.00±1.00^{c}
12	Cu(µg/g)	23.55±0.02^{c}	28.94±0.05^{b}	31.38±0.03^{a}
13	Fe(µg/g)	27760±1.00^{a}	25568±1.00^{a}	22329±2.00^{a}
14	Mn(µg/g)	609.00±1.00^{a}	580.00±1.00^{b}	526.00±1.00^{c}
15	Ni(µg/g)	44.01±0.01^{a}	43.47±0.02^{b}	41.11±0.05^{c}
16	Zn (µg/g)	73.92±0.01^{c}	104.00±0.00^{b}	125.00±1.00^{a}
	Trace elements			
17	Ba(µg/g)	344±2.00^{b}	471.00±2.00^{a}	523.00±2.00^{a}
18	Cr(µg/g)	64.25±0.02^{c}	78.05±0.03^{b}	82.11±0.00^{a}
19	Sr(µg/g)	483.00±2.00^{c}	802.00±1.00^{b}	1017.00±0.00^{a}
20	Ti(µg/g)	2345.00±1.00^{a}	2232.00±2.00^{b}	2040.00±1.00^{c}
21	Zr (µg/g)	39.18±1.00^{a}	35.73±0.02^{b}	31.43±1.00^{c}

Values are expressed as mean ± SD. The different superscripts on mean ± SD within a column are significantly different ($p<0.05$) by Tukey´s test.

Table 3: Elemental composition of fruits of selected olive cultivars (*O. europaea*) collected from three districts of Balochistan.

N0	Element	Area	Olive Cultivars						
			Leccino	Frantoio	Koroneiki	Coratina	Arbequina	Arbosana	Suri
						Organic elements			
1	C (%)	Quetta	67.24± 0.02^{k}	67.05±0.02^{kl}	64.40±0.20^{m}	70.33±0.01^{f}	90.21± 1.00^{a}	71.95±1.00^{e}	58.23±0.02^{o}
		Loralai	66.87±1.00^{l}	69.56±0.02^{gh}	69.80±0.10^{g}	68.08±0.01^{j}	84.21± 0.02^{b}	66.96±0.02^{kl}	61.76±0.37^{n}
		Khuzdar	69.80± 0.10^{g}	75.25±0.01^{d}	69.42±0.02^{hi}	69.19±0.03^{i}	81.25± 0.02^{c}	69.32±1.00^{hi}	53.01±0.03^{p}
2	H (%)	Quetta	13.14±1.00^{i}	12.72±0.02^{j}	12.65±0.02^{j}	13.65±0.02^{ef}	ND	13.89±0.30^{c}	11.48±1.00^{l}
		Loralai	13.45± 0.02^{g}	14.22±1.00^{b}	13.55±0.01^{fg}	13.29±0.01^{h}	12.06± 0.02^{k}	13.30±0.20^{h}	18.22±0.01^{a}
		Khuzdar	13.80± 0.04^{cd}	ND	ND	13.10±0.01^{i}	11.53± 1.00^{l}	13.73±1.00^{de}	10.37±0.02^{m}
3	N (%)	Quetta	1.03± 0.01^{jk}	0.70±0.03^{m}	0.97±0.01^{l}	0.97±0.02^{l}	1.17± 0.02^{fg}	1.05±0.02^{ij}	0.71±0.01^{m}
		Loralai	1.64± 0.03^{b}	0.98±0.01^{kl}	1.10±0.03^{hi}	1.47±0.02^{c}	1.81± 0.01^{a}	1.42±0.01^{c}	1.18±0.01^{f}
		Khuzdar	1.34± 0.02^{d}	1.32±0.02^{de}	1.17±0.02^{fg}	1.07± 0.01^{ij}	1.12±5.77^{gh}	1.27±0.02^{e}	0.66±0.03^{m}
						Macroelements			
4	Ca (µg/g)	Quetta	2154.0±1.00^{ab}	2248.0±2.00^{ab}	2162.0±2.00^{ab}	1821.0±1.00^{b}	2113.0±2.00^{ab}	1471.0±1.00^{bc}	1540.0±1.00^{bc}
		Loralai	862.00±2.00^{bc}	3057.0±1.00^{a}	1875.0±1.00^{b}	1533.0±1.00^{bc}	1652.0±1.00^{bc}	1576.0±2.00^{bc}	1260.0±1.00^{bc}
		Khuzdar	1977.0±1.00^{c}	1975.0±2.00^{b}	2254.0±2.00^{ab}	1626.0±2.00^{bc}	2080.0±1.00^{ab}	1793.0±1.00^{b}	1686.0±2.00^{bc}
5	K (µg/g)	Quetta	23326±2.00^{abcde}	24047±2.00^{de}	15328±1.00^{de}	22962±1.00^{abcde}	20728±1.00^{abcde}	19071± 1.00^{bcde}	17407±2.00^{cde}
		Loralai	29543±1.00^{a}	26705±1.00^{abc}	15555±1.00^{de}	22664±2.00^{abcde}	27888±1.00^{ab}	20315±2.00^{abcde}	13992±1.00^{e}
		Khuzdar	21860±1.00^{abcde}	22504±2.00^{abcde}	19741±2.00^{bcde}	25488±1.00^{abc}	23687±2.00^{abcd}	20362±1.00^{abcde}	20703±1.00^{abcde}
6	Mg (µg/g)	Quetta	735.0± 2.00^{b}	608.0±1.00^{d}	524.0±2.00^{h}	558.0±1.00^{e}	470.33±9.86^{j}	432.0±1.00^{k}	385.0±3.00^{l}
		Loralai	638.00±1.00^{c}	733±2.00^{b}	544.0±1.00^{f}	540.0±1.00^{fg}	753.0±2.00^{a}	548.0±1.00^{f}	307.0±2.00^{m}
		Khuzdar	501.0±2.00^{i}	560±1.00^{e}	740.0±1.00^{b}	630.0±1.00^{c}	533.0±2.00^{g}	503.0±2.00^{i}	439.0±1.00^{k}
7	P (µg/g)	Quetta	1468.0±2.00^{e}	1507±2.00^{d}	1158.0±1.00^{l}	1377.3±2.51^{h}	1529.0±1.00^{c}	757.0±2.00^{q}	415.0±1.00^{s}
		Loralai	2372.0±1.00^{a}	1533±1.00^{c}	1135.0±2.00^{m}	1193.0±1.00^{j}	1247.0±2.00^{i}	1033.0±1.00^{n}	573.0±3.00^{r}
		Khuzdar	1409.0±1.00^{f}	825±2.00^{p}	1396.0±1.00^{g}	936.0±1.00^{o}	1247.0±1.00^{i}	1174.0±2.00^{k}	1556.0±2.00^{b}
8	S (µg/g)	Quetta	682.00±1.00^{b}	679±1.00^{b}	617.0±1.00^{d}	538.0±2.00^{j}	591.0±1.00^{g}	452.0±2.00^{o}	332.0±2.00^{p}
		Loralai	513±3.00^{m}	530±1.00^{k}	535.0±2.00^{jk}	601.0±0.00^{ef}	623.0±3.00^{c}	571.0±1.00^{h}	335.0±2.00^{p}
		Khuzdar	910± 2.00^{a}	487±2.00^{n}	596.0±1.00^{fg}	523.0±2.00^{l}	604.0±1.00^{e}	548.0±1.00^{i}	515.0±2.00^{m}
						Beneficial elements			
9	Na (µg/g)	Quetta	2355.0±1.00^{c}	699±0.00^{j}	2891.7±1.52^{a}	408.0±1.00^{o}	539.0±2.00^{l}	787.0±1.00^{i}	2334.0±2.00^{d}
		Loralai	211.0±2.00^{q}	2437± 2.00^{b}	1853.0±3.00^{f}	17.07±0.02^{s}	203.0±1.00^{r}	330.0±1.00^{p}	1668.0±1.00^{g}
		Khuzdar	461.00±1.00^{m}	410 ±3.00^{no}	1607.0±2.00^{h}	599.0±0.05^{k}	415.0±3.00^{n}	699.0±2.00^{j}	1942.0±2.00^{e}
10	Al (µg/g)	Quetta	24.76±0.03^{g}	5.51±1.00^{s}	13.51±0.03^{p}	28.85±0.02^{d}	29.63±0.02^{c}	24.07±0.02^{i}	15.28±0.02^{m}
		Loralai	28.50±0.01^{e}	8.62±0.01^{q}	0.96±0.03^{u}	14.19±1.00^{o}	16.43±1.00^{l}	24.47±0.03^{h}	14.58±1.00^{n}
		Khuzdar	18.05±0.02^{k}	ND	7.04±0.02^{r}	27.54±1.00^{f}	32.89±0.02^{a}	31.18±1.00^{b}	20.29±0.05^{j}
						Microelements			
11	B (µg/g)	Quetta	14.13±0.02^{l}	16.16±0.03^{jkl}	37.87±0.01^{b}	18.24±1.00^{ghij}	24.13±0.02^{de}	20.71±0.025^{fgh}	17.24±0.02^{ijkl}
		Loralai	16.25±0.01^{jkl}	22.57±1.00^{ef}	19.82±1.00^{fghi}	21.45±0.02^{efg}	29.44±0.02^{c}	26.49±0.05^{cd}	19.74±1.00^{fghi}

		Khuzdar	14.88±3.44^{kl}	16.06±0.02^{jkl}	24.12±3.44^{de}	24.67±1.00^{de}	25.20±0.10^{a}	25.97±0.02^{d}	18.07±0.02^{hijk}
12	**Cu (µg/g)**	Quetta	4.28±0.01^{j}	3.37±0.01^{l}	3.90±0.01^{k}	3.74±0.02^{k}	6.22±0.01^{g}	4.60±0.20^{i}	2.56±0.01^{n}
		Loralai	8.50±0.20^{b}	5.96±0.03^{h}	4.19±1.00^{j}	9.09±0.02^{a}	7.33±1.00^{e}	8.26±0.03^{c}	2.56±0.02^{n}
		Khuzdar	7.65±0.03^{d}	3.33±0.05^{lm}	8.42±1.00^{bc}	6.45±0.02^{f}	8.29±0.50^{c}	6.63±1.00^{f}	3.15±0.03^{m}
13	**Fe (µg/g)**	Quetta	ND	1.45±0.01^{p}	ND	12.15±0.02^{l}	20.87±1.00^{d}	19.50±0.01^{f}	17.97±0.02^{h}
		Loralai	5.84±0.02^{n}	ND	4.49±1.00^{o}	16.40±0.01^{k}	17.13±1.00^{i}	19.69±0.01^{e}	16.65±1.00^{j}
		Khuzdar	6.23±0.01^{m}	ND	ND	20.96±0.03^{c}	32.57±0.02^{a}	23.12±1.00^{b}	18.96±0.02^{g}
14	**Mn (µg/g)**	Quetta	4.34±0.02^{j}	4.72±0.01^{i}	4.40±0.05^{j}	5.62±1.00^{de}	4.92±1.00^{h}	4.29±0.19^{j}	2.94±0.02^{l}
		Loralai	5.09±0.01^{g}	6.33±0.02^{b}	5.42±1.00^{f}	7.32±0.01^{a}	5.69±1.00^{d}	6.04±1.00^{c}	2.87±0.01^{l}
		Khuzdar	6.32±0.01^{b}	4.65±0.02^{i}	7.32±0.01^{a}	4.97±0.01^{gh}	6.30±2.00^{b}	5.49±1.00^{ef}	3.90±0.01^{k}
15	**Ni (µg/g)**	Quetta	0.77±0.01^{d}	0.83±0.01^{bc}	0.49±0.01^{i}	0.77±0.02^{d}	0.88±0.01^{a}	0.52±0.02^{hi}	0.53±0.02^{hi}
		Loralai	0.86±0.02^{ab}	0.64±0.02^{ef}	0.80±0.01^{cd}	0.51±0.02^{hi}	0.51± 0.02^{hi}	0.64±0.01^{ef}	0.63±0.03^{f}
		Khuzdar	0.51±0.02^{hi}	0.44±0.01^{j}	0.87±0.01^{ab}	0.63±0.01^{f}	0.68±0.01^{e}	0.58±0.01^{g}	0.54±0.02^{gh}
16	**Zn (µg/g)**	Quetta	10.38±0.01^{ef}	6.65±0.03^{j}	7.25±0.02^{i}	7.25±0.02^{i}	14.10±0.20^{a}	10.70±0.20^{d}	3.36±0.02^{m}
		Loralai	13.27±0.02^{b}	10.24±0.02^{ef}	7.28±0.01^{i}	7.28±0.01^{i}	8.28±1.00^{h}	9.51± 0.01^{g}	3.14±0.02^{m}
		Khuzdar	10.45±0.01^{de}	4.95±1.00^{l}	10.45±0.02^{de}	10.45±0.02^{de}	9.28±1.00^{g}	11.19±0.05^{c}	6.13±0.32^{k}
						Trace-elements			
17	**Ba (µg/g)**	Quetta	1.86±0.01^{c}	2.17±0.02^{a}	1.33±0.02^{f}	1.40±0.02^{e}	1.65±0.02^{d}	1.05±0.01^{i}	0.57±1.00^{m}
		Loralai	0.89±0.02^{k}	2.20±0.01^{a}	1.03±0.02^{i}	0.71±0.01^{l}	1.98±0.01^{b}	0.73±0.02^{l}	0.55±0.04^{m}
		Khuzdar	1.23±0.01^{g}	1.17±0.02^{h}	1.38±0.02^{ef}	0.92±0.01^{jk}	1.13±0.03^{h}	0.97±0.02^{j}	0.96±0.02^{j}
18	**Cr (µg/g)**	Quetta	ND	ND	ND	ND	0.15±0.02^{bc}	0.13±0.05^{bc}	0.20±0.10^{b}
		Loralai	ND	ND	0.37±0.01^{a}	ND	0.20±0.01^{b}	ND	0.22±0.01^{b}
		Khuzdar	ND	ND	ND	0.22±0.01^{b}	0.20±0.10^{b}	0.08±1.00^{cd}	0.19±0.02^{b}
19	**Sr (µg/g)**	Quetta	18.43±0.02^{i}	20.87±1.00^{h}	26.65±1.00^{d}	23.32±0.01^{fg}	17.45±0.02^{j}	15.10±0.10^{k}	14.32±1.00^{l}
		Loralai	12.22±1.00^{m}	31.71±0.05^{c}	23.91±0.02^{ef}	20.90±0.01^{h}	27.33±1.00^{d}	24.07±1.00^{e}	12.20±0.20^{m}
		Khuzdar	23.54±0.02^{ef}	22.67±0.02^{g}	35.90±0.02^{b}	17.39±0.02^{j}	76.0±1.00^{a}	23.27±0.02^{fg}	15.63±0.01^{k}
20	**Ti (µg/g)**	Quetta	ND	ND	0.26±0.02^{h}	ND	1.02±0.01^{cd}	0.28±1.00^{h}	2.61±0.01^{a}
		Loralai	ND	ND	0.10±0.02^{i}	0.40±0.10^{gh}	0.83±0.02^{e}	0.66±0.02^{f}	1.46±0.02^{b}
		Khuzdar	ND	ND	ND	0.50±0.20^{g}	1.05±0.01^{cd}	0.94±1.00^{de}	1.14±0.01^{c}
21	**Zr (µg/g)**	Quetta	ND	ND	ND	ND	ND	ND	ND
		Loralai	ND	ND	ND	ND	ND	ND	ND
		Khuzdar	ND	ND	ND	ND	ND	ND	ND

Values are expressed as mean ± SD. The different superscripts on mean ± SD within column are significantly different ($p<0.05$) by Tukey´s test. (ND: Not Detected)

Table 4: Elemental composition of olive oil of seven selected olive cultivars (*O. europaea*) collected from three districts of Balochistan.

S.	Eleement	Area	Olive Cultivars						
			Leccino	Frantoio	Koroneiki	Coratina	Arbequina	Arbosana	Suri
1	Ca mg/L	Quetta	2.15 ± 2.00^{r}	8.26 ± 2.00^{f}	6.02 ± 2.00^{jk}	6.02 ± 1.00^{k}	9.20 ± 2.00^{a}	9.03 ± 2.00^{c}	9.96 ± 3.00^{b}
		Loralai	6.48 ± 1.52^{i}	7.26 ± 2.00^{h}	4.27 ± 2.00^{n}	8.62 ± 2.00^{e}	8.04 ± 3.00^{g}	4.00 ± 1.52^{p}	9.00 ± 2.00^{d}
		Khuzdar	5.06 ± 0.03^{m}	4.03 ± 1.52^{o}	5.38 ± 3.00^{l}	6.04 ± 4.00^{j}	5.07 ± 2.00^{m}	3.11 ± 4.00^{q}	9.01 ± 6.08^{cd}
2	Fe mg/L	Quetta	0.05 ± 3.00^{t}	1.73 ± 2.00^{n}	5.40 ± 3.00^{e}	3.29 ± 1.00^{i}	1.05 ± 2.00^{q}	3.20 ± 2.00^{j}	6.65 ± 1.00^{d}
		Loralai	4.03 ± 2.00^{h}	0.99 ± 1.00^{r}	8.27 ± 1.00^{b}	12.23 ± 1.00^{a}	2.42 ± 2.00^{m}	4.60 ± 3.00^{g}	5.21 ± 2.00^{f}
		Khuzdar	0.39 ± 0.02^{s}	2.79 ± 2.00^{k}	2.65 ± 2.00^{l}	1.65 ± 1.00^{o}	1.11 ± 1.00^{p}	7.81 ± 3.00^{c}	5.37 ± 0.05^{e}
3	K mg/L	Quetta	0.12 ± 1.00^{n}	9.11 ± 2.00^{c}	0.09 ± 1.00^{o}	0.02 ± 1.00^{rs}	4.02 ± 1.00^{j}	0.01 ± 1.00^{s}	4.09 ± 3.00^{i}
		Loralai	10.23 ± 1.00^{a}	6.25 ± 3.00^{f}	3.75 ± 1.00^{k}	4.86 ± 2.00^{h}	2.81 ± 1.00^{l}	8.00 ± 2.00^{e}	0.04 ± 0.03^{qr}
		Khuzdar	0.21 ± 3.00^{m}	0.06 ± 3.00^{pq}	0.14 ± 2.00^{n}	9.00 ± 1.00^{d}	6.03 ± 2.00^{g}	9.52 ± 1.00^{b}	0.07 ± 2.00^{op}
4	Mg mg/L	Quetta	0.90 ± 2.00^{t}	3.06 ± 3.00^{k}	6.04 ± 2.00^{d}	4.04 ± 2.00^{f}	4.01 ± 1.00^{h}	2.03 ± 1.00^{o}	1.62 ± 3.00^{q}
		Loralai	6.09 ± 3.00^{c}	8.87 ± 2.00^{b}	2.61 ± 1.00^{l}	19.54 ± 1.00^{a}	3.31 ± 2.00^{i}	3.20 ± 2.00^{j}	2.06 ± 1.00^{n}
		Khuzdar	2.03 ± 1.00^{o}	1.02 ± 2.00^{r}	5.08 ± 1.00^{e}	1.01 ± 2.00^{s}	2.00 ± 2.00^{p}	4.03 ± 2.00^{g}	2.07 ± 2.5^{1m}
5	Mn mg/L	Quetta	0.02 ± 1.00^{l}	0.19 ± 1.00^{e}	0.05 ± 1.00^{i}	0.05 ± 2.00^{i}	0.03 ± 1.00^{l}	0.05 ± 2.00^{jk}	0.18 ± 1.00^{f}
		Loralai	0.07 ± 1.00^{g}	0.64 ± 2.00^{a}	0.45 ± 1.00^{b}	0.32 ± 1.00^{c}	0.06 ± 2.00^{gh}	0.07 ± 1.00^{gh}	0.06 ± 2.00^{h}
		Khuzdar	0.05 ± 1.00^{ij}	0.04 ± 3.00^{k}	0.31 ± 2.00^{d}	0.03 ± 2.00^{l}	0.03 ± 2.00^{l}	0.18 ± 3.00^{f}	0.07 ± 1.52^{gh}
6	Zn mg/L	Quetta	0.03 ± 1.00^{no}	0.55 ± 2.00^{d}	0.39 ± 0.00^{fgh}	0.23 ± 3.00^{jk}	0.02 ± 2.00^{o}	0.16 ± 0.11^{klm}	0.31 ± 1.00^{hi}
		Loralai	0.28 ± 1.00^{ij}	0.82 ± 2.00^{b}	0.51 ± 1.00^{de}	0.70 ± 1.00^{c}	0.10 ± 2.00^{lmn}	0.40 ± 5.29^{fg}	0.42 ± 1.00^{f}
		Khuzdar	0.33 ± 1.00^{ghi}	0.17 ± 1.00^{kl}	0.94 ± 2.00^{a}	0.09 ± 2.00^{mno}	0.04 ± 1.00^{no}	0.43 ± 3.00^{ef}	0.42 ± 4.6^{1f}

Values are expressed as mean ± SD. The different superscripts on mean ± SD within the column is significantly different ($p<0.05$) by Tukey´s test.

cultivars like Suri and Arbequina might have genetic traits that may helped in Ca accumulation. These results were in agreement with the Ca concentration range in oil previously reported (Anthemidis *et al*., 2005; Astolfi *et al*., 2021). Suri stood as a promising cultivar for high-calcium olive oil production. Among macro-elements Potassium (K) was also quantified in selected oil samples due to its crucial role in oil quality assessment and general plant physiology. Among selected sites, Loralai deciphered the highest range of 10.23 mg/L to 0.04 mg/L in selected olive cultivars, followed by Khuzdar (9.52-0.06mg/L) and Quetta (9.11-0.01). Despite overall lower availability, some cultivars could still effectively accumulate K such as Leccino from Loralai, Arbosana and Coratina from Khuzdar and Frantoio from Quetta. The findings highlighted the importance of cultivar accumulation traits under varying environmental and edaphic factors and aligned with previous studies (Zeiner *et al*., 2005; Astolfi *et al.,* 2021). The analysis further revealed notable variability in magnesium (Mg) concentrations among olive cultivars and collection sites (Table 4). The data revealed a comparatively higher range of 19.54 to 2.06 mg/L in Loralai followed by 6.04 to 0.09 in Quetta and 5.08 to 1.01 in Khuzdar. Coratina among all selected cultivars showed exceptionally high levels of Mg content (19.54 mg/L) followed by Frantoio in the Loralai site. These elevated Mg levels in cultivars like Coratina and Frantoio might improve olive oil's nutritional quality while emphasizing the accumulation traits of cultivars in response to their growing conditions in assessing olive oil benefits (Benincasa *et al*., 2007; Astolfi *et al*., 2021). Iron (Fe) is an essential micronutrient influencing plant health and olive oil quality, with higher concentrations enhancing nutritional profiles and oxidative stability. Among other essential elements, the data showed significant variability in iron (Fe) concentrations among olive cultivars across all the collection sites (Table 4). The overall concentration range was highest in the Loralai samples with 12.23 to 0.99 mg/L followed by Khuzdar samples with 7.81 to 0.39 and Quetta with 6.65 to 0.05 mg/L. Coratina demonstrated the highest Fe (12.23 mg/L) levels followed by Koroneiki (8.27mg/L) collected from the Loralai site. The findings highlighted the importance of both cultivar traits and environmental conditions in determining Fe content and overall olive oil quality. The results were consistent with the range of Fe concentration documented earlier (Llorent-Martínez *et al*., 2011; Astolfi *et al.,* 2021). The present study also showed significant variability in manganese (Mn) concentrations among olive cultivars and study sites (Table 4). Among study sites, the highest range was documented in the Loralai site (0.64-0.06mg/L) followed by Khuzdar (0.31-0.03 mg/L) and Quetta (0.19-0.02mg/L) sites. Among cultivars, Frantoio with 0.64 mg/L showed a high Mn content suggesting an optimal nutrient accumulation potential while Leccino with very low Mn content (02 mg/L) demonstrated a limited accumulation capacity. The findings highlighted the importance of cultivar traits and environmental conditions in Mn accumulation, which can enhance the nutritional quality of olive oil (Lia *et al.,* 2020; Astolfi et al., 2021). The study revealed significant variability in zinc (Zn) concentrations among different olive cultivars and locations (Table 4). Overall data exhibited a high Zn content in the Khuzdar site with 0.94 to 0.04 mg/L followed by Loralai (0.82-0.10 mg/L) and Quetta (0.55-0.02) sites. Among cultivars, Koroneiki (0.94) and Frantoio (0.82 mg/L) exhibited the highest Zn concentration particularly thriving in the favorable conditions of Khuzdar and Loralai respectively. The findings highlighted the significance of cultivar traits and environmental conditions in influencing Zn levels, which can enhance the nutritional quality of olive oil (Anthemidis *et al*., 2005; Astolfi *et al*., 2021). The variation in accumulation potential of cultivars growing under the same edaphic and environmental conditions was evident highlighting genetic traits influencing lipophilic binding affinities of selected olive samples for mineral nutrients. Based on present data analysis among all cultivars Coratina from the Loralai site showed exceptional abilities to serve as a mineral-rich source of oil by exhibiting good quantities of Ca, Mg, Fe, and Zn.

Conclusion: Significant differences in mineral composition were observed among the seven olive cultivars grown in Quetta, Loralai, and Khuzdar. The levels of major macronutrients (Calcium, Potassium, Magnesium, Phosphorus, Sulfur) and micronutrients (Boron, Copper, Iron, Manganese, Nickel, Zinc) varied considerably with both cultivar and growing location. These results highlight the interactive effects of genotype and site conditions on mineral uptake, emphasizing the importance of selecting suitable cultivars for specific sites to enhance the nutritional quality of olives in the climatic conditions of Balochistan.

Conflicts of interest: The authors declared that there aren't conflicts of interest

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