

Quelites Pasados of the Sierra Tarahumara, Chihuahua, Mexico: An Interdisciplinary Ethnobotanical Study of Leafy Green Vegetables

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Abstract Leafy green vegetables have been a part of human diets throughout human history. Globally, they are gaining recognition since these wild foods could play an important role in food security. Quelites (the Mexican term for these resources) are dehydrated to produce “quelites pasados” by the Rarámuri in anticipation of the scarcity of food in winter. The diversity of quelites in the state of Chihuahua includes species of the widely consumed *Amaranthus*, as well as endemic, native, and introduced species that are eaten locally. The present work generated nutritional, sensory, and molecular information on four species that are consumed in the Sierra Tarahumara: *Amaranthus palmeri*, *Amaranthus powellii*, *Arracacia edulis*, and *Phacelia platycarpa*. Their nutritional analysis exhibited high protein values and a significant concentration of macro- and micronutrients. The acceptance by the public of the species of *Amaranthus* was high, while that of *Arracacia edulis* and *Phacelia platycarpa* was lower. Because of the morphological similarity within the two pairs of quelites, their DNA barcodes were generated as an identification tool which, together with the nutritional and sensory results, provides added value to the four “quelites pasados” of the Sierra Tarahumara. This study could be considered a starting point for sustainable use of native vegetables in future economic programs of regional agrobiodiversity, and even replicated globally.

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Resumen Las verduras de hoja verde han sido una parte importante de la dieta humana que están ganando reconocimiento a nivel global, ya que estos recursos silvestres podrían jugar un papel importante en la seguridad alimentaria. Los quelites (el término en náhuatl para planta tierna comestible) son deshidratados por los taráhmuri para producir quelites pasados como previsión de la escasez de alimentos en invierno. La diversidad de quelites en el estado de Chihuahua incluye especies de gran consumo, como el amaranto, así como especies endémicas, nativas e introducidas que se comen localmente. El presente trabajo generó información nutricional, sensorial y molecular de cuatro especies que se consumen en la Sierra Tarahumara: *Amaranthus palmeri*, *Amaranthus powellii*, *Arracacia edulis* y *Phacelia platycarpa*. Su estudio nutricional exhibió altos valores de proteína y una concentración significativa de macro- y micronutrientes. La aceptación por parte del público en general de las especies de *Amaranthus* fue alta, mientras que la de *Arracacia edulis* y *Phacelia platycarpa* fue menor. Debido a la similitud morfológica entre los dos pares de quelites analizados, se generaron sus códigos de barras moleculares como una herramienta de identificación que, junto con los resultados nutricionales y sensoriales, brindan un valor agregado a los cuatro quelites pasados de la Sierra Tarahumara. Este estudio podría considerarse un punto de partida para el uso sostenible de vegetales nativos en futuros programas económicos de la agrobiodiversidad regional, e incluso replicarse a nivel mundial.

Keywords: Quelites, Nutritional values, Sensory Analysis, DNA barcodes, Agrobiodiversity, Leafy green vegetables

Introduction

Leafy green vegetables (LGV; also referred to as pot herbs) have been a part of human diets throughout human history. While many grow spontaneously (and are hence called “wild greens”), some have been domesticated and incorporated into modern agriculture. *De Materia Medica* of Dioscorides (1968) recorded 55 pot herbs or “lachana” that were wild and cultivated varieties from the Mediterranean region, including vegetables that are grown globally. As the Europeans encountered “new” continents and peoples, they recorded novel edible plants including LGV. Such is the case of Bernardino de Sahagún who arrived in New Spain (today known as Mexico) in 1529. Under his direction, the “tlacuilo” (Aztec illustrator) drew 58 edible greens in the Florentine Codex (Sahagún 1979, 3 fol. 134r).

Subsequent acculturation has diminished the frequency of consumption and diversity of LGV due to substitution by exotic vegetables, increased consumption of processed foods, and social prejudice (Bye and Linares 2011). As awareness about the detrimental costs to health and food security due to the loss of

LGV grows, wild greens are being reevaluated in terms of their health and social-environmental benefits, as well as “rediscovered” for their gastronomical novelty (Luczaj et al. 2012). Such situation not only provides the opportunity to reinforce regional cultural values that are threatened by globalization, but also to provide traditional farmers the opportunity to derive economic benefits through the sale of their native LGV.

In response to mounting crises associated with health problems and food security, the World Health Organization (WHO) and Food and Agriculture Organization (FAO) of the United Nations (1998) have collaborated with more than 100 countries in Asia and the Pacific, Europe, North America, Latin America, and the Caribbean to establish national Food Based Dietary Guidelines (FBDG) to encourage the consumption of fresh, unprocessed or minimally processed foods as a critical part of sustainable dietary patterns. Such sustainable food systems consist of dietary patterns that promote all dimensions of individuals’ health and wellbeing while minimizing environmental pressure and impact. This food security emphasizes accessible,

affordable, safe, and equitable local alimental resources that are culturally acceptable. The latest edition of FBDG for Mexico was published in 2015 (Bonvecchio et al. 2015) and focuses on minimizing the burden of malnutrition in the Mexican population, both malnutrition problems and obesity and chronic diseases related to food. The recommendations were considered by the official national regulation on health promotion and education in alimentary matter (Secretaría de Salud 2013) which recommends that food-related diseases can be prevented, in part, by eating quelites and LGV.

The term “quelites” refers to edible greens or leafy vegetables in Mexico and adjacent regions once under the influence of New Spain. Quelite is a loan word derived from the Nahuatl “quiltil” which early Spanish chroniclers (e.g., Sahagun 1979) equated with “hortaliza” (vegetable) and “verdura” (greens) to describe tender parts of edible plants (Bye and Linares 2011; 2018b). These “quiltil” plants have developing leaves and stems as well as homologous plant structures such as seedlings, inflorescences (of one or more flowers that are composed of modified leaves and positioned at a stem apex), and bulbs (short stems with overlapping fleshy leaves or leaf bases).

Given the great number of quelites recorded by the Spanish chroniclers after the conquest of central Mexico (Cortés 1981; Díaz del Castillo 2004; Hernández 1959; Sahagún 1979), it is evident that quelites were important elements of the Aztec diet. These edible herbs have continued to this day as a fundamental component of Mexican agriculture and diet (Mapes and Basurto 2016; Mera et al. 2011). The roles of quelites in Mexican foodways have changed over time through acculturation, as habitat alteration, social prejudice, and introduction of exotic plants, among other factors, have altered their diversity (Bye and Linares 2011). Nonetheless, they play a key role in Mexico’s food security. Quelites grow as wild plants in the forest and as synanthrophites in various anthropogenic habitats, and occur in mono- and polycultures (SNICS 2018). Access to these resources is either seasonal according to rainfall in rural communities (Balcázar-Quñones et al. 2020; Díaz-José

et al. 2019; Leyva-Trinidad et al. 2020), while others are cultivated intensively and distributed through urban markets (Linares et al. 2019; Linares and Bye 2016; Manzanero-Medina et al. 2020). Although these factors have varied over the past five centuries of Mexico’s history, quelites persist in Mexico. This is not only because they are a part of the culinary heritage of the country, but also due to recognition of the health benefits and sensorial diversity of wild greens in Mexico (Mateos-Maces et al. 2020; Morales et al. 2013; Santiago et al. 2018; 2020) and in other parts of the world (Ghirardini et al. 2007; Romojaro et al. 2013). Such studies promote the availability of quelites for Mexico’s food security as new generations discover their nutritional and gustatory attributes (Bourges et al. 2013; Gálvez 2019).

The Tarahumara people, who refer to themselves as *Rarámuri*, reside principally in southwestern Chihuahua, Mexico, numbering about 122,000 of whom 75,500 speak the *Rarámuri* language that belongs to Tarachita branch of the Uto-Aztec family (Pintado 2004). Traditionally, they live in isolated ranches scattered throughout the pine-oak forests of the mountains with an average elevation of 2200 m asl and the seasonally dry tropical forest of the canyons at 500 m asl on the Pacific slope of the Sierra Madre Occidental. Their “milpa,” defined as a Mesoamerican agricultural system of maize-bean-squash (*Zea mays* L., *Phaseolus* spp., and *Cucurbita* spp., respectively) with associated plants as well as minor and major livestock provides sustenance throughout the year. Traditionally, they perform ceremonies with music, dance, and songs throughout the year to aid the Creator in maintaining order in the universe as well as to promote social integration (Merrill 1983; Pennington 1983; Pintado 2004).

The consumption of quelites is a survival strategy employed by subsistence agriculturalists, among them the *Rarámuri* (Bye 1981; Merrill 1983; Pennington 1963; Salmón 2000; Wyndham 2009). These edible greens of the *Rarámuri*, known collectively as “kiribá” or “quilibá” (a cognate of the Nahuatl “kilitl” or “quiltil”, Bye and Linares 2011), are not only part of their

everyday life but are also incorporated into their cosmology. Until recently, the health status of the general Rarámuri population, which was characterized by the absence of hypertension, heart diseases, and diabetes, was attributed to the abundant intake of vegetables; however, contemporary dietary changes are altering this situation (Acuña 2010). The consumption of quelites by the Rarámuri is a critical complement to their diet based upon the Mesoamerican agricultural triad of maize-bean-squash. In addition to being part of the seasonal diet at the onset of the agricultural calendar, “kiribá” also compensate for food scarcity in times of crisis when adversities reduce crop harvests (Linares et al. 2016). In anticipation of the need for quelites during the winter months as well as to forestall future famines, the Rarámuri developed a dehydration technique to produce “quelites pasados” or “kiribá wakichéame” which was noted in the nineteenth century (see Electronic Supplementary Material, Appendix 1). In addition to their agronomic and nutritive benefits, quelites in the context of traditional agricultural practices are recognized as part of Mexico’s Intangible Cultural Heritage (Bye and Linares 2018a). More importantly, they are a component of the kincentric ecology of the Rarámuri world generally referred to as “iwígara” (Salmón 2000). The fundamental relationship of the Rarámuri people with the natural world (which is one of seven levels in their cosmography) is founded upon the respect for the soul or breath (“iwí”) of all beings. The Rarámuri were placed on this Earth (“gawí”) by the Creator (“onorúame”) to care for these beings as well as to aid in the welfare of the Creator. Their ritual and agricultural practices in the milpas strengthen the “iwí” of the cultivated fields that, in return, produce an abundance of “sepé,” one class of quelites (Salmón 2000). To understand the role of quelites in the Rarámuri foodways, it is important to determine the dietary role and biodiversity of their quelites.

To date, quelites are consumed at the household level. On occasions they may circulate among members of the community through trade, or the mutual security network known as “kórima,” especially when resources are scarce. Because the quelites are plantlets developed from recently germinated seeds in the

milpa, they are available in fresh form only 4 to 6 weeks of the year. To extend their availability during the rest of the year, especially for winter use or in times of food scarcity, the Rarámuri process them as “quelites pasados”, which maintains their edibility for up to 5 years.

In recent years, some Rarámuri farmers have expressed interest in selling their dehydrated products in local markets where residents know and appreciate these vegetables. In addition, the growing tourist sector in the region has expressed curiosity in including these greens in their restaurant menus. Providing opportunities for rural communities to market their surplus milpa products through local trade is fundamental to both Mexico’s agrobiodiversity program (Astier et al. 2021) as well as international programs of Localized Agrifood Systems (or Sistemas Agroalimentarios Localizados, SIAL) that promote sustainable and inclusive rural development, contribute to food security, reduce poverty, and improve living conditions in rural areas (Renard Hubert 2016).

To introduce novel quelites into the consumers’ diet, quality control of these greens is needed. Many people are unfamiliar with morphological differences among the quelites, especially after they have shriveled into an amorphous mass as is the case with traditional Rarámuri dehydrated greens. Also, unintentional adulterations can occur, especially with young or inexperienced collectors. The morphological characteristics of plantlets in the quelite stage with juvenile leaves are poorly known compared to their respective reproductive stage or seedling state (with cotyledons and initial leaf). In addition to morphological descriptions, the application of molecular markers (DNA barcodes) may be a useful tool for distinguishing plant material of similar appearance not only for quality control of food items in niche markets but also for agrobiodiversity inventory and studying domestication processes (Cristians 2020; Newmaster and Ragupathy 2010). DNA barcoding has proven useful for linking and recognizing different stages in the species life cycle (Erickson et al. 2008).

In addition, the analysis of the physicochemical properties and the sensorial attributes is fundamental to understanding the diversity of food

products. These parameters were considered since the formalization of governmental programs, as attested by the evaluations of Native American food plants in the nineteenth century by the US Department of Agriculture (Bye and Linares 2021). Such data are not only important to the Indigenous peoples who originally consume these edibles but also for informing potential consumers looking to diversify their diet.

About 120 kinds of quelites are consumed in southwestern Chihuahua. While some species (such as members of *Amaranthus*, *Chenopodium*, and *Portulaca*) are known in other parts of Mexico and adjacent southwestern USA, others are endemic species (e.g., *Arracacia edulis* S. Watson) to the region of northern Sierra Madre Occidental. Although limited studies have been conducted on quelites in other regions in Mexican and adjacent US, there are no sensorial, physicochemical, and molecular data on species from this region. To initiate the evaluation of the economic botany of this rich ethnoflora, four species were selected to represent: (1) two pairs of species with contrasting leaf morphology; and, (2) within each of these pairs, species with similar leaf morphology. One pair consisted of species with leaves with simple lamina, while the other had pinnately compound leaves that are arranged in a rosette during the initial growth stage.

The members of the first pair are species of *Amaranthus*, a genus known for its edible “seeds” (i.e., “alegría”) and greens (i.e., “quintonil”) in central Mexico. The edible greens are derived from the following American species (*Amaranthus albus* L., *Amaranthus blitoides* S. Watson, *Amaranthus caudatus* L., *Amaranthus cruentus* L., *Amaranthus fimbriatus* (Torrey) Benth. ex S. Watson, *Amaranthus hybridus* L., *Amaranthus leucocarpus* S. Watson, *Amaranthus hypochondriacus* L., *Amaranthus powellii* S. Watson, *Amaranthus retroflexus* L., and *Amaranthus spinosus* L.) and Asian species (*Amaranthus tricolor* L.) (Linares and Bye 2020). In the Sierra Tarahumara, the *Amaranthus* species selected are *Amaranthus powellii* and *Amaranthus palmeri* (“wasori” or “quelite de agua”) derived from the temperate sierras and the subtropical canyons, respectively (Figs. 1A, B). The species of the second pair grow in the pine-oak forests of the Mexican cordilleras and are reported to be consumed only in the Sierra Tarahumara. *Arracacia edulis* (syn. *Tauschia edulis* (S. Watson) Coulter

& Rose) (Apiaceae) (“basiáwari”) is a member of the genus *Arracacia* with 26 species, of which 19 are endemic to Mexico (Fig. 1C) (Villaseñor 2016). In the case of *Arracacia edulis*, its distribution is limited to mountains of western Chihuahua. *Phacelia platycarpa* (Cav.) Spreng. (Hydrophyllaceae) (“gonírora” or “quelite rosado”) is a member of the genus *Phacelia* with 56 species, of which 16 are endemic to Mexico (including *Phacelia platycarpa*) (Villaseñor 2016). In contrast, this species ranges through the Mexican cordilleras from Chihuahua to Chiapas, although it is reported as a quelite only from the Sierra Tarahumara (Fig. 1D).

Given the contrasting features of these quelites, we would expect differences among them in terms of their nutrimental composition as well as their sensorial properties. On the other hand, given the similarity of the juvenile leaves, one would anticipate that molecular markers would be useful in separating species pairs with similar leaf morphology. In addition, it would be useful to distinguish between the edible and poisonous taxa of Apiaceae.

Objectives

1. To determine the nutritional values and sensory attributes of selected quelites of the Sierra Tarahumara, and to identify the correlation between these characteristics with their acceptance by consumers.
2. To determine the molecular markers that are appropriate to distinguish among the species studied.

Methods

ETHNOBOTANICAL DATA

The quelites here reported were selected from the quelite inventory initiated during ethnobotanical field studies by R. Bye. Participatory observations since 1971 have been documented by herbarium specimens and ethnobotanical samples that represent voucher specimens (i.e., specimens in the state of actual consumption), as well as corroborative specimens (i.e., specimens representing plants derived from the same population as the voucher specimens and possessing

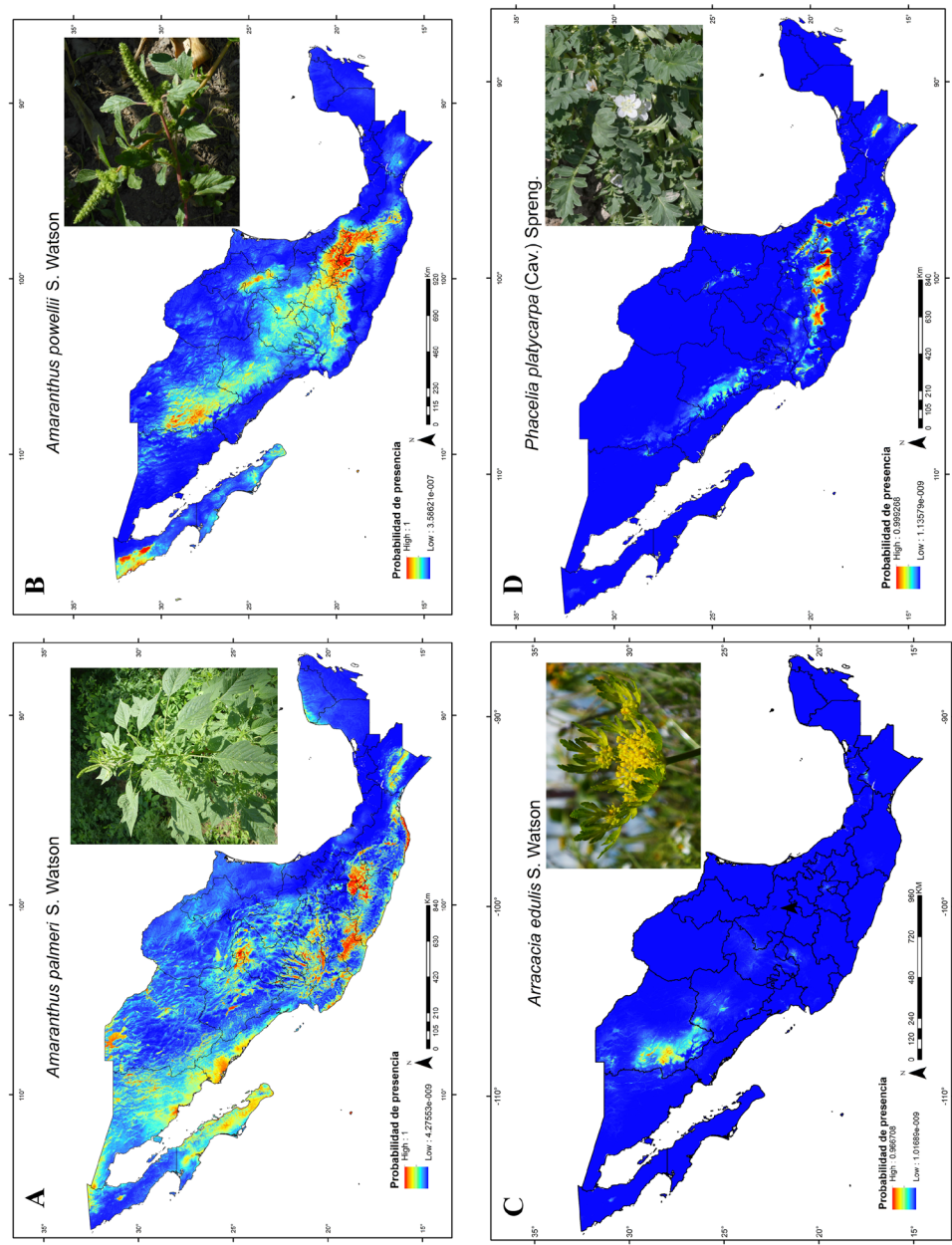


Fig. 1. Characteristic plants of four quelites of the Sierra Tarahumara and their geographic distributions based upon herbarium specimens and their probability of presence (probabilidad de presencia). **A** *Amaranthus palmeri*, **B** *Amaranthus powellii*, **C** *Arracacia edulis*, and **D** *Placelia platycarpa*

diagnostic taxonomic characters) (Bye 1986). In addition to recording information from the etic viewpoint, the emic perspective has been published in video and print formats (Linares and Bye 2019; Mares et al. 1999, respectively). Between 2015 and 2022, semi-structured interviews, recall surveys, focus groups, and community workshops were conducted in various communities of the Sierra Tarahumara to amplify the quelite inventory. The quelites were recorded by their names in Spanish and Rarámuri. These terms were linked to scientific names either by quelite samples provided by the collaborators, or by the responses of participants to stimuli (e.g., pressed specimens or photographs of various edible and non-edible plants).

PLANT MATERIAL

Plantlets, young plants, of the four quelites were obtained in 2020 from milpas in the Sierra Tarahumara, Chihuahua, Mexico, and dehydrated traditionally for physicochemical analyses, sensorial evaluations, DNA extractions, and voucher specimens. Because quelites are usually eaten as juvenile plants that lack reproductive structures, corroborative specimens were collected from these populations to confirm their botanical identities. Herbarium voucher and corroborative specimens are deposited in Mexico's National Herbarium (MEXU) and include: *Amaranthus palmeri* (Urique, Municipio Urique: Bye et al. 40324; MEXU 1533860, 1533861 and 1533862), *Amaranthus powellii* (Choguita-Gumísachi valley, Municipio Bocoyna: Bye et al. 39632, 39708, 39715, 40325, and 40326; MEXU 1533858 and 1533865), *Arracacia edulis* (Choguita, Municipio Bocoyna: Bye et al. 39015, 39023, 39951, and 40329; Tónachi, Municipio Guachochi: Bye et al. 39733, 39747, 39944, and 40328; MEXU 1533864 and 1533866), and *Phacelia platycarpa* (Choguita, Municipio Bocoyna: Bye et al. 39632, 39953, and 40327; MEXU 1533863 and 1533867).

PHYSICOCHEMICAL ANALYSIS

The physicochemical characterization of the four quelite pasado samples was carried out in the Chemical Analysis and Toxicology Laboratory of the Faculty of Veterinary

Medicine and Zootechnology, Universidad Nacional Autónoma de México (UNAM), according to Official Methods of Analysis of the Association of Official Analytical Collaboration (AOAC) for crude fiber (AOAC962.09, 2015), ether extract (AOAC920.39, 2015), crude protein (AOAC2001.11, 2015), and ashes (AOAC942.05, 2015). The true protein was determined according to Krishnamoorthy et al. (1982), and simple carbohydrates were determined by difference. The concentration of minerals (Ca, Na, K, Mg, Mn, Fe, and Zn) was analyzed by atomic absorption spectroscopy (AOAC985.35, 2015); in the case of phosphorus, UV-Vis spectrophotometry (AOAC965. 17, 2005) was employed.

SENSORIAL ANALYSIS

Sample Preparation

Over the years working in the Sierra Tarahumara with the Rarámuri, different recipes have been compiled on how to prepare quelites. The most common is the one used in this study, which was standardized in the Sensory Evaluation Laboratory of the Faculty of Chemistry, UNAM, in which the ingredients were weighed, and the preparation times were timed. After rehydrating the leaves of the four quelite pasado samples in water at room temperature for 30 min, they were prepared using the standard recipe formulation consisting of: 70% quelites, 22% onion, 5% salt, 3% oil, and 0.2% garlic. The onion and garlic were finely chopped; the pot was heated with the oil; once the oil was hot, the onion and garlic were added and fried until the onion took on a translucent tone. The quelites were added followed by 250 mL of water. Then, the pot was covered for 25 min, until the added water evaporated.

Flash Profile Modified

The Flash Profile modified (FPm) is a methodology developed in the Sensory Evaluation Laboratory that, in general terms, consists of developing a quick profile using a group of judges trained in descriptive methodology (ISO 2014). The attributes and the order in which they are perceived are selected by consensus and a

structured scale of 9 points is use. Samples are evaluated one by one. The trained judges were selected based on International Standardization Office standards for sensory analysis of the food (ISO 2008; 2012; 2014). Based on triangle test (ISO 2004), the judges presented low thresholds to detect the basic tastes: sweet, bitter, acid, salty and umami, and good flavor discriminating ability, more than 78% of different foods were recognized and food attributes were described. They comply with the characteristics for the selection, training and monitoring of selected assessors and expert sensory assessors (ISO 2014).

The FPM was carried out by an evaluation panel of 15 trained judges (20–29 years old, 11 women and 4 men, students from the Faculty of Chemistry), who had 1 year of judging experience in conventional descriptive analysis of dehydrated food. A better response consensus is obtained in the FPM rapid test because it generates a joint list of attributes of the samples evaluated (Väkeväinen et al. 2020).

In the first session, the judges were presented with the four samples of prepared quelites, and they were asked to describe the sensory attributes of appearance, aroma, taste, texture, and aftertaste for each quelite. In the second session, a consensus list of attributes was drawn up, eliminating synonyms, ambiguous, or affective terminology. In the third session, the evaluation of the prepared quelites was carried out using a questionnaire that shows a 9-point scale for each attribute, where 1 represents the minimum intensity of the stimulus and 9 the maximum with which they perceive them.

In all sessions, each judge received the prepared quelite samples in a 100 mL transparent plastic cup, identified with three-digit codes. Judges were also provided with a glass of water and some soda crackers to rinse their palates between each sample. Sensory evaluation sessions and questionnaires were analyzed using FIZZ software (Biosystems, version 2.51c, Acquisition and Judge modules, Courtenon, France).

Acceptance Test

The evaluation of the level of acceptance of the quelites by the general public was carried out in Mexico City, which is Mexico's most populated urban center and principal market for

quelites. Randomly, we selected 65 consumers (40 women and 25 men) between the ages of 13 to 78 years. More than half, 54%, quelites regularly at home and accompany them with other foods. Most consumers (63) were unfamiliar with quelites from the Tarahumara area, which is 1,300 km northwest of Mexico's capital city; only two consumers were from indigenous communities. For the evaluation, a 9-point hedonic scale was used, in which 1 corresponds to "I extremely dislike" and 9 to "I extremely like." The quelites were prepared as described for the FPM. One by one, each quelite sample was provided in a white dish (100 g) and water was given as a mouth rinse in between tasting. The questionnaire was developed in Google forms, and consumers answered it from their smartphone.

DNA BARCODING

DNA Extraction

DNA was extracted from leaves of the plant species using a commercial DNA extraction kit, DNeasy Plant Mini Kit (QIAGEN, Düsseldorf, Germany), with some modifications. Briefly, the incubation time was extended to 15 min and mixed four times during the incubation process. The final steps were also modified adding 75 mL of AE buffer solution to the column, leaving 15 min for DNA recovery, centrifuged and then the steps were repeated with 50 µL of the same solution. The final goal was to increase the concentration and quality of the DNA obtained. In all samples the DNA was stored at -20°C before use. DNA quality and concentration were quantified using a NanoDrop (Thermo Fisher Scientific, Wilmington, DE, USA) by measuring the absorbance 260 and 280 nm, and a 1% agarose gel electrophoresis.

Barcode Amplification

DNA amplification was carried out in a first stage using the primers suggested by the International Barcode of Life: *matK* (F-ACC CAGTCCATCTGGAAATCTTGGTTC, R-CGT ACAGTACTTTTGTGTTTACGAG) and *rbcL* (F-ATGTCACCACAAACAGAGACTAAA GC, R-GTAAATCAAGTCCACCRG) (Kress

and Erickson 2012) and refined later with more informative chloroplast primers (Shaw et al. 2007): *rpl32-trnL* (F-CAGTTCCAAAAAAC GTACTTC, R-CTGCTTCCTAAGAGCAGC GT) and *trnH-psbA* (F-CGCGCATGGTGGATT CACAATCC, R-GTTATGCATGAACGTAAT GCTC) and nuclear primer *ITS2* (F-ATGCGA TACTTGGTGTGAAT, R-GACGCTTCTCCA GACTACAAT) (Chen et al. 2010; Kress and Erickson 2012; Shaw et al. 2007).

The polymerase chain reactions (PCR) were performed using a final volume of 30 mL for all five markers; nevertheless, different reaction mixes and amplification programs were implemented (Cristians et al. 2018). For *matK*: 0.625 U of GoTaq Flexi polymerase (Promega, Madison, WI, USA) in Colorless GoTaq Flexi buffer, 1.5 mM of MgCl₂, 0.2 mM dNTP's (Fermentas, Vilnius, Lithuania), 0.1 mM of each primer, and 10 ng/mL of DNA. For *rbcL*: 0.625 U of GoTaq Flexi polymerase in Colorless GoTaq Flexi buffer, 1 mM of MgCl₂, 0.2 mM dNTP's, 0.1 mM of each primer, and 10 ng/mL of DNA. For *rpl32-trnL*: 1 U of GoTaq Flexi polymerase in Colorless GoTaq Flexi buffer, 1.5 mM of MgCl₂, 0.4 mM dNTP's, 0.25 mM of each primer, and 10 ng/mL of DNA. For *trnH-psbA*: 1 U of GoTaq Flexi polymerase in Colorless GoTaq Flexi buffer, 0.66 mM of MgCl₂, 0.4 mM dNTP's, 0.25 mM of each primer, and 10 ng/mL of DNA. For *ITS2*: 1 U of GoTaq Flexi polymerase in Colorless GoTaq Flexi buffer, 1.5 mM of MgCl₂, 0.4 mM dNTP's, 0.6 mM of each primer, and 10 ng/mL of DNA.

The amplification was carried out in a GeneAmp PCR System 9700 Thermocycler (Applied Biosystems, Norwalk, CT, USA) using the following conditions: *matK* and *rbcL*—an initial denaturation step at 94 °C for 2 min, followed by 29 cycles at 94 °C for 30 s, 52 °C for 40 s, and 72 °C for 40 s, with a final extension period at 72 °C for 5 min; *rpl32-trnL*—an initial denaturation step at 95 °C for 2 min, followed by 35 cycles at 94 °C for 1 min, 53 °C for 1 min, and 72 °C for 2 min, with a final extension period at 72 °C for 10 min; *trnH-psbA*—an initial denaturation step at 94 °C for 2 min, followed by 40 cycles at 94 °C for 30 s, 55 °C for 40 s, and 72 °C for 40 s, with a final extension period at 72 °C for 5 min; and *ITS2*—an initial denaturation step at 95 °C for 5 min, followed by 40 cycles at 94 °C for 30 s, 55 °C for 30 s, and

72 °C for 45 s, with a final extension period at 72 °C for 10 min. After amplification, the PCR products were visualized on a 1% agarose gel stained with Midori Green Advance (Nippon Genetics, Dürren, Germany). Because some samples did not yield amplicons in the subsequent PCR reaction, the final dataset considered only a total of 46 samples.

The PCR reactions were sequenced in the Biodiversity and Health Genomic Sequencing Laboratory, Institute of Biology, UNAM, using a 3730xL DNA Analyzer with 96 in-capillary detection by dual-side illumination (Applied Biosystems, CA, USA).

DATA ANALYSIS

For the statistical analysis of sensory and physicochemical data, the XLSTAT software for Microsoft Excel® (XLSTAT version 2020.2.2, Addinsoft) was used. The results of proximal chemical analysis and mineral content were analyzed by Analysis of Variance (one-way ANOVA) followed by Tukey's Multiple Comparison Test, $p < 0.05$. To find out if there was a statistically significant difference in the degree of liking of the samples, one-way ANOVA was used followed by the LSD test, $p < 0.05$ (results are not shown, they were only used for discussion).

The FPM results were analyzed using the General Procrustes Analysis obtaining the graphical representation (PCA) to evaluate the consensus of the judges. To simultaneously process the results of the different analyses (sensory profile and liking level analysis), the MFA (Multi-Factor Authentication) was performed, which allows the simultaneous analysis of various tables of variables, and obtain results, especially graphs, that allow studying the relationship between observations, variables, and tables. Within a table, the variables must be of the same type (quantitative or qualitative), but the tables can be of different types.

The DNA sequences were edited using the DNA Dynamo sequence analysis software (Blue Tractor Software, North Wales, UK). Bases with low quality or discordances between the forward and reverse strands were manually edited. The DNA barcodes were generated using only the molecular markers that could be amplified and

showed discriminative capacity by means of two different types of analyses (Cristians et al. 2018). One phylogenetic analysis used the Maximum Likelihood (ML) statistical method by the nucleotide substitution model that showed the lowest Bayesian information criterion level. For the phylogeny test, we achieved a bootstrap method test with 1000 replications. All the phylogenetic and tree assembly analyses were performed in MEGA 6 software (Tamura et al. 2013), while the trees were edited using the tree figure drawing tool FigTree v.1.4.2 (Institute of Evolutionary Biology, University of Edinburgh, UK). Additionally, a barcoding gap analysis was performed using the Automatic Barcode Gap Discovery method (ABGD) (Puillandre et al. 2012) to detect a significant barcoding gap between intra- and interspecific variation and predict the finest partition of the data set into candidate species.

In the case of *Amaranthus* species, the discriminative capacity was achieved by comparison of both species and other samples available in the GenBank. In the case of the pinnately leaved herbs, *Arracacia edulis*, the samples were compared with *Tauschia madrensis* J.M. Coult. & Rose, a similar endemic species, and *Conium maculatum* L., a toxic invasive species, which has been confused with some native species of Apiaceae, while *Phacelia platycarpa* samples were compared with other *Phacelia* species available in the GenBank.

Results

ETHNOBOTANICAL DATA

Of the native quelites, the species of *Amaranthus* (“quelite de agua” in Spanish; “wasorí,” “huasolí,” or “basorí” in the Rarámuri dialects) are the most consumed quelites and are widely distributed throughout the region with *A. powellii* in the pine-oak temperate forests and with *Amaranthus palmeri* in the seasonally dry subtropical forests. These annual herbs occur naturally in disturbed habitats; they form dense populations inside and along the margins of the milpas. Plantlets of both species appear 2 to 4 weeks after the first rains (usually in May and June) in the mountains while *Amaranthus palmeri* has an additional seasonal availability

in the canyons during the short-lived winter rains known as “equipatas” (usually in February). After rehydrating the leaves of each of the four quelites pasados samples in water, they are cooked for a few minutes in a pot of hot water, the young leaves are squeezed and eaten directly with the meals or heated with onions and other ingredients in lard or vegetable shortening. The cooked leaves can also be ground with processed maize kernels to make tamales and tortillas. These edible greens are processed frequently as quelite pasado to be eaten during winter season.

In the case of the other two species, these perennial herbs have restricted distribution and are consumed by Rarámuri who live near the scattered populations. Known as “quelite rosado” in Spanish and “gonírora” in Rarámuri, *Phacelia platycarpa* is found naturally as isolated individuals in the pine-oak forests of the mountains. However, in milpas, the plants are common; the plowing of the fields divide these perennial herbs with ramified roots and disperse them throughout in a manner like that of *Jaltomata procumbens* (Cav.) J.L. Gentry (Davis and Bye 1982). During the weeding of the milpas, they are tolerated and permitted to remain. The young rosettes of pinnately compound leaves are cut from the caudex with a knife for consumption after they expand with the early rains in May and June. The resprouting rosettes can be harvested throughout the growing season until the reproductive stems emerge. Some Rarámuri have planted these herbs in protected garden plots fertilized with animal dung to increase their availability; this practice, however, contrasts to that of the temporary animal corrals in the milpas where other quelites such as “mekuásare” (*Brassica rapa* L.) and “rochíware” (*Lepidium virginicum* L.; Brassicaceae) are cultivated (Bye 1979). After cooking, the squeezed rosettes are eaten along with the meals or heated in lard along with onions and other ingredients. For consumption during the winter season, they can be processed as quelite pasado.

In contrast, *Arracacia edulis* grows in isolated patches along “arroyos” (seasonal streams) of the pine-oak forests. When milpas are nearby, they grow along the margins and may invade the edges the untilled fields. The taproot does not regenerate after being exposed by plowing. The young rosettes of pinnately

compound leaves are cut from the caudex with a knife for consumption after they expand with the early rains in May and June. The resprouting rosettes can be harvested throughout the growing season until the reproductive stems emerge. The cooked leaves are squeezed and eaten directly with the meals or heated with onions and other ingredients in lard (pork or vegetable). They can be processed as quelite pasado for later consumption. This quelite appears to be declining due to its restricted distribution. Along with habitat destruction, the Rarámuri suggest that overgrazing has reduced its populations. In Norogachi, the type locality of this endemic species of northern Sierra Madre Occidental (Watson 1886), no extant populations are known and only the elders of the community recall eating it in earlier days.

PHYSICOCHEMICAL AND SENSORIAL ANALYSES

To distinguish between the pairs of the two classes of quelites, correlations were observed among the sensorial attributes derived from MFA (Multi-Factor Authentication for appearance, texture, aroma, and flavor) and levels of Liking recorded in the FPM (appearance, aroma, flavor, degree of liking) and from physicochemical characteristics (proximal chemical analysis and mineral content) (Fig. 2). The sample codes are presented in the Electronic Supplementary Material (Appendix 2).

The first and second axis of MFA explains 47% and 33% of the total variance, respectively (Appendix 3). A positive correlation of both components is found in the case of *Amaranthus powellii*. The correlated sensorial attributes of this quelite included: (1) cooked appearance

Fig. 2. PCA mapping from multiple factor analysis of the proximal chemical analysis, mineral and sensory profile of quelites *Amaranthus powellii*, *Amaranthus palmeri*, *Arracacia edulis*, and *Phacelia platycarpa*. The codes correspond to those shown in Appendix 2. Codes 1S-15S correspond to appearance attributes; 16S-27S texture; 28S-38S aroma; 39S-50S taste (or flavor); 51S-52S aftertaste; 53-56 liking; 57PCHA-63PCHA proximal chemical analysis and 64 M-73 M minerals

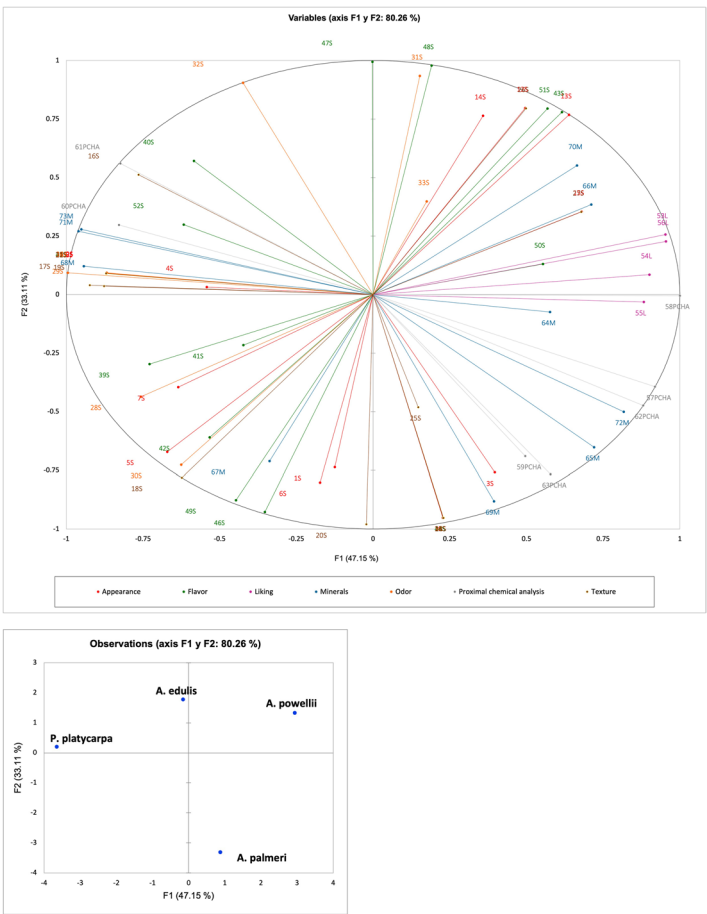


TABLE 1. PROXIMATE COMPOSITION (% DRY BASIS, DB) AND MACRO- (% DB) AND MICROMINERAL (MG/100 G DB) OF FOUR QUELITES (*AMARANTHUS POWELLII*, *AMARANTHUS PALMERI*, *ARRACACIA EDULIS*, AND *PHACELIA PLATYCARPA*) FROM THE SIERRA TARAHUMARA. THE RESULTS OF PROXIMATE COMPOSITION SHOW THE MEAN OF DUPLICATE $\pm$ S.D., C.V. < 5%, AND FOR MINERALS SHOW THE MEAN OF TRIPLICATE $\pm$ S.D., C.V. < 5%. THE AVERAGE CONCENTRATION OF EACH PARAMETER/MINERAL WITH A DIFFERENT LETTER IS SIGNIFICANTLY DIFFERENT ACCORDING TO THE TUKEY'S TEST ($P < 0.05$). THE MORE DISTANT THE LETTERS ARE FROM EACH OTHER, THE GREATER IS THE DIFFERENCE BETWEEN THEM; THE SAME LETTERS INDICATE NO SIGNIFICANT DIFFERENCE BETWEEN THE SPECIES FOR THE GIVEN ATTRIBUTE

Physicochemical parameter/mineral	<i>Amaranthus powellii</i>	<i>Amaranthus palmeri</i>	<i>Arracacia edulis</i>	<i>Phacelia platycarpa</i>
Crude fiber	7.32 ^a	8.94 ^b	12.96 ^c	12.7 ^c
Lipid	4.65 ^d	3.99 ^b	3.64 ^b	2.53 ^a
Crude protein	28.35 ^d	29.23 ^e	21.07 ^c	14.65 ^a
True protein	22.37 ^c	23.93 ^d	16.83 ^b	12.66 ^a
Carbohydrate by difference	40.19 ^b	36.74 ^a	50.36 ^c	54.52 ^e
Ash	19.49 ^d	21.1 ^e	11.98 ^b	15.61 ^c
Ca	2.35 ^e	1.54 ^d	0.76 ^b	1.37 ^c
P	2.61 ^c	2.68 ^c	0.53 ^b	0.37 ^a
Na	0.02 ^a	0.03 ^a	0.14 ^b	0.28 ^c
K	0.24 ^a	0.35 ^b	3.58 ^d	2.74 ^c
Mg	0.70 ^c	1.20 ^d	0.20 ^a	0.46 ^b
Fe	36.59 ^b	56.79 ^c	13.46 ^a	58.53 ^d
Mn	25.25 ^e	6.50 ^a	10.53 ^c	8.64 ^b
Zn	16.85 ^e	13.41 ^d	4.42 ^a	11.00 ^c

and pieces of garlic; (2) garlic and onion smell, garlic flavor, metallic note, sweet taste, and onion aftertaste; and, (3) crunchy texture and palatability. The physicochemical composition revealed the highest content of manganese and copper (Table 1) that may contribute to the perception of a metallic note. Also, it contained the highest contents of protein and fat (Table 1), two of the nutrients that most impact the feeling of satiety. *A. powellii* was the preferred quelite for its aroma, flavor, and general degree of liking: For aroma, with ratings of 6.3 for consumers of quelites (and 6.1 for people who do not consume quelites); for flavor, with ratings of 6.9 for consumers of quelites (and 6.5 for people who do not consume quelites); and for general degree of liking, with ratings of 6.8 for consumers of quelites (and 6.6 for people who do not consume quelites) and with an acceptance classification of “like moderately.” No significant difference ($p < 0.05$) was found between the consumers of quelites and those who did not consume them. The high rating of this quelite may be due to the sweet note that is one of the preferred tastes by the Mexican consumer.

The quadrant with positive correlation of component 1 and negative correlation of component 2 contains *Amaranthus palmeri*. The correlated sensorial attributes include appearance (brightness, fried, rough), texture (adhesive texture and fat sensation), earthy aroma, and acidic taste. The physicochemical composition of this quelite includes the highest content of lipids, crude protein, true protein, ash, as well as three minerals (calcium, cobalt, and phosphorous) (Appendix 4). The degree of liking of its appearance was 5.6 for people who consume quelites (and 5.4 for people who do not consume them), for aroma it was 6.2 for people who consume quelites (5.6 for non-consumers). Moreover, the general degree of liking was 6 for people who consume quelites (5.5 for non-consumers), corresponding with a degree of liking of “slightly.” No significant difference ($p < 0.05$) was found between consumers of quelites and those who did not consume them. This degree of liking could be influenced by its spinach flavor, since in Mexico City this exotic green is a widely accepted and consumed vegetable. *Amaranthus palmeri* from

the Zongolica, Veracruz, Mexico, was also reported as the quelite with the highest content of calcium and magnesium (Turner et al. 2011). Our results coincide with those of Wesche-Ebeling et al. (1995) in which *Amaranthus palmeri* contained the highest levels of crude proteins and crude lipids compared to *Amaranthus blitoides*, *Amaranthus viridis* and *Amaranthus retroflexus*.

The quadrant with negative correlation for component 1 and positive correlation for component 2 includes *Arracacia edulis* and *Phacelia platycarpa*. The correlated sensorial attributes included texture (hardness, rough, sandy, chewiness, and fibrous), aroma (cooked, field, merchandise, green, and bitter), and flavor (fried, herbal, green note, and bitter after taste). Physicochemical composition of this quelite presented the highest content of carbohydrate by difference, crude fiber, as well as the minerals sodium, zinc and potassium and iron.

The degree of liking differed from the previous quelites as well as between them. In the case of *Arracacia edulis*, the degree of liking for appearance was 5 regardless of the type of consumer, for aroma it was 6.3 for quelites consumers (and 6.1 for those who do not consume quelites), while the general degree of liking of 6.2 for quelites consumers (6 for non-consumers) can be considered as “like slightly.” On the other hand, *Phacelia platycarpa* registered the lowest value for flavor and appearance, for flavor it was 4.3 for consumers of quelites (4.1 for non-consumers), while for appearance it was 5 for consumers of quelites (4.7 for non-consumers), and with a general degree of liking of 4.4 for consumers of quelites (4.1 for non-consumers), which is considered “dislike slightly.” No significant difference ($p < 0.05$) was found between consumers and non-consumers.

DNA BARCODING

For *Amaranthus* species, the molecular markers from chloroplast, *matK* and *rbcL*, and the nuclear, *ITS2*, differentiated both species (Fig. 3), *ITS2* being having more informative sites. The comparison with other *Amaranthus* species (i.e., *Amaranthus hypochondriacus*, *Amaranthus hybridus*, and *Amaranthus*

spinosus) available in GenBank suggests that any of those molecular markers are capable of distinguishing among American edible greens belonging to this genus (data not shown).

In the case of *Arracacia edulis*, only the chloroplast markers *matK* and *trnH-psbA* (Fig. 3) allow differentiation among other endemic species, *Tauschia madreensis*, a member of the “wasiá” plant complex and the unintentional, toxic substitute *Conium maculatum* (data not shown). In this case, combining both molecular markers is suggested to generate a strong quality control tool.

Finally, *Phacelia platycarpa* could be identified using the chloroplast markers *rbcL* and *trnH-psbA*, and the nuclear *ITS2* (Fig. 3) when compared with other *Phacelia* species accessible in GenBank (data not shown). It is important to point out that there is only one accession available of the genus *Phacelia* molecular marker *trnH-psbA*; hence, the comparisons with more species must be generated to ensure the discriminative efficacy of this molecular marker.

Discussion

Of the quelites presented in this study, it is notable that there is a preference among the sensorial analyses for the *Amaranthus* species. Although the two species are more common in northern Mexico, their relatives (*Amaranthus hybridus* and *Amaranthus hypochondriacus*, in particular) are highly valued throughout central and southern Mexico (Linares et al. 2019; Mapes and Basurto 2016).

The lower values shown in flavor and appearance for the other two species may be due to the high intensity of the flavor in which the green note and bitter aftertaste predominated. It is essential to mention that in a previous work carried out by this group (Linares et al. 2021), the Rarámuri evaluated food prepared with quelites using a 5-point hedonic scale and gave the food general ratings of “I like it very much” with scores of 4.7. Familiarity can explain these results because Rarámuri consume quelites; therefore, the hedonic response obtained in this study with non-habitual consumers of quelites may be due to their lack of familiarity with them.

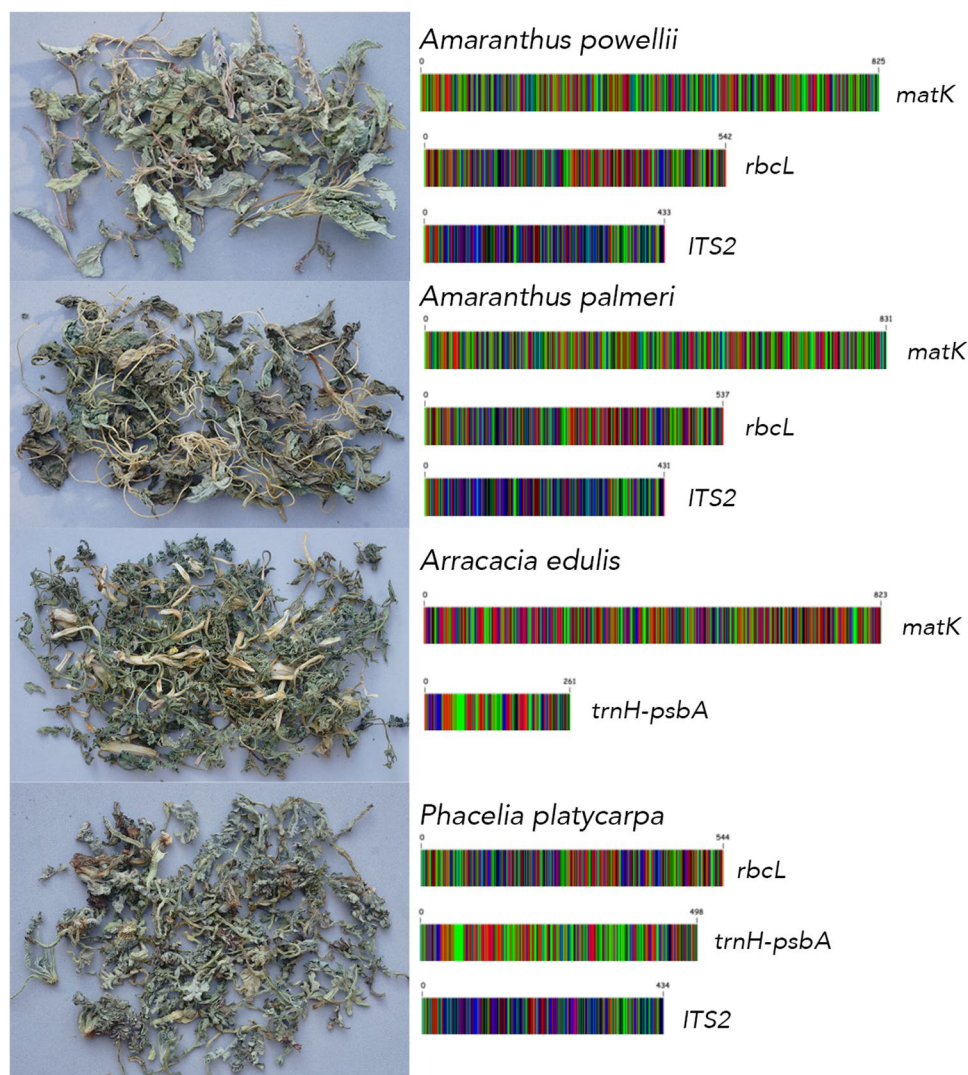


Fig. 3. DNA Barcodes (*matK*, *rbcL*, *trnH-psbA*, and *ITS2*) for four quelites (*Amaranthus powellii*, *Amaranthus palmeri*, *Arracacia edulis*, and *Phacelia platycarpa*) from the Sierra Tarahumara

Also, these quelites are used medicinally, in which the green note and bitter aftertaste is common (Linares et al. 2016). Other studies have observed that healthier foods were generally perceived as not tasting good (De la Cruz-Silva et al. 2020). Consumers' attention to such sensorial attributes is associated with shifts in eating habits toward a focus on natural and organic foods (Tandon 2020).

The unfamiliar attributes were certainly an important influence, although unusual flavors can develop consumer acceptance over time, as illustrated by the European rocket salad (*Eruca sativa* L.; Padulosi and Pignone 1997). A relative of the endemic species *Arracacia edulis*, *Arracacia decumbens* (Benth.) Benth. & Hook. f. ex Hemsl. (syn. *Tauschia decumbens* (Benth.) J.M. Coult. & Rose ex Drude) has a greater

distribution in central Mexico but its consumption is limited to the central region of Michoacán. It is known as “shakuá kumba” and eaten by the Purépecha (personal observations, Bye and Linares; reported as an unidentified plant with the name “akumba” by Santos-Rivera 2013). On the other hand, the peculiar flavor of *Phacelia platycarpa* appears to be appreciated only the Tarahumara. Even though this species stretches across the latitudinal length of Mexico, reports of its consumption are limited to southwestern Chihuahua. Other species of *Phacelia* (*Phacelia distans* Benth., *Phacelia dubia* (L.) Trel., *Phacelia heterophylla* Pursh, *Phacelia ramosissima* Dougl. Lehm.) (Moerman 1998) are known to have been consumed in northwestern Mexico and adjacent USA but have been abandoned due to labor intensive processing required to remove their antinutritional factors.

The demand for foods rich in dietary fibers has increased in the last decade and has led to the development of many fiber-rich products and ingredients (Bingham et al. 2003). Of the quelites reported here, *Phacelia platycarpa* and *Arracacia edulis* represent a good option due to their high fiber content, which was also observed in their proximal analysis. Crude fiber levels are low in the leaves and whole plant, but high in stems; overall crude fiber levels are slightly higher in vegetable amaranths than in traditional vegetable greens. Ash and nitrogen-free extract levels are very similar in all plant parts and comparable to traditional vegetable greens. In addition to presenting a specific sensory profile, quelites have physicochemical characteristics that show that they are foods with high nutritional value. Whole plants and leaves of wild *Amaranthus* species in the vegetative stage showed the greatest potential as green vegetables. They had good protein, nitrogen free extract levels, but the crude fiber levels were slightly higher than in commercial vegetables such as cabbage, cauliflower, broccoli, lettuce, and spinach (Aramrueang et al. 2019).

This study introduces for the first time the use of DNA barcodes for identification of quelites pasados that could be applied in other leafy green vegetables worldwide, especially in food traceability where they are already widely used for quality control of various food products (Galimberti et al. 2013).

The ability to distinguish among the various species of quelites has important applications when considering that they are consumed in juvenile stages or dehydrated. Also, this study contributes new information to the limited molecular data for these plants that present taxonomic dilemmas. There is a diversity of species of the three genera studied, *Amaranthus*, *Phacelia*, and *Arracacia*, which occur in other regions of Mexico. Distinguishing among these species could be incorporated into commercial branding practices and geographic origin labeling to inform consumers and improve the market prices of quelites (Torres 2017). In addition, it could be useful in avoiding poisoning, for example in the case of *Arracacia edulis* that can be confused with *Conium maculatum*, an invasive, poisonous herb commonly found on the margins of irrigation canals in some urbanized areas of Sierra Tarahumara.

In terms of current food security in Mexico, these quelites offer minimum assurance of satisfying the needs beyond the communities in the Sierra Tarahumara. The availability of the young plants is unpredictable because it depends on adequate soil moisture retained from winter snows and captured from the spring rains in addition to the quantity of plants germinating in their natural and anthropogenic habitats. In general, none of the four species are cultivated. This situation contrasts with the Tarahumara's intense cultivation of *Brassica rapa* and *Lepidium virginicum* in corral-fertilized milpa agriculture. Not only has there been insufficient promotion of the production of these four quelites, but also the domesticated grain amaranth, *Amaranthus hypochondriacus* (“oquf”) is not consumed as leafy greens and its occurrence in home gardens has declined, maybe due to cultural erosion.

The access to these quelites pasados continues to be restricted to local exchange networks. Occasionally excess quelites of *Amaranthus* are packaged and sold door to door or in local stores in towns like Creel and Guachochi (Mera et al. 2021). Efforts to link quelite producers with restaurants have not been successful due to insufficient stock.

The utilization of quelites pasados (as well as fresh quelites) is prioritized for home consumption. Most Tarahumara families maintain them in domestic food reserves throughout the year but give priority to Brassicaceae species and secondarily to the *Amaranthus* species.

The availability of these four quelite pasados is at risk in the long run. The increasing duration of droughts, the acculturation of children in boarding schools away from their traditional diets, the lack of public security, among other factors, impact the food security in the region. Educational programs in local schools and capacity building in the communities are being carried out by various non-governmental organizations and institutions to help Tarahumara leaders raise awareness of the situation in their communities (Astier et al. 2021). Linking Tarahumara farmers with markets and restaurants in the region is underway by educational institutions and gastronomic associations. Food tastings and surveys of tourists visiting the region indicate a strong interest of the visitors for consuming quelites. These and other quelites pasados offer a culturally appropriate avenue for the development of the value chain. The principal concern among consumers is the quality of unfamiliar foods including accurate identification of the quelites, clarification of their nutritional and sensorial attributes, maintenance of hygiene of the products, and application of fair market practices. Our study complements the aforementioned social actions to improve the food security role of quelites for both the inhabitants and the visitors to the Sierra Tarahumara, Chihuahua.

As of 2020, over 25 countries in the region of Latin America and the Caribbean have national dietary guidelines (FAO 2015). Even though most countries list vegetables as being the second most important food category for food security, only Guyana specifies “colored greens.” Mexico recommends quelites as an important food source, not only for the different indigenous groups of the country, but also for all the population as a nutritious option (Bonvecchio et al. 2015; Secretaría de Salud 2013; Vázquez et al. 2004). Quelites could improve the diet and give an option to control the overweight problem in the country. The FBDG of the other five regions of the world list the vegetable as secondary to the cereal food group. Only two regions emphasize eating plenty of LGV: Nepal in Asia and Kenya and Sierra Leone in Africa. Over the last three decades, Africa has encouraged LGV as a main component

for food security (Oniang’o et al. 2008; Shayanowako et al. 2021) by promoting over 100 species (Maseko et al. 2017).

Conclusion

The four species of quelites pasados from the Sierra Tarahumara showed considerably high nutritional values, representing a key element for food security in northwestern Mexico. Their level of acceptance by urban consumers is still uneven. The species of the genus *Amaranthus* are the most appreciated. DNA barcodes were developed for the two pairs of quelites, assuring the accurate identification of each species, and contributing with data that could be used for food traceability or geographic origin. Although its potential as a leafy green vegetable is promising, local production, mainly seasonal harvesting, makes it difficult to propose these plants for large-scale marketing. The results obtained about the nutritional potential, together with the identification of the species through their molecular barcodes, generates added value, which, together with future propagation programs, will allow these quelites to be available beyond local consumption. Such expansion will affect the management of local plant populations and generate fair trade that will benefit inhabitants of the Sierra Tarahumara under a sustainable development scheme. Finally, due to the increase in global interest in leafy green vegetables, this multidisciplinary study can be used as an example for carrying out integrative research in other areas, especially in developing countries that need to promote and utilize their plant diversity to assure their food sovereignty.

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Declarations

Ethics Approval and Consent to Participate Field studies and laboratory research were conducted with respect for cultural norms and with prior informed consent of the participants. The research project was reviewed and approved by the University’s Commission of Ethics and Scientific Responsibility (CEARC/Bioética/310821).

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