RESEARCH

Open Access

Production process, rheology, and sensory characterization of Algerian porridge and flatbread derived from *Arum italicum* tubers

Hayat Bourekoua[1*], Radia Ayad[2,3], Hamida Mahroug[1], Fairouz Djeghim[1], Rayene Belmouloud[1], Aya Louifi[1], Alla Eddine Mansouri[1] and Anis Chikhoune[4]

*Correspondence:
Hayat Bourekoua
bourekoua.hayat@umc.edu.dz

Full list of author information is available at the end of the article

Abstract
The traditional knowledge currently practiced by mountain dwellers and older people is in danger of disappearing among younger generations. The preservation of this knowledge enriches culinary diversity and is a response to the challenges of food security and sustainability. This research aims to contribute to this field and focuses on the comprehensive analysis of *Arum italicum* tuber powder, encompassing physicochemical and structural characterization. Additionally, it explores the traditional making processes of products derived from these tubers. The research included a survey conducted at the regional level in Algeria to establish manufacturing diagrams for products. The key findings reveal that *A. italicum* tubers are an energetic food, providing 366.88 kcal/100 g, with a notably high total carbohydrate content (80.86%). Moreover, the tuber powder displays remarkable water-holding capacity and solubility. In-depth Fourier-Transform Infrared analysis elucidates the prevalence of β-sheet in the amide I band, with an R ratio of 0.57corresponding to the crystalline and amorphous fractions of starch. According to the survey results, the preparation procedures for the two doughs–flatbread named *Kesra* and porridge named *ayerni*–are identical. The tubers must first be precooked before being sliced and steamed. The porridge and flatbread are next made using the chopped tubers in accordance with particular diagrams. Rheological analysis revealed superior consistency in porridge, while sensory evaluation confirmed equal consumer acceptance of both porridge and flatbread. This study preserved ancestral knowledge and provided useful scientific information for future uses by enabling the scientific characterization of the natural resource.

Keywords *A. italicum* tubers characteristics, Survey, Rheology, Sensory evaluation, Porridge, Flatbread

1 Introduction

Wild tuber plants play a vital role in diversifying the human diet by serving as a significant source of food energy, mainly in the form of carbohydrates. Throughout history, humans have utilized wild plants for various purposes, including as food, fodder, and medicine. In the early stages of human evolution, the underground storage organs (tubers) of wild plants were considered essential sources of energy and formed an integral part of the diet of early hominids [1, 2].

In recent times, there has been a significant increase in the utilization of wild edible plants in both developed and developing countries due to their therapeutic properties. Among these plants, *Arum italicum*, from the Arum genus, holds particular significance as a species of the Araceae family. This genus (Arum) comprises 29 species that grow in temperate and Mediterranean climates [2, 3].

Arum italicum Mill., is distributed across Southern and Western Europe, the Balkans, North Africa (south to Morocco and Algeria), the Caucasus, Iraq, and Turkey. This self-propagating species possesses inherent toxicity [4].

The Arum genus (A. italicum and A. maculatum) has garnered scientific interest due to its diverse range of beneficial properties and its historical applications in traditional medicine. These plants have been shown to be effective in treating a variety of conditions, including hemorrhoids, furuncles, chilblains, arthritis, contusions, rheumatism, and varicose ulcers. Across various regions, the tubers, leaves, and fruits of *A. italicum* are employed for various remedies. Dried tubers are recommended at a daily dosage of 1–2 g for their laxative and expectorant properties. A mixture of powdered tubers and honey is used to treat stomach ulcers. Fresh tubers are applied topically for eczema, fissures of the feet, and nipple fissures, as well as for treating wounds and abscesses [4, 5].

Culinary uses are also documented. The tubers and leaves of Arum species have historically been used as soap in Europe. The tubers of *A. italicum* and *A. maculatum* are still utilized in Bosnia for the preparation of focaccia or boiled meats. The consumption of *A. italicum* during times of famine in Albania has been documented, and its use continues today in various forms. Additionally, the leaves are consumed in southeastern Europe after being repeatedly boiled. In Switzerland, eating Arum leaves in the spring is considered a cleansing treatment [6]. Furthermore, Guarrera [7] and Paura and Di Marzio [6] highlight the tubers of *A. italicum* as a fascinating source of high-quality starch, employed in Sicily for making candies and confetti, flour, and bread.

In addition, *A. italicum* contains active compounds, specifically referred to as phenolic compounds or polyphenols, which are secondary metabolites widely distributed throughout the plant kingdom including saponins, alkaloids, steroidal compounds, neolignans, and furan-type lignans. While primarily abundant in roots [8].

Because of their high starch, which is especially significant in regions facing food security challenges, tubers are a potential source of energy and essential nutrients [2]. Research into the understudied tubers of *A. italicum* is crucial for the diversification of food sources and the development of innovative food products, especially given the current lack of scientific data on their composition.

The fresh tuber of *Arum italicum* is highly acrid and toxic, but heat neutralizes its harmful properties. Consumption of the raw tuber can lead to symptoms ranging from a burning sensation in the mouth and throat, swollen tongue, vomiting, and diarrhea to cardiac irregularities and stomach pain. Despite these characteristics, local communities use it both for its health benefits and as a food source [2, 9].

This toxicity primarily results from the presence of extremely irritating insoluble calcium oxalate crystals in the plant. Additionally, a toxic saponin or alkaloid further enhances the toxic effect of oxalate crystals. Arum tubers also contain alkaloids related to conicine: aronine, aroine, and arodine [10, 11]. However, *Arum italicum* tubers are safe to eat after cooking, as the acrid principle dissipates through boiling in water for at least fifteen minutes. This heat treatment breaks down sharp calcium oxalate crystals and neutralizes other potential irritants. Additionally, various detoxification methods are employed before consumption, including extended boiling, which usually involves straining the boiled water and reducing the pH using lemon juice, sumac, citric acid, sorrel leaves, or pomegranate juice. On the other hand, drying the tubers and rhizomes, grinding them into flour, boiling the flour in water, and then drying the resulting mixture is also reported. This flour can be mixed with other flours to make bread [12, 13].

At the local level, the tubers of *A. italicum* are steamed to remove toxic substances, making them easier to handle and obtain dough. This dough is then used to make flatbread and porridge. This traditional knowledge faces the risk of vanishing among the younger generations, as it is currently practiced by people from the mountains and the elderly. Preserving this knowledge remains a priceless aspect of community life, as it not only enriches the culinary diversity of different cultures but also provides practical solutions to challenges related to food security and sustainability. This traditional knowledge deserves scientific attention to ensure the wisdom of our ancestors continues to nourish and inspire future generations. Moreover, certain characteristics of *A. italicum* tubers, such as their structural and techno-functional properties, have not been thoroughly studied.

This work aligns with the context and aims to characterize the tubers of *A. italicum* while shedding light on the ethnic Algerian practices involving their use to enrich the scientific knowledge of tubers and preserve the cultural heritage of Algerian communities.

First, the physicochemical, techno-functional, and structural properties of tuber powder were evaluated to gain a comprehensive understanding of its potential applications. In addition, traditional diagrams for the preparation of different products from the tubers were established, describing the main preparation steps for each product through a survey conducted in different localities in northeastern Algeria. The products were then characterized by their rheological and sensory properties.

2 Materials and methods

2.1 Materials

Samples of *Arum italicum* were collected from the *Texenna* region located in the Jijel province, in northeastern Algeria. The tubers were harvested when reaching their maturity during the spring period of March (this is reflected in aged leaves and tubers with hard skin and large size). The materials included a list of questions about the processing of porridge and flatbread. A camera and audio were utilized to help group and analyze data. Other materials used were utensils, tagines, and dishes. The ingredients used to prepare the traditional products were purchased from a local market. The composition of wheat semolina was the following: moisture content (12.23%), ash content (0.83%), lipid content (0.67%), and protein content (13.93%). The buttermilk (*Lben*) displayed a pH of 4.5, an acidity of 83 °D, and a dry weight of 79.66 g/L. Other ingredients such as salt and butter were also utilized in the experiments.

2.2 Characterization of *A. italicum* tubers

2.2.1 Elaboration of powder

The *A. italicum* tubers were washed, brushed, drained, carefully wiped, and then peeled. They were sliced into 2 mm thick pieces and dried at 40 °C for 4 h in a ventilated dryer (MAXEL S.A. ARRAS MAXEI, Type MC 100, Arras, France).As reported by Cosme-De Vera et al. [14], this temperature can be used for drying tubers shaped into circles. The drying was conducted in three replicates. Once dried, the tubers were finely ground to obtain powder particles using a BOMANN grinder with a capacity of 100 g, running at high speeds (2800 rpm; 1300 w). The obtained powder was sieved through a 500 µm sieve to separate the fine flour from any larger particles. Preparation steps of tuber powder are illustrated in Fig. 1.

2.2.2 Determination of proximate composition of tuber powder

The contents of protein, fat, and ash were determined on a dry matter basis following AOAC standard methods [15]. The moisture content was assessed using the AOAC 926.12 method, ash content by the AOAC 942.05 method, and protein content by the AOAC 960.52 method. The fiber content was determined using the Weende method [16] with a raw fiber extractor. The carbohydrate content was calculated by subtracting the percentage of protein, fat, moisture, ash, and dietary fiber content from 100% of the dry matter. The calorific value per 100 g of tuber powder was calculated based on energy factors: 9 for fats, 4 for carbohydrates, and 4 for proteins. The values were the means of three replicates.

2.2.3 Determination of functional properties of tuber powder

2.2.3.1 Water-holding capacity The water-holding capacity (WHC) of the tubers was determined according to Nguyen et al. [17] with modifications. 1 g of tuber powder (analytical balance AS R2 PLUS) was mixed with 15 mL of distilled water using a vortex (VELP Scientifica, ZX3) and left to rest overnight at room temperature (19 °C ± 2), followed by

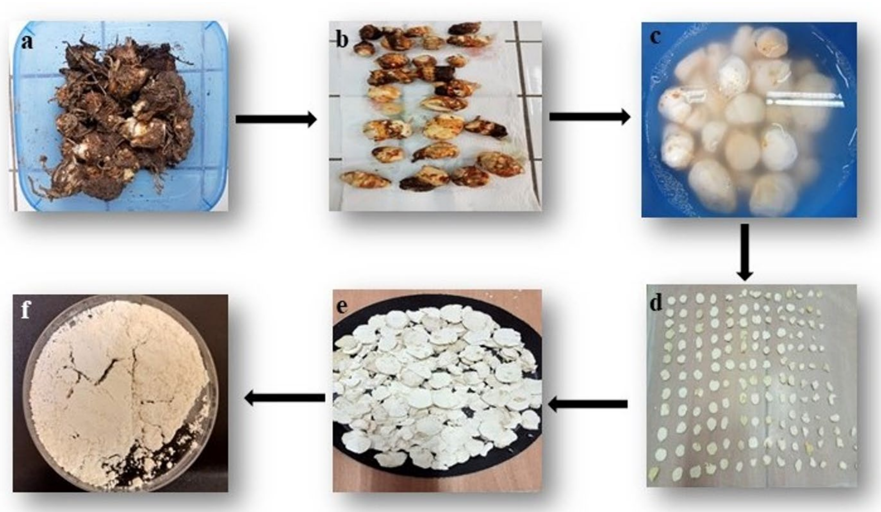

Fig. 1 *Arum italicum* tuber powder production steps. **a**: *A. italicum* tubers; **b**: cleaned tubers; **c**: washed and peeled tubers; **d**: divided tubers; **e**: dried tubers: **f**: tuber powder

centrifugation at 15000× g for 20 min using a Sigma 3-30K centrifuge (Osterode am Harz, Germany). The supernatant was decanted, and the new mass of the sample was recorded. WHC (g water/g powder) was calculated as the mean of three replicates as:

$$WHC\left(\frac{g}{g}\right) = \frac{Total\ water\ mass}{Dry\ matter\ mass} \tag{1}$$

2.2.3.2 Oil-holding capacity The oil holding capacity (OHC) of the tuber powder was determined according to Badia-Olmos et al. [18]. Tuber powder (1 g) was mixed with 15 mL of sunflower oil for 5 min. The mixture was left to rest at room temperature overnight (19 ± 2 °C), and then centrifuged at 15000 × g for 20 min (Sigma 3–30 K centrifuge, Osterode am Harz, Germany. The supernatant was decanted, and the centrifuge tube with the precipitate was weighed. The OHC was calculated as the mean of three replicates as follows:

$$OHC\left(\frac{g}{g}\right) = \frac{(m_{oiled} - m_d)}{m_d} \tag{2}$$

Where: m_d and m_{oiled} are the mass of dry material and the masse of sample including held oil respectively.

2.2.3.3 Solubility The water solubility of tuber powder was determined following Cano-Chauca et al. [19]. One gram of powder was dispersed in 100 mL of distilled water by mixing at high speed (13,000 rpm) for 5 min using an Osterizer mixer (Oster, Mexico). The dispersed powder was then centrifuged at 3000 × g for 5 min. Afterward, 25 mL of the supernatant was carefully pipetted and transferred into a pre-weighed Petri dish (dried in the oven at 105 °C for 5 h). Weighing was carried out every hour. The solubility of the powder was determined as the mean of three replicates as follows:

$$S\,(\%) = \frac{Dried\ supernatant\ mass}{powder\ mass} \times 100 \tag{3}$$

2.2.3.4 Swelling capacity The swelling capacity (SC) of tuber powder was determined according to Jurevičiūtė et al. [20] with modifications. One gram of tuber powder was mixed with 15 mL of distilled water and left to swell at room temperature (20 °C ± 2) for 24 h. The SC was expressed in milliliters of swollen sample per gram of dry powder and calculated as the mean of three replicates using the following formula:

$$SC\left(\frac{mL}{g}\right) = \frac{volume\ after\ swelling - initial\ volume}{powder\ mass} \tag{4}$$

2.2.4 Fourier-transform infrared spectroscopy analysis

FTIR spectroscopy was used to analyze the secondary structure of proteins and starch conformation in arum flour using the IRAffinity-1S Fourier-transform infrared spectrometer (Shimadzu, Izasa Scientific, France), equipped with a diamond attenuated total reflectance attachment (ATR). Spectra were collected ranging from 4000 to 400 cm^{-1} with 128 scans and a resolution of 8 cm^{-1} against the background, with five replicates.

Each spectrum was baseline-corrected using Origin software (version 8.0724 PRO, Origin Lab Corporation, USA). The analyzed spectra were averaged over five registered spectra series. In order to separate the overlapping bands in the amide I region and to allow an identification of the constituents of protein secondary structure, the second derivative of the amide I band was calculated using a five-points two-degree polynomial function. Following that, the second derivative spectra were smoothed with an 11-points, two-degree polynomial Savitsky–Goly function. To estimate quantitatively the fraction of each type of secondary structure amide I band (1590–1720 cm^{-1}), baseline corrected and normalized, was deconvoluted with Gaussian curves using Origin software (version 8.0724 PRO, Origin Lab Corporation, USA) and PeakFit software (Version 4.6 PeakFit, USA) according to the second derivative peak identification. The quality of the band deconvolution was indicated by $R^2 \geq 0.990$. The relative composition of secondary protein structures participating in the amide I band was expressed as a percentage of the area of the fitted region expressed as a relative area of components centered at specific wavenumbers [21]. The secondary structure assignment was based on absorption wavenumbers according to the studies of Bock and Damodaran [21] and Yang et al. [22]. The crystalline and amorphous fractions of starch were analyzed by estimating the intensity ratio of peak I (1047 cm^{-1}) to peak I (1022 cm^{-1}).

2.3 Survey about traditional products from *Arum italicum tuber* and data collection

To study the traditional Algerian products prepared from *A. italicum* tuber, a survey was conducted in the cities of Jijel, Skikda, Constantine, Mila, and Annaba in Northeast Algeria (Fig. 2). The choice of these towns was based on the preliminary study conducted in other localities in Algeria where only people from the selected regions responded to the survey. These towns are the most popular in terms of the use of cuckoo pint tubers. The selected participants agreed to volunteer. A simple random sampling approach was utilized to identify respondents at various locations, including artisans and merchants

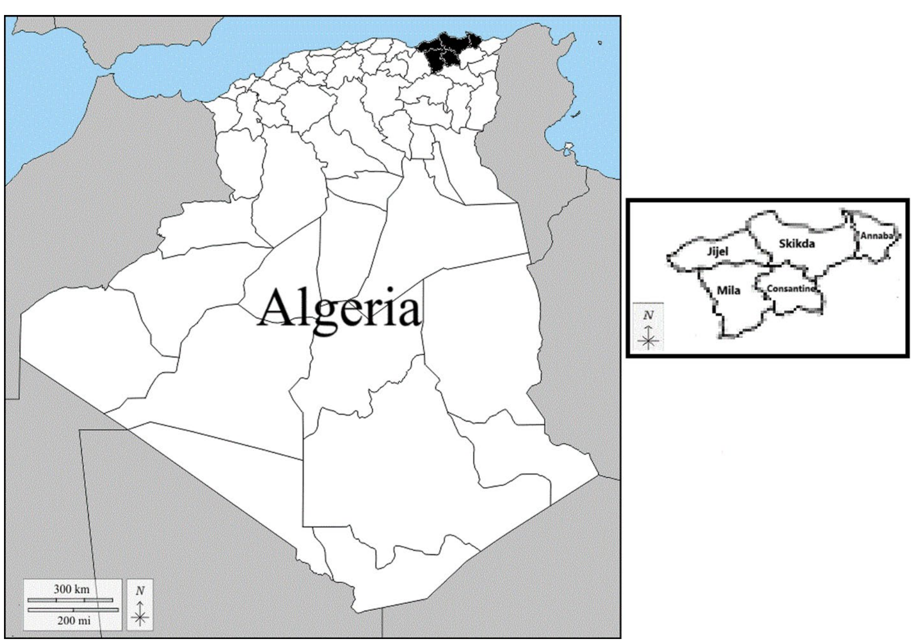

Fig. 2 Map of surveyed provinces in northeastern Algeria

who sell the tubers, as well as residents of mountain regions. Participants were selected based on their familiarity with the plant, traditional practices, and consumption habits. The local language was used to ensure effective communication and accurate data collection. Individuals who have no familiarity with the traditional practice being studied were excluded from participation.

A total of 52 homemakers and consumers of tubers participated in the survey, including the largest number of people who are familiar with the plant and its traditional applications. It can be considered representative due to the rarity of individuals practicing this tradition, as it is in the process of disappearing and is not known by the new generation. This traditional knowledge is specific to an older generation of people who mostly live in certain areas. The survey is conducted with individuals who have a deep understanding of this plant, ensuring more accurate and reliable information.

The data collection was conducted using a questionnaire containing general open-ended questions about the *Arum italicum* plant. The questionnaire was pre-tested with ten consumers and experts of the plant and its usage in different regions of the study area. Based on the pre-survey results, relevant modifications were made to the questionnaire to validate the final version used. The questionnaire was structured as follows: First, respondents provided their identification details (age, gender, and residence location). Then, information about products made from the cuckoo pint tuber and the common name of each product was collected. The most crucial section of the questionnaire gathered information about the ingredients and their proportions for manufacturing each product, along with the manufacturing steps and flow diagram. The surveyed population was asked to respond based on their personal knowledge and experiences.

2.4 Reproduction of traditional products preparation

The production processes for porridge and flatbread were reproduced based on data collected during the survey. The specific utensils employed in each stage are described in subsequent sections. Both products were subjected to rheological and sensory evaluation.

2.5 Rheological measurements of porridge and flatbread dough

In this study, the flow properties of both porridge and flatbread dough were evaluated using a Haake VT 550 Rheoviscosimeter (Haake Mess Technik GmbH Co, Karlsruhe, Germany). Flatbread dough was prepared according to a traditional recipe, and both the dough and porridge samples were allowed to rest for 20 min prior to testing. For rheological measurements, the dough and porridge samples were placed between parallel plates with a 4.5 mm gap, utilizing a plane-plane geometry (Haake, PK 5, 0.5 grads). To prevent slippage, sandpaper was applied to the inner and lower surfaces of the parallel plate, following the method described by Djeghim et al. [23]. Additionally, a preliminary 5-minute resting period was observed before initiating measurements. This step facilitated the release of any residual stress and ensured temperature stabilization at 25 °C, achieved using the HAAKE DC3 thermostat and HAAKE K15 cryostat. Shear rates ranging from 1.2 to 30 s^{-1} were applied. The rheological data collection spanned a 3-minute analysis using the Haake TheoWin version 2.09 software. The consistency index was determined as the mean of four replicates. The power-law model (Ostwald de Waele) was used:

$$\eta_{ap} = K.\gamma^{n-1}$$

Where: η_{ap}: apparent viscosity (Pa.s); γ: shear rate (s^{-1}); and *n*: flow behavior index. *K* (consistency index, Pa.s^n) represents the stress required to obtain a shear rate of 1 s^{-1}.

2.6 Sensory evaluation

The sensory analysis of porridge and flatbread was performed on a panel of 55 consumers, aged between 18 and 45 years old. Some individuals in the panel claimed to have previously consumed products made from *A. italicum* tubers. A consumer-based rating test was performed by tasters on a nine-point hedonic scale (1: dislike extremely, 5: neither like nor dislike, 9: like extremely) [24]. Taste, aroma, color, texture, appearance, and overall acceptability were evaluated for each sample. The chosen panelists participated on a voluntary basis. Participants were briefed on the study's objectives prior to the test and gave their consent in accordance with the ethical guidelines of the INATAA Institute, Constantine 1 Frères Mentouri University.

2.7 Data analysis

The results obtained are expressed as mean ± standard deviation. Data analysis for the survey was performed using Epi Info statistical software (version 7.2, CDC, Atlanta, GA, USA). The response rate was determined by dividing the number of respondents by the total survey population. Data was expressed as the percentage of respondents rounded to the total number of the surveyed population. The means of rheological properties and sensorial analysis were compared by a Student T-test with STATISTICA software version 10 (Statsoft, France). The letters *a* and *b*, indicate the different groups at the significance level of 0.05.

3 Results and discussion

3.1 *Arum italicum* tubers characteristics

3.1.1 Proximate composition of A. italicum tubers

It is important to evaluate the biochemical composition and nutritional value when a powder is considered as a food source. Emphasizing the nutritional value of tubers is preferable for potential diversification of their uses and to maintain our overall health. The demand for detailed composition information is on the rise globally, as consumers seek more comprehensive knowledge about both raw and processed foods [25, 26]. Table 1 depicts the proximate composition and calorific value of *A. italicum* tuber powder.

According to the Table, the moisture content was 9.7%, while protein, fat, ash, fiber, and carbohydrate contents were 7.05%, 2.8%, 1.62%, 1.9%, and 76.93%, respectively. The

Table 1 Proximate composition and calorific value of *A. italicum* tubers (per 100 g of dry weight)

Tubers	Value per dry weight
Moisture (%)	9.7 ± 0.04
Protein (%)	7.05 ± 0.12
Fat (%)	2.8 ± 0.03
Ash (%)	1.62 ± 0.01
Fiber (%)	1.9 ± 0.02
Carbohydrate (%)	76.93
Calorific value (kcal/100 g)	361.12

substantial carbohydrate content, in the form of starch, is responsible for the high carbohydrate value. The results of carbohydrate align with those of Alcantara et al. [27] for other species of the Araceae family (*Colocasia esculenta*), which contained 86.11% of carbohydrate. As previously reported by Lim [28], tubers serve as a storage organ for the plant.

The protein content of *A. italicum* tuber powder is supported by that found in taro (*Colocasia esculenta*) with 8.07% protein, while the fiber content is lower than taro's (3.10%). The protein and the fiber content of *A. italicum* tuber remain higher than that of sweet potato (1.6%), cassava (1.4), and yam (1.5%). However, tubers are storage organs that are typically rich in starch but contain lower amounts of protein compared to other food sources such as cereals and legumes [25, 29].

In terms of fat content (Table 1), *A. italicum* tubers have a higher fat content (2.8%) compared to taro with a value of 0.45% [27]. The high ash content in *A. italicum* tubers makes them excellent providers of minerals. The calorific value of cuckoo-pint tubers is 361.12 kcal/100 g, which is attributed to their high carbohydrate content. Roots and tubers are significant sources of dietary energy, mainly derived from carbohydrates [30]. With a calorific value greater than 300, tubers are considered an energy source, as reported by Bourekoua et al. [31]. *A. italicum* tubers' high carbohydrate content makes them an ideal energy food, though they are extremely low in lipids and fiber.

Yang et al. [32] found that tubers, which comprise a range of carbohydrate-rich foods including traditional starchy staples, are high in carbohydrate but have a lower glycemic index (GI) than cereals (below 55). Potato, yam, and lotus powders are reported to have a lower GI than boiled and steamed tubers. The considerable differences in the GI of different tubers suggest that factors such as processing and the type of food significantly influence the GI value.

3.1.2 Functional properties

The functional properties of flours arise from the intricate interplay between various factors and components. Proteins and starch, in particular, are essential in food product manufacturing, allowing for adjustments in formulations to meet the unique requirements of each food application (dough formation, bakery products, etc.) [33]. The techno-functional properties of *A. italicum* powders, including water holding capacity, oil holding capacity, solubility, and swelling capacity, are crucial for product manufacturing, as they significantly impact the shelf life and overall stability of powdered products. Table 2 presents these properties.

3.1.2.1 Water-holding capacity Water holding capacity is an essential indicator to be determined because it makes it possible to know whether the powders can be incorporated into aqueous food formulations [34].

Table 2 Techno-functional properties of *A. italicum tubers*

Properties	***A. italicum*** **tuber powder**
WHC (g/g d.w)	4.71 ± 0.39
OHC (g/g d.w)	1.176 ± 0.24
Solubility (%)	61.82 ± 10.94
SC (mL/g)	3.16 ± 0.23

WHE: water holding capacity; **OHC**: oil holding capacity; **SC**: swelling capacity

A. italicum tuber powder demonstrated a WHC value of 4.71 g/g d.w (Table 2), higher than that of fruits and tubers, as reported by Longe [35]. However, it was lower than the value found by Lauková et al. [36] for sweet potato (9.00 g/g). A higher WHC value of the tubers indicates that the resulting powder has a greater ability to absorb and bind water, playing a decisive role in the preparation of various food products. Consequently, the final products are likely to be thicker and more viscous.

The WHC value can be attributed to the presence of a large number of carbohydrates as well as the non-starch components such as fiber, which contribute to the high water absorption capacity of *A. italicum* tuber powder [37]. It also indicates that tuber powder may have more hydrophilic constituents, such as polysaccharides. WHC is also linked to the chemical structure and hydrophobic/hydrophilic balance at the surface of polysaccharides [23]. In addition, food's water-holding capacity (WHC) is directly linked to the amount of water its proteins can bind. This implies that a higher protein content leads to increased water interaction. This characteristic is attributed to the hydrogen bonding between water molecules and matrix proteins. Consistent with this, foods with more protein demonstrate greater WHC [38], indicating that an *A. italicum* tuber powder protein level significantly affects its WHC.

The water holding capacity of *A. italucum* tuber powder is important, as it can positively affect the texture, juiciness, and taste of food formulations based on these tubers. Products such as porridge and flatbread made from these tubers may possess interesting viscosity properties.

The tuber powder of *A. italicum* serves as a valuable ingredient in bakery products due to its high water retention capacity, allowing for the addition of more water to the dough. This enhances its workability while preserving the freshness of the final product [34].

3.1.2.2 Oil-holding capacity The ability of powder to bind oil is the primary reason for its commercial use, which involves emulsification. The ability of powder to bind with oil may help to improve flavor and to maintain the structure and the texture of the resulting product [39]. As depicted in Table 2, the value calculated for OHC of *A. italicum* tuber powder is 1.176 g/g, similar to tuber starches of sweet and bitter cassava and potato with values ranging from 0.962 to 1.152 g/g [40]. The latter explained that the oil absorption capacity is related to the emulsifying ability, and high oil absorption properties are essential for meat replacers and extenders, baked goods, and soups. The presence of hydrophobic groups in the tuber molecules likely contributes to this value [41]. According to Sanchez-Portillo et al. [42], *Arracacia xanthorrhiza* tuber flour exhibited a higher value of OHC compared to *A. italicum*, suggesting its potential in structural interactions within foods, particularly in retaining flavors and aromas, improving quality, and extending shelf life, making it particularly valuable for long-term food preservation, especially in bakery products.

High OHC values in samples indicate their potential as emulsifiers and their functional role in enhancing viscosity and texture in formulated foods [43]. The physical trapping of fat by proteins and the lipophilic nature of the granules affect oil absorption [44].

3.1.2.3 Solubility The solubility of tuber powder was 61.82% (Table 2), which is considerable compared to tuber starches of sweet and bitter cassava, as well as the findings of Azima et al. [40] on tuber starches of sweet and bitter cassava.

The ability of water to penetrate the powder is indicated by its solubility. The amount of amylose in the starch and its origin influence powder solubility. Thus, the rate of amyloidosis diffusion in the water could explain these differences [45]. It is reported that powders with high water retention capacity exhibit high solubility, and vice versa. Therefore, WHC is closely related to the soluble fraction of the powder, as suggested by Andrade-Mahecha et al. [46]. The presence of amylose in the starch and its origin influence powder solubility. Greater amorphous surfaces in the powder lead to higher solubility, while a more crystalline state corresponds to lower solubility [19]. Sanchez-Portillo et al. [42] suggest that flour with high solubility can function as a thickener and improve dough elasticity and plasticity.

It is observed that tuber powder exhibits high water retention capacity and solubility. This could indicate that water retention capacity is closely linked to the soluble fraction present in the powder. These properties make tuber powder a valuable ingredient for bakery products.

3.1.2.4 Swelling capacity Swelling capacity is a measure of hydration capacity and an essential factor in food flavor and water retention in swollen starch granules [47]. The tuber powder demonstrated a swelling capacity of 3.16 mL/g (Table 2). This value is lower than that found by Lauková, Minarovičová et al. [36] for sweet potato (8.16 mL/g) and may be attributed to its higher intermolecular association and elevated amylose content, as reported by Kusumayanti et al. [48].The starch content, protein, lipid, and varietal origin influence the swelling capacity. Thus, the existence of strong bonds, most likely due to proteins and lipids forming inclusion complexes with amylose, can explain the swelling capacity [49].

A flour's swelling capacity depends on the source material, how it's processed, and its particle size. This swelling ability, along with water absorption capacity, contributes to the viscosity of liquid and semi-liquid foods. The amount of amylose and amylopectin, including their chain lengths and the presence of starch phosphate groups, are known to affect both the swelling capacity and retrogradation of flours and starches [50].

According to Ashogbon [51], roots and tubers typically have a greater swelling power than grains because their starch granules are larger.

Krisbianto and Minantyo [52] found that cocoyam tuber flour has a high swelling capacity, suggesting its suitability for products requiring volume expansion when cooked with water, such as noodles.

According to [33], flours with high swelling capacity may enhance the formulation of aqueous-based food products. On the other hand, flours with low swelling capacity are particularly suitable for creating dense, nutrient-rich foods intended for infants.

3.1.3 The secondary structure of proteins and starch conformation in A. italicum tuber powder

The structural properties of *A. italicum* powder tubers, specifically the secondary structure of proteins and starch conformation, were analyzed to gain insights into its molecular properties.

Figure 3 shows deconvoluted amide I bands [1590–1720] cm^{-1} where the protein backbone of the examined flour was fitted with five peaks according to second derivative peak identification.

Secondary structure composition of tuber powder can be delineated by examining distinct peaks centered at specific wavenumbers: 1606 and 1628 cm^{-1}, assigned to β-sheet, 1645 cm^{-1} associated with random coil; 1659 cm^{-1} characterizing α-helix, and 1673 cm^{-1} representing β-turn structures (**details in Supplementary Table S1**). In terms of quantification, the amide I band predominantly reflects β-sheet content (46.47%), followed by β-turn (20.35%) and random coil (20.36%) structures, with α-helix structure (12.78%) constituting the least prevalent.

Absorbance bands situated at 1047 cm^{-1} and 1022 cm^{-1} correspond to the crystalline and amorphous fractions of starch, respectively.

As reported by Shevkani et al. [53] and Mirzapour-Kouhdasht et al. [54], a higher β-sheet content is associated with lower solubility and digestibility, which in turn impacts nutrient bioavailability. Consequently, a high β-sheet content results in diminished functional properties related to solubility, such as foaming, emulsifying ability, and water retention capacity. However, a high β-sheet content increases thermal stability and gel formation properties.

The absorbance intensity ratio, designated as R equal to I (1047 cm^{-1})/I (1022 cm^{-1}), is a commonly employed indicator of the arrangement of different starch components [55, 56]. A high R value indicates a prevalence of crystalline conformation over the amorphous form, indicating a significant tendency towards retrogradation and a marked level of ordered structure in the outer region, closely resembling amylomaize starch [55]. The calculated R ratio of *A. italicum* tuber powder stands at 0.57. This value is lower than the R ratio value found for Lotus rhizome by Yuet al. [57], which exceeded 0.93. The *A.*

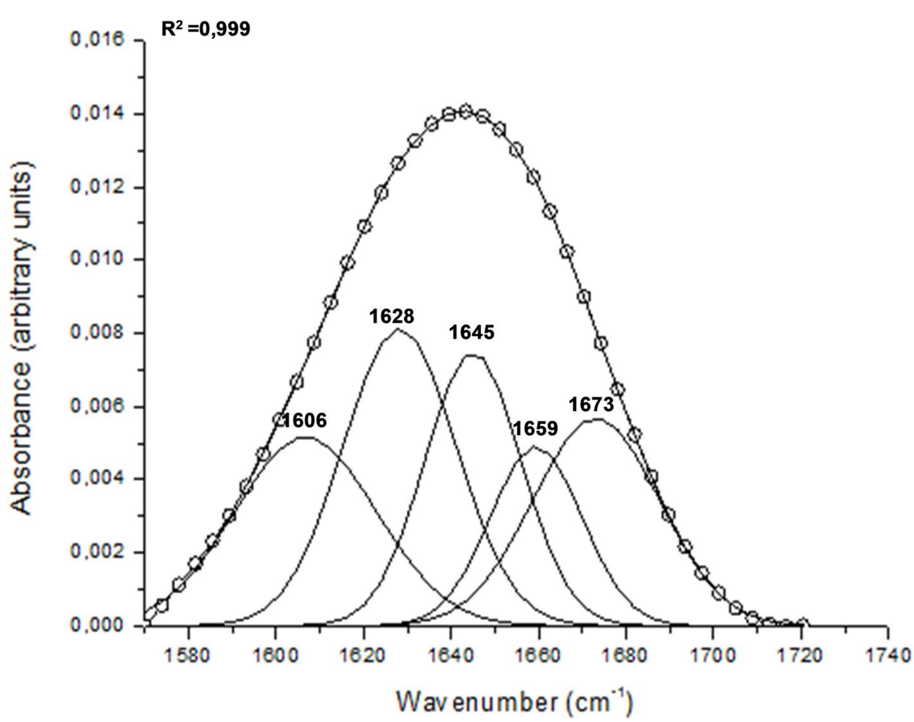

Fig. 3 Deconvoluted amide I band (1590–1720 cm^{-1}) of *A. italicum* powder

italicum tuber used in this study is characterized by lower starch crystallinity. This conclusion is reinforced by the aforementioned solubility results of tuber powder, indicating that increased water solubility occurs when amorphous surfaces are more prevalent within it. Our results indicate that starch with low crystallinity is digested more easily and more quickly and improves gelatinization properties [58, 59].

3.2 Results of the survey

The survey showed (Table 3) that the majority of the surveyed population (63.46%) were women, and 36.53% were men. The age distribution indicated that 17.30% were between 18 and 35 years, 32.69% were between 35 and 55 years, and 50% were between 55 and 75 years. The surveyed population resided mainly in Jijel (60%), followed by Constantine (21.15%), Annaba (7.69%), Skikda (7.69%), and Mila (5.76%). These results correlate with the number of participants familiar with this tradition, who are predominantly located in the region where the plant grows. Specifically, Jijel province, with its extensive mountainous terrain, is home to a significant population that practices this traditional knowledge. Given the age and geographic distribution of the majority of participants, it appears that these traditional practices are still followed in this area. Older generations showed a strong interest in this information. Interestingly, a sizable portion of younger participants demonstrated engagement as well, suggesting that the knowledge is transmitted across generations. Compared to men, women were more firmly linked to this transmission.

3.2.1 Main ingredients and traditional preparation steps of products

Based on the survey results, two main traditional products from *A. italicum* tubers were identified: porridge named *Ayerni* or *Keriwa* (80.76% of the surveyed population) and flatbread named *Kesra* (19.24% of the surveyed population). All of the surveyed declared using the same ingredients for making flatbread, namely semolina, salt, and the required amount of water for dough formation. On the other hand, the survey showed that 60% of homemakers used buttermilk to prepare the porridge, whereas only 40% made it using water. On the other hand, 77% used butter at the end, while 23% added olive oil to prepare the porridge. The overall diagrams for traditional porridge and flatbread preparation were established (Figs. 4 and 5). These figures illustrate the production processes as described by the interviewed producers, based on the calculated percentages.

Table 3 Characteristics and sociodemographic structure of the 52 surveyed persons

Surveyed population	N	%
Age (years)		
18-35	9	17.30
35-55	17	32.69
55-75	26	50
Gender		
Women	33	63.46
Men	19	36.53
Region		
Jijel	30	60
Constantine	11	21.15
Annaba	4	7.69
Skikda	4	7.69
Mila	3	5.76

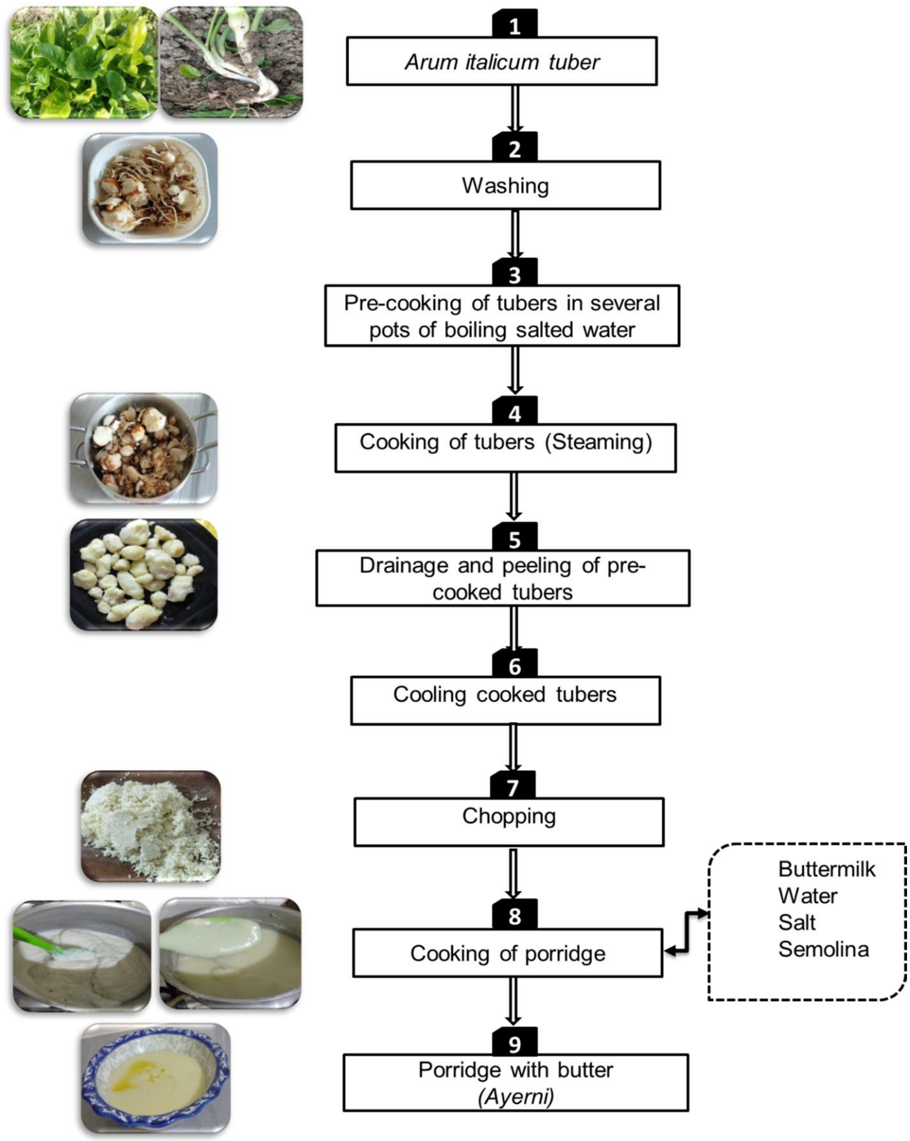

Fig. 4 Preparation steps for porridge from *A. italicum* tuber based on the survey results

Table 4 presents the main ingredients used for the preparation of porridge and flatbread from *A. italicum* tubers according to the survey results.

3.2.1.1 Dough preparation main steps Both processes (for flatbread and porridge) followed the same dough preparation method, as reported by all interviewers:

3.2.1.2 Pre-cooking of tubers Pre-cooking in salted water is the first step after washing, defined by all interviewers (100%) for both the flatbread and porridge processes. This step is crucial to eliminate the tuber toxicity. The fresh tuber is composed of volatile, bitter-tasting substances, starch, gum, sugar, potassium, calcium, oxalates, and saponin salts. When properly dried and ground, the plant's root is safe to eat. However, the saponin oxalates in its fresh state can cause skin irritations, such as wounds and blisters. It is crucial to prepare it correctly to avoid its toxic effects [11].

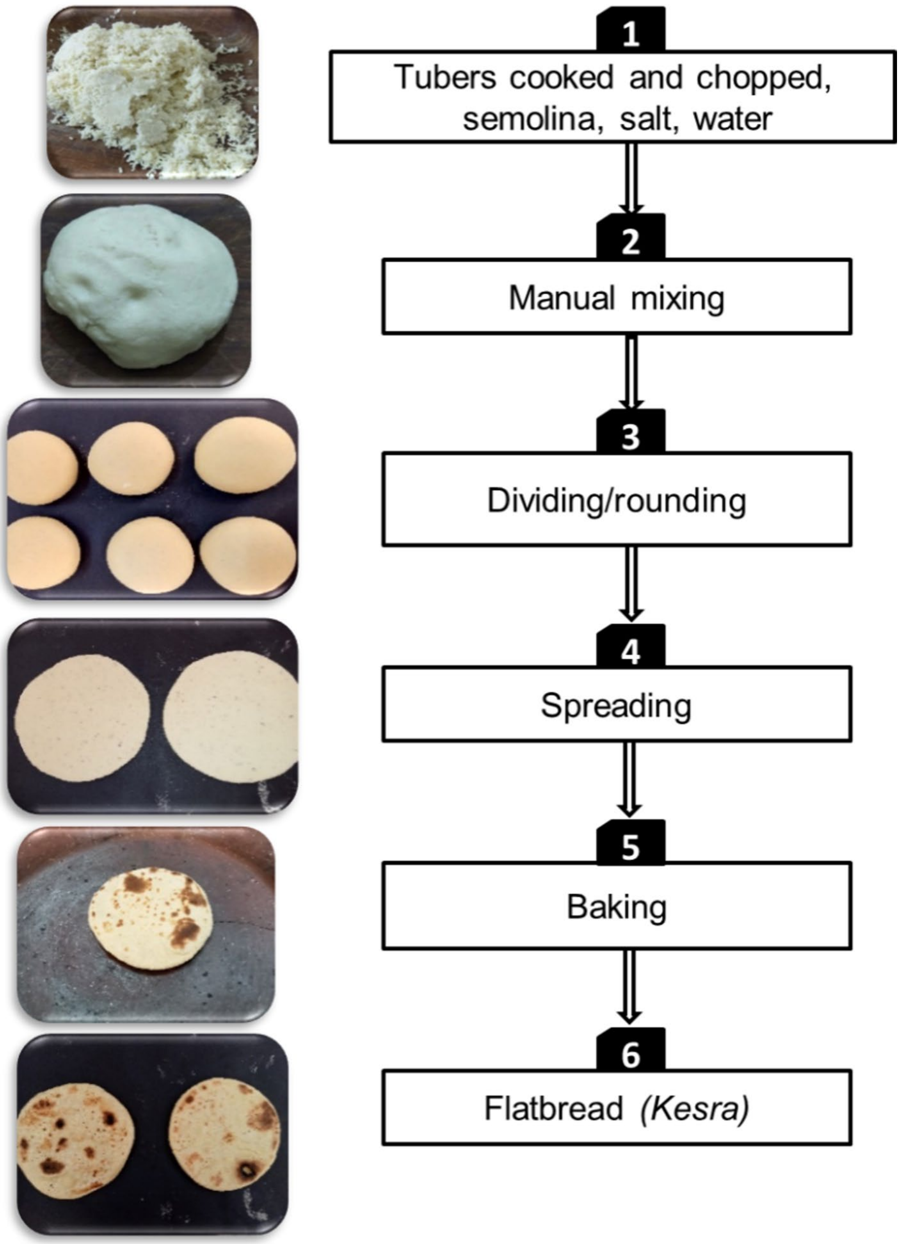

Fig. 5 Preparation steps for flatbread from *A. italicum* tuber based on the survey results

Table 4 Main ingredients used in the preparation of traditional products

Porridge	Flatbread
Chopped tuber (300 g)	Chopped tuber (250g)
Semolina (30 g)	Semolina (200g)
Buttermilk (300 mL)	Water (50 mL)
Water (150 mL)	Salt (5 g)
Salt (6 g)	
Butter (15 g)	

Soudy et al. [12] reported that boiling Arum genius tubers in water for at least fifteen minutes neutralizes these toxic components, making them safe to consume. It is important to highlight that specific empirical data on the toxicity of Arum genius tubers following traditional drying processes is lacking. Therefore, further studies on this subject are necessary.

3.2.1.3 Cooking of tubers (steaming) All interviewers (100%) reported a steaming step to obtain tuber dough, which takes approximately one hour and thirty minutes. The cooking step ensures food safety by neutralizing the rest of toxic compounds, such as oxalates and saponins. Furthermore, heating accentuates and enhances the tubers' natural flavors, making the recipes more appealing. It also softens the tubers, making them more tender, and promotes their inclusion into diverse dishes.

3.2.1.4 Chopping of tubers After steaming, the cooked tubers were peeled and chopped to facilitate their use in various ethnic products, such as flatbread and porridge, according to all interviewers.

3.2.2 Porridge manufacturing

According to the survey results, the traditional recipe for porridge (*ayerni)* involved using cooked and chopped tubers (300 g), wheat semolina (30 g), salt, buttermilk (300 ml), and butter (Table 4). The chopped tubers were mixed with buttermilk, water, and semolina. The total cooking time was about two hours. The mixture was cooked over low heat for about 45 min. Before serving the porridge, butter was added. The main steps are shown in Fig. 4.

3.2.3 Flatbread manufacturing

A mixture was prepared to make flatbread based on *A. italicum* tuber. It consisted of chopped cooked tubers (about 250 g) in dough form, wheat semolina (200 g), salt (5 g), and hydration water (Table 4). The preparation procedure involved manually kneading the ingredients for 10 min until a homogeneous dough was formed. The dough was then divided into lumps, which were shaped and flattened with a rolling pin to form disks measuring about 0.5 cm in thickness. The flatbread was cooked for about 5 min on both sides in a preheated griddle (*clay tajine kesra*). The flow diagram resulting from the survey of traditional flatbread (*Kesra)* is shown in Fig. 5.

3.3 Flow properties of *A. italicum* tuber porridge and flatbread dough

The viscosity of fluid foods plays a crucial role in designing food processes and processing equipment, as well as in evaluating and controlling the quality of food products. Furthermore, it provides insights into the structural characteristics of food materials.

Table 5 presents the coefficients of consistency (K), flow behavior index, (n) and r-value (statistical correlation coefficient) for both porridge and flatbread dough.

Table 5 Flow properties of *A. italicum* tuber porridge and flatbread dough

	K ($Pa.s^n$)	*N*	*r*
Porridge	5391.66 ± 735.54^a	-1.044 ± 0.03	0.87 ± 0.009
Flatbread dough	93.85 ± 35.00^b	0.214 ± 0.098	0.93 ± 0.047

Letters a, b indicated significant difference at 0.05 levels

Table 6 Sensory characteristics of *A. italicum* tuber porridge and flatbread

	Taste	Aroma	Color	Texture	Appearance	Overall
Porridge	6.20 ± 2.22^a	5.85 ± 2.29^b	7.29 ± 1.48^a	6.76 ± 1.77^a	6.98 ± 1.66^a	6.69 ± 1.60^a
Flatbread	6.47 ± 1.48^a	6.58 ± 1.74^a	6.85 ± 1.35^a	6.80 ± 1.72^a	6.96 ± 1.48^a	7.09 ± 1.13^a

Letters a, b indicated significant difference at 0.05 levels for the same column

For porridge and flatbread dough, the power-law model demonstrated a high correlation coefficient. This suggests that the power-law model is a good fit for analyzing the properties of porridge and flatbread dough.

The consistency coefficient of *A. italicum* tuber porridge is 5391.66 ± 735.54 Pa·s^n at a temperature of 25 °C. This value indicates the resistance to flow exhibited by the porridge. Interestingly, the consistency coefficient of *A. italicum* tuber porridge is higher compared to that of rice porridge [60, 61] and sweet potato porridge [62] at different temperatures. According to Ezekiel and Singh [63], flours with lower amylose content and higher water absorption exhibit higher consistency coefficients. Additionally, the *A. italicum* tuber porridge displays non-Newtonian shear-thinning behavior, evident by having a flow behavior index (n) less than 1. This behavior implies that the porridge's viscosity decreases with increasing shear rate. The negative value of the flow behavior index (n) for porridge could be attributed to the presence of slippage in the fluid, viscosity dispersion, or molecular degradation of the sample [23, 64].

The consistency coefficient of flatbread dough was 93.85 ± 35.00 Pa·s^n. This value was higher compared to the results obtained by Baljeet et al. [65] for wheat varieties of *Triticum aestivum* dough. The increase in the consistency coefficient may be attributed to the incorporation of *A. italicum* tuber porridge. Adding this porridge to the mixture might have changed the viscosity, leading to a higher consistency coefficient. This could be attributed to the specific composition and properties of *A. italicum* tuber, which might have contributed to the overall characteristics of the dough.

In a study conducted by Ezekiel and Singh [63], the rheological properties of dough made from mixtures of wheat and potato flour were investigated. The researchers discovered that as the proportion of potato flour increased in the dough, its consistency significantly increased as well. This suggests that the addition of potato flour had a notable impact on the viscosity of the dough.

On the other hand, the flow behavior index of flatbread dough was 0.214 ± 0.098; it still remained below the value of 1. This indicates a significant shear-thinning behavior or pseudo-plasticity observed in the flatbread dough.

3.4 Sensorial characteristics of porridge and flatbread

The palatability of food results from the delicate interplay of texture and taste. Hedonic tests are imperative to comprehend the factors underlying a food's desirability, helping identify local preference determinants. Table 6 depicts the average scores given by consumers for traditional porridge and flatbread made from cuckoo-pint tubers.

A *T-test* conducted on sensory attributes (taste, aroma, color, texture, appearance, and overall acceptability) confirms no significant differences *(> 0.05)* between traditional products made from *A. italicum* tubers (porridge and flatbread). The only exception *(< 0.05*) is observed for aroma, where flatbread scores higher with 6.58 compared to porridge's score of 5.85.

Overall, both products are well-received by tasters in terms of taste (6.20 for porridge and 6.47 for flatbread), color (7.29 for porridge and 6.85 for flatbread), texture (6.76 for porridge and 6.80 for flatbread), appearance (6.80 for porridge and 6.96 for flatbread), and overall acceptability (6.69 for porridge and 7.09 for flatbread). Considering all attributes, the traditional *A. italicum* tuber products receive positive feedback and acceptance from all tasters.

The richness of tubers in carbohydrates and their considerable protein content influence their functional properties. Therefore, the texture, firmness, taste, color, and flavor of the finished product are affected. All these characteristics of the arum tubers result in products highly appreciated by tasters, even among the new generations who may not necessarily know the traditions associated with this tuber.

4 Conclusions

The utilization of *Arum italicum* tubers addresses three main challenges: *i)* valuing the cultural heritage of local traditional Algerian cuisine as a green, healthy, and sustainable diet to generate innovative recipes for reshaping industrially processed food products;*ii)* creating new access channels to food markets and exploiting the benefits of using such natural raw materials to manufacture affordable products for consumers; and *iii)* introducing and adapting commonly effective agroecological practices to increase local smallholders' revenues, create a business model that is crisis resilient, and increase food production. The tubers' composition mainly consists of carbohydrates, predominantly starch. Also, the unique techno-functional properties make them an attractive ingredient for enhancing the quality and nutritional profile of various food products, due to their high water-holding capacity and solubility. The structural analysis revealed complex protein and starch structures, which provided knowledge of their functionality. These properties are essential for the prediction of the behavior of the tubers' powder enrichment in a complex food matrix. The processed end product from this powder is expected to hold the native nutritional and bioactive qualities with minimal impact on the environment if appropriate technologies are used during the preparation of the tubers' powder, specifically, to completely remove the toxicity of the tubers. Despite a long history of traditional use including a detoxification method for tubers, experimental validation via advanced toxicity tests is still essential to ensure its safety. The study also demonstrated the consumer acceptability of traditional products, such as porridge and flatbread made from *A. italicum* tubers. These products' acceptability and consumer response towards claims associated with tubers powder-enriched food products may also be evaluated strategically by other complementary acceptability sensory tests and conjoint analysis. Ultimately, information on food safety, regulatory and economic feasibility of *A. italicum* tubers as a natural and functional new ingredient is needed for the development of new and diverse food items.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44187-025-00556-7.

Supplementary Material 1

Acknowledgements

The authors would like to greatly acknowledge all the persons and informants who participated in this study especially the homemaker: Rekaik Yamouna.

Author contributions
H.B and R.A: Conceptualization, Methodology, Writing-Original draft; H.M: FT-IR analysis; F.D and R.B: Data curation, Software; L.A and M.A.E.: investigation, visualization; A.C and H.B: supervision, writing—review and editing validation. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
The protocol was approved by the institute of INATAA- Constantine 1 Frères Mentouri University in accordance with the Scientific Council of the institute. The Scientific Council of the INATAA Institute is the ethics committee/IRB at INATAA University of Constantine 1– Frères Mentouri.

Informed consent
Informed Consent was obtained from all the participants to participate in the study.

Plant guidelines
· The authors confirm that all methods were carried out by relevant guidelines and regulations of INATAA - University of Constantine 1Frères Mentouri. · The experimental protocols were approved by the laboratory of LNTA-INATAA University Research. · The collection of the plants used in the study complies with local or national guidelines with no need for further affirmation.

Author details
[1]Equipe FNPAA, Laboratoire de Nutrition et Technologie Alimentaire (L.N.T.A.), Institut de la Nutrition, de l'Alimentation et des Technologies Agro-Alimentaires (I.N.A.T.A-A.), Université Constantine1 Frères Mentouri, Route de Ain El-Bey, 25000 Constantine, Algeria
[2]Laboratory of Phytochemistry and Pharmacology, Department of Chemistry, Faculty of Exact Sciences and Informatics, University of Jijel, 18000 Jijel, Algeria
[3]Research Unit: Valorization of Natural Resources, Bioactive Molecules, and Physicochemical and Biological Analyses, Department of Chemistry, Constantine 1-Frères Mentouri University, 25000 Constantine, Algeria
[4]Equipe PVNTA, Laboratoire ALIMENTS, École Supérieure des Sciences de l'Aliment et des Industries Agroalimentaires (ESSAIA), Avenue Ahmed Hamidouche Route de Beaulieu, El Harrach, 16200 Alger, Algeria

Received: 16 January 2025 / Accepted: 21 July 2025

Published online: 26 July 2025

References

1. Calle J, Gasparre N, Benavent-Gil Y, Rosell CM. Aroids as underexplored tubers with potential health benefits. Adv Food Nutr Res. 2021;97:319–59. https://doi.org/10.1016/bs.afnr.2021.02.018.
2. Ceylan F, Sahingoz SA. Using ethnobotanical plants in food preparation: cuckoo pint (*Arum maculatum* L). Int J Gastron Food Sci. 2022;29:100529. https://doi.org/10.1016/j.ijgfs.2022.100529.
3. Bilir G, Sarıahmet M, Ekinci D. Purification and characterization of glutathione reductase enzyme from *Arum maculatum* leaf. Black Sea J Agric. 2023;6(3):269–74. https://doi.org/10.47115/bsagriculture.1247272.
4. Ağalar HG, Ciftci GA, Göger F, Kirimer N. Activity guided fractionation of *Arum italicum* Miller tubers and the LC/MS-MS profiles. Rec Nat Prod. 2018. https://doi.org/10.25135/rnp.06.17.05.089.
5. Lourenço SC, Moldão-Martins M, Alves VD. Antioxidants of natural plant origins: from sources to food industry applications. Molecules. 2019;24(22):4132. https://doi.org/10.3390/molecules24224132.
6. Paura B, Marzio PD. Making a virtue of necessity: the use of wild edible plant species (also toxic) in bread making in times of famine according to Giovanni Targioni Tozzetti (1766). Biology. 2022;11(2):285. https://doi.org/10.3390/biology11020285.
7. Guarrera PM. Il patrimonio etnobotanico Del Lazio. Plant Biosyst. 1994;128(1):446–446. https://doi.org/10.1080/11263509409437253.
8. Ulusoylu M, Gürbüz B. The cytotoxicity and the antimicrobial activities of *Arum italicum* Miller. J Res Pharm. 2022. https://doi.org/10.29228/jrp.196.
9. Kozuharova E, Kochmarov V, Kachaunova E, Espíndola A, Aleksandrov B, Mincheva I. Distribution of *Arum* (Araceae) in Bulgaria. Flora Mediterr. 2014;24:51–62. https://doi.org/10.7320/FlMedit24.051.
10. Yayla Ö. Tirsik: turning poison into an alternative medicine. J Tour Gastron Stud. 2021;9(3):1536–46. https://doi.org/10.21325/jotags.2021.853.
11. Saygın S, Varol B, Ozdemır N, Sargin I, Arslan G. Encapsulation of edible cuckoopint (*Arum maculatum*) tuber powder. Selçuk Üniversitesi Fen Fakültesi Fen Dergisi. 2023;49(2):46–52. https://doi.org/10.35238/sufefd.1333046.
12. Soudy I, Delatour P, Grancher D. Effects of traditional soaking on the nutritional profile of taro flour (*Colocasia esculenta* L. Schott) produced in Chad. Rev Med Vet. 2010;1(2010):37–42.

13. Łuczaj Ł, Emre G. Lords-and-ladies (Arum) as food in Eurasia: a review. Plants. 2025;14(4):577. https://doi.org/10.3390/plants14040577.
14. Cosme-De Vera FH, Rubi RVC. A comprehensive review on the drying kinetics of common tubers. Appl Sci Eng Prog. 2021;14(2):146–55. https://doi.org/10.14416/j.asep.2021.03.003.
15. AOAC. Official methods of analysis. Association of Official Analytical Chemists: Arlington; 2005.
16. Henneberg W, Stohmann F. Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer. Verlag der Bayerischen Akademie der Wissenschaften. 1863.
17. Nguyen DQ, Mounir S, Allaf K. Research article functional properties of water holding capacity, oil holding capacity, wettability, and sedimentation of swell-dried soybean powder.Sch. J. Eng. Tech. 2015; 3(4B):402-412
18. Badia-Olmos C, Sánchez-García J, Laguna L, Zúñiga E, Haros CM, Andrés AM, Tarrega A. Flours from fermented lentil and quinoa grains as ingredients with new techno-functional properties. Food Res Int. 2024;177:113915. https://doi.org/10.1016/j.foodres.2023.113915.
19. Cano-Chauca M, Stringheta PC, Ramos AM, Cal-Vidal J. Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. Innov Food Sci Emerg Technol. 2005;6(4):420–8. https://doi.org/10.1016/j.ifset.2005.05.003.
20. Jurevičiūtė I, Keršienė M, Bašinskienė L, Leskauskaitė D, Jasutienė I. Characterization of berry pomace powders as dietary fiber-rich food ingredients with functional properties. Foods. 2022;11(5):716. https://doi.org/10.3390/foods11050716.
21. Bock JE, Damodaran S. Bran-induced changes in water structure and gluten conformation in model gluten dough studied by Fourier transform infrared spectroscopy. Food Hydrocoll. 2013;31(2):146–55. https://doi.org/10.1016/j.foodhyd.2012.10.014.
22. Yang H, Yang S, Kong J, Dong A, Yu S. Obtaining information about protein secondary structures in aqueous solution using Fourier transform IR spectroscopy. Nat Protoc. 2015;10(3):382–96. https://doi.org/10.1038/nprot.2015.024.
23. Djeghim F, Bourekoua H, Różyło R, Bieńczak A, Tanaś W, Zidoune MN. Effect of by-products from selected fruits and vegetables on gluten-free dough rheology and bread properties. Appl Sci. 2021;11(10):4605. https://doi.org/10.3390/app11104605.
24. Lim HS, Park SH, Ghafoor K, Hwang SY, Park J. Quality and antioxidant properties of bread containing turmeric (*Curcuma longa* L.) cultivated in South Korea. Food Chem. 2011;124(4):1577–82. https://doi.org/10.1016/j.foodchem.2010.08.016.
25. Sarkiyayi S, Hamman B. Research Article nutritional evaluation of some legumes and vegetables cultivated and consumed in Yola, Adamawa State, Nigeria. Adv J Food Sci Technol. 2015;7(9):658–67. https://doi.org/10.19026/ajfst.7.1624.
26. Akalu ZK, Geleta SH. Comparative analysis on the proximate composition of tubers of *Colocasia esculenta*, L. Schott and *Dioscorea alata* cultivated in Ethiopia. Am J Biosci Bioeng. 2019;7(6):93–101. https://doi.org/10.11648/j.bio.20190706.13.
27. Alcantara RM, Hurtada WA, Dizon EI. The nutritional value and phytochemical components of taro [*Colocasia esculenta* (L.) Schott] powder and its selected processed foods. J Nutr Food Sci. 2013;3(3):1–7. https://doi.org/10.4172/2155-9600.1000207.
28. Lim TK. Edible medicinal and non-medicinal plants, vol. 1. Springer; 2012. https://doi.org/10.1007/978-94-017-9511-1.
29. Chovatiya NC, Goswami PB, Barvaliya PP, Rafaliya R. Roots and tubers crops: nutritional value and functional food potential—a comprehensive review.J.Biochem. 2025; 8(1): 1–12.DOI: 10.52338/job.2025.4349
30. Arutselvan R, Raja K, Pati K, Chauhan VBS, Nedunchezhiyan M. Tuber crops and their potential in food and nutritional security. In: Pandemics and innovative food systems. CRC Press; 2023. p. 122– 136.
31. Bourekoua H, Djeghim F, Ayad R, Benabdelkader A, Bouakkaz A, Dziki D, Różyło R. Development of energy-rich and fiber-rich bars based on puffed and non-puffed cereals. Processes. 2023;11(3):813. https://doi.org/10.3390/pr11030813.
32. Yang Y-X, Wang H-W, Cui H-M, Wang Y, Yu L-D, Xiang S-X, Zhou S-Y. Glycemic index of cereals and tubers produced in China. World J Gastroenterol. 2006;12(21):3430. https://doi.org/10.3748/wjg.v12.i21.3430.
33. Belmouloud R, Bourekoua H, Wójtowicz A, Mahroug H, Ayad R, Krajewska M, Rózyło R. Physicochemical, functional, antioxidant, pasting and FT-IR spectroscopic properties of fermented acorns and Sorghum using traditional Algerian processes. Processes. 2024. https://doi.org/10.3390/pr12081647.
34. Randrianantenaina AR, Razafimahefa TAF, Rajaonarison JF. Propriétés fonctionnelles des farines de trois variétés Malagasy de manioc les plus cultivées dans la Région de DIANA. Afr Sci. 2018;14(3):274–81.
35. Longe O. Water-holding capacity of some African vegetables, fruits and tubers measured in vitro. J Food Sci. 1984;49(3):762–4. https://doi.org/10.1111/j.1365-2621.1984.tb13205.x.
36. Lauková M, Minarovičová L, Karovičová J, Kohajdová Z. Quality evaluation of sweet potato powder-enriched cereal products. Food Sci Technol Int. 2019;25(6):523–32. https://doi.org/10.1177/1082013219842711.
37. Oyim IR, Anyango JO, Omwamba MN. Effect of pre-gelatinization conditions on the total oxalate content and techno-functional properties of taro (*Colocasia esculenta*) flour. Food Nutr Sci. 2022;13(6):511–25. https://doi.org/10.4236/fns.2022.136039.
38. Traynham T, Myers DJ, Carriquiry AL, Johnson LA. Evaluation of water-holding capacity for wheat–soy flour blends. J Am Oil Chem Soc. 2007;84(2):151. https://doi.org/10.1007/s11746-006-1018-0.
39. Jayanthi B, Divya D, Indran S, Aruna M, Karthika R, Arjunan S, Selvankumar T, Manikandan E, Santhi R. Influence of freeze-drying and fresh cooking on starch morphology and physicochemical and thermal properties of various tropical tubers. Int J Biol Macromol. 2021;183:1794–806. https://doi.org/10.1016/j.ijbiomac.2021.05.136.
40. Azima F, Nazir N, Efendi H. Characteristics of physico-chemical and functional properties of starch extracts from tubers. J Phys Conf Ser. 2020. https://doi.org/10.1088/1742-6596/1469/1/012002
41. Tharise N, Julianti E, Nurminah M. Evaluation of physico-chemical and functional properties of composite flour from cassava, rice, potato, soybean and xanthan gum as alternative of wheat flour. Int Food Res J. 2014;211641-1649.
42. Sanchez-Portillo S, del Rosario Salazar-Sánchez M, Campos-Muzquiz LG, Ascacio-Valdés JA, Solanilla-Duque JF, Badillo CML, Flores-Gallegos AC, Rodríguez-Herrera R. Proximal characteristics, phenolic compounds profile, and functional properties of *Ullucus tuberosus* and *Arracacia xanthorrhiza*. Explor Foods Foodomics. 2024;2(6):672–86. https://doi.org/10.37349/eff.2024.00058.
43. Aydin E, Gocmen D. The influences of drying method and metabisulfite pre-treatment on the color, functional properties and phenolic acids contents and bioaccessibility of pumpkin flour. LWT. 2015;60(1):385–92. https://doi.org/10.1016/j.lwt.2014.08.025.

44. Soro S, Konan G, Elleingand E, N'guessan D, Koffi E. Formulation d'aliments infantiles à base de farines d'igname enrichies au soja. Afr J Food Agric Nutr Dev. 2013;13(5):8313–39. https://doi.org/10.18697/ajfand.60.12655.
45. Chanapamokkhot H, Thongngam M. The chemical and physico-chemical properties of sorghum starch and flour. Agric Nat Resour. 2007;41(5):343–9.
46. Andrade-Mahecha MM, Tapia-Blácido DR, Menegalli FC. Physical–chemical, thermal, and functional properties of achira (*Canna indica* L.) flour and starch from different geographical origin. Starch-Stärke. 2012;64(5):348–58.
47. Ikegwu O, Okechukwu P, Ekumankana E. Physico-chemical and pasting characteristics of flour and starch from achi *Brachystegia eurycoma* seed. J. Food Technol. 2010; 8 (2): 58-66.
48. Kusumayanti H, Handayani NA, Santosa H. Swelling power and water solubility of cassava and sweet potatoes flour. Procedia Environ Sci. 2015;23:164–7. https://doi.org/10.1016/j.proenv.2015.01.025.
49. Nasrin TAA, Noomhorm A, Anal AK. Physico-chemical characterization of culled plantain pulp starch, peel starch, and flour. Int J Food Prop. 2015;18(1):165–77. https://doi.org/10.1080/10942912.2013.828747.
50. Melese A, Abera S, Mitiku D. Investigation of wheat—anchote (*Coccinia abyssinica* (Lam.)) composite flours and baking temperature for cookies production. Food Res. 2021;5(1):252–65.
51. Ashogbon AO. Roots and tubers: functionality, health benefits, and applications. In: Handbook of cereals, pulses, roots, and tubers. CRC Press, 2021. p. 531-550..
52. Krisbianto O, Minantyo H. Physicochemical characteristics of tannia cocoyam (*Xanthosoma sagittifolium*) corm flour compared to flours and starches of other grains and tubers. Food Res. 2024;8(3):54–61. https://doi.org/10.26656/fr.2017.8(3).226.
53. Shevkani K, Singh N, Chen Y, Kaur A, Yu L. Pulse proteins: secondary structure, functionality and applications. J Food Sci Technol. 2019;56:2787–98. https://doi.org/10.1007/s13197-019-03723-8.
54. Mirzapour-Kouhdasht A, Shaghaghian S, Majdinasab M, Huang J-Y, Garcia-Vaquero M. Unravelling the digestibility and structure–function relationship of lentil protein through germination and molecular weight fractionation. Foods. 2025;14(2):272. https://doi.org/10.3390/foods14020272.
55. Smits AL, Ruhnau FC, Vliegenthart JFG, van Soest JJG. Ageing of starch based systems as observed with FT-IR and solid state NMR spectroscopy. Starch-Stärke. 1998;50(11–12):478–83.
56. Meziani S, Jasniewski J, Gaiani C, Ioannou I, Muller J-M, Ghoul M, Desobry S. Effects of freezing treatments on viscoelastic and structural behavior of frozen sweet dough. J Food Eng. 2011;107(3–4):358–65. https://doi.org/10.1016/j.jfoodeng.2011.07.003.
57. Yu H, Cheng L, Yin J, Yan S, Liu K, Zhang F, Xu B, Li L. Structure and physicochemical properties of starches in lotus (*Nelumbo nucifera* Gaertn.) rhizome. Food Sci Nutr. 2013;1(4):273–83. https://doi.org/10.1002/fsn3.37.
58. Kadam S, Tiwari B, O'Donnell C. Improved thermal processing for food texture modification. In: Modifying food texture. 2015. p. 115–31. https://doi.org/10.1016/B978-1-78242-333-1.00006-1.
59. Qi X, Tester R. Impact of starch gelatinization on digestibility and human health. Starch-Stärke. 2023;75(5–6):2200195. https://doi.org/10.1002/star.202200195.
60. Syahariza Z, Yong H. Evaluation of rheological and textural properties of texture-modified rice porridge using tapioca and sago starch as thickener. J Food Meas Charact. 2017;11(4):1586–91. https://doi.org/10.1007/s11694-017-9538-x.
61. Li H, Yaoa X, Yinga Z, Panga Z, Caoa J, Wangb Y, Liu X. Rheological and tribological characteristics of mung bean-rice porridge and its impact on sensory evaluation. Int J Food Prop. 2020;23(1):1490–505. https://doi.org/10.1080/10942912.2020.1810065.
62. Ahmed J, Ramaswamy HS. Viscoelastic properties of sweet potato puree infant food. J Food Eng. 2006;74(3):376–82. https://doi.org/10.1016/j.jfoodeng.2005.03.010.
63. Ezekiel R, Singh N. Use of potato flour in bread and flat bread. In: Flour and breads and their fortification in health and disease prevention. Elsevier; 2011. p. 247–59. https://doi.org/10.1016/B978-0-12-380886-8.10023-6
64. Bourekoua H, Ferradji S, Ayad R, Chikhoune A, Belmouloud R, Djeghim F, Wójtowicz A, Różyło R. Enhancing gluten-free bread-making: process optimization of starch blend in premix with rice and corn flour enriched with various natural flours. Cereal Res Commun. 2025. https://doi.org/10.1007/s42976-025-00655-2.
65. Baljeet S, Yogesh S, Ritika B. Physicochemical and rheological properties of Indian wheat varieties of *Triticum aestivum*. Qual Assur Saf Crops Foods. 2017;9(4):369–81. https://doi.org/10.3920/QAS2015.0745.

Publisher's Note