Heliyon 10 (2024) e29174

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Integration of local knowledge in the secondary school chemistry curriculum - A few examples of ethno-chemistry from Zambia

Bitwell Chibuye [a,b,*], Indra Sen Singh [b]

[a] Department of Chemistry Education, School of Education, Mukuba University, Kitwe, PO Box 20382, Itimpi Campus, Zambia
[b] Department of Chemistry, School of Mathematics and Natural Sciences, The Copperbelt University, PO box 21692, Kitwe, Zambia

ARTICLE INFO

Keywords:
Ethnochemistry
Ethnopedagogy
Cultural society
Culturally responsive teaching

ABSTRACT

Before formally introducing chemistry in schools, Africans practiced it as ethnochemistry as they lived in their ethnic groupings. To a large extent, it may be true for other ethnic groups and communities across the globe as well. This study aimed to document a drop from the ocean of ethnochemistry knowledge that people in Zambia practiced in the past and modern times to use such ethnochemistry knowledge to teach chemistry in ethnically responsive ways. Further, this study sought to raise the profile of indigenous cultural knowledge in the globalized world dominated by modernity. Ethnography research design was used including unstructured interviews for data collection. This study purposively selected twenty (20) research participants using snowball sampling. Results show that many relevant ethnochemistry practices in Zambia can be used to grow the national economy, enrich the teaching of Secondary School Chemistry to ethnically diverse students, and generate secondary school students' interest and better familiarity with Chemistry.

1. Introduction

Chemistry is as old as probably the existence of people on earth. Before the formal introduction of chemical education in Africa, chemistry existed. Chemistry has been part of the life of the people in their communities since ancient times. Indeed, all matter is chemistry, and in support of this proposition, in 2008, chemists declared "What on Earth is not chemistry!" [1]. To start with, it is important to note that matter is a real and factual phenomenon. However, the material components of the universe, which exist in a form that is not classified, and are not influenced by humans, do not constitute chemistry. The current formal education in chemistry is rooted in Western scientific innovations, which have achieved worldwide prominence since the Renaissance. Within this framework, ethnochemistry explores how various cultures uniquely comprehend and imbibe knowledge regarding transformations in matter arising from their cultural practices [2]. Put simply, ethnochemistry refers to the cultural and communal practices that are chemically related. It explains the traditional chemical methods used by individuals and communities, and can be thought of as the exploration of the collective chemical knowledge present within a cultural society. The term 'ethno' is a wide concept that encompasses the traditional customs, language, unique vocabulary, rules of conduct, folklore genre, and symbols of a cultural society [3,4]. In other words, "ethno" denotes members of a cultural society recognized by their traditional practices, language, and thinking patterns.

Centuries prior to the arrival of Europeans in Africa, Africans managed to develop strategies for their survival. The Africans had

* Corresponding author. Department of Chemistry Education, School of Education, Mukuba University, Kitwe, PO Box 20382, Itimpi Campus, Zambia.

E-mail addresses: bitwellchibuye@gmail.com, bchibuye@mukuba.edu.zm (B. Chibuye), indra@cbu.ac.zm (I.S. Singh).

https://doi.org/10.1016/j.heliyon.2024.e29174
Received 14 March 2023; Received in revised form 21 March 2024; Accepted 2 April 2024
Available online 8 April 2024

acquired expertise in cultural and economic practices, as well as in using their knowledge of chemistry to treat illnesses. The idea of a contemporary chemical laboratory had not yet been established. The ancient Africans were fortunate to have a close connection with nature, which served as their natural laboratory. In an environment that mimics a laboratory, individuals came up with techniques for producing both alcoholic and non-alcoholic drinks, harnessing energy, and storing food. The Africans engaged in chemistry while residing in the lap of the natural environment. Chemistry permeated almost all aspects of their lives. The knowledge and application of chemistry by various ethnic groups and communities throughout history can be referred to as 'ethnochemistry.' This practice continues to be observed by people in Zambian communities and potentially in other parts of the world as well.

There is a scarcity of information concerning ethnochemistry in Zambia. A careful literature survey shows that relatively little work has been done on the subject of ethnochemistry practices in Zambia, both ancient and modern. Therefore, some of these practices must be documented, preserved, and integrated into chemistry lessons. Otherwise, the treasure of invaluable knowledge acquired through experience and distilled wisdom of hundreds of years would have been lost. The ancient Africans did not document this knowledge but instead passed it on to future generations through storytelling, which could have resulted in the loss of invaluable knowledge. The study aimed to document ethnochemistry practices in Zambia and increase the profile of indigenous cultural knowledge in a globalized world. A knowledge base will be developed regarding cultural diversity in the secondary school chemistry curriculum to teach chemistry to ethnically diverse students in ethnically responsive ways [5]. Teaching chemistry from an ethnochemistry perspective is important, as it links students' home-cultures to the subject, grounds chemistry problems in real-world examples, and connects to students' experiences [6]. It is assumed that skills and knowledge become more meaningful when placed in learners' frames of reference and lived experiences, creating higher engagement [5]. This study aimed to promote the value of indigenous cultural knowledge and compared modern and indigenous ethnochemical practices that could be used in culturally responsive teaching. Ethnochemistry practices documented in this study include separation, complete/incomplete combustion, blast furnace iron extraction, utilization of copper, dissolution, and crystallization from the secondary school chemistry curriculum.

1.1. Research question

Which ethnochemistry practices in Zambia have the potential to boost student involvement with the secondary school chemistry curriculum, ultimately revitalizing and fostering a sense of pride in traditional knowledge and practices?

2. Literature review

2.1. Ethnoscience

Before discussing the concept of ethnoscience, it is critical to clarify the concept of nature, for ethnoscience is a product of nature. From the outset, we must make it clear that the concept of "nature" is, in particular, a complex one to grasp, with a substantial historical evolution [7]. For this work, and in the broadest sense, nature is the universe or the physical world. It includes animals, plants, landscapes, the earth with various products, and landscapes devoid of human and human creations. To survive, people in different communities of the world have impacted nature, though the extent of impact differs from community to community. However, modernity impacts the world much more than ethnoscience does [8]. Ethnoscience deals with the distinct body of knowledge that relies mainly on peoples' interaction with the inherently rich domains of nature [9–11]. Ethnoscience, or traditional knowledge, is the knowledge that is distinctive to a cultural society. It is different from international knowledge which is created through the global network of learning institutions such as universities and research institutes [12]. Ethnoscience is the knowledge that is peculiar to a given cultural grouping. Additionally, it reflects the local peoples' thinking about how their physical environment is to be classified. Further, ethnoscience is the tool with which people learn about their surrounding environment, its natural resources and challenges, and how to manage and utilize them productively and sustainably [13].

2.2. Ethnochemistry

The work of Eldeen et al. (2016) seems inclined more toward ethnobotany than ethnochemistry [14]. Since ethnochemistry relates to how humans have worked with various substances and matter in their cultural contexts, the work of Eldeen does not fall into this category. Ethnochemistry refers to various chemically related indigenous knowledge and practices present in various cultures [2]. For example, the traditional way of brewing alcohol is a cultural practice in which chemical processes such as fermentation and distillation take place.

Ethnic knowledge and practices can be relevant to economic growth and sustainability and flavor the sciences' teaching. Ethnic knowledge also referred to as traditional or indigenous practices, refers to various ways of inherited ancestral processes of deducing, perceiving, recognizing, reasoning, acting, and comprehending due to human encounters with the natural environment. Indigenous knowledge can also allude to a complete body of ethnic group information and practical knowledge preserved and developed by people in rural communities due to interaction and experience with the natural world [10,15]. It may suffice to add that indigenous or traditional knowledge was constructed through observing natural processes, devising survival modes, obtaining food and medicines from plants and animals, and utilizing natural products and resources to make utensils, tools, and equipment [16].

However, it is noted that indigenous or traditional knowledge is jeopardized by the spread of foreign cultures and established forms of cultural transmission [17,18]. In the quest for modernization, the local is eroded by other cultures, wherein Africans generally have flawed thinking that whatever is foreign is good [19,20]. It must be mentioned that Indigenous education has a comprehensive and extensive knowledge of living in communities. However, institutionalized education systems have distorted indigenous knowledge's day-to-day practical life views and replaced them with theoretical knowledge and scholarly systems of learning [21].

2.3. Ethnopedagogy and ethnochemistry

The teaching approach based on ethnopedagogy is an appropriate and relevant concept for understanding ethnic cultures, with vast local practical knowledge and local wisdom values reflecting the identity of either the ethnic group or the nation. Ethnopedagogy is a method of teaching that combines cultural education and science learning to enhance student involvement and understanding of different cultures. It motivates students to value and show interest in their ethnic background, historical heritage, and cultural traditions during a time of societal uncertainty [22]. What constitutes ethnochemistry is contextualizing local chemistry ideas in secondary school chemistry lessons, which may interpret local wisdom based on humanity so that exclusive cultural chemistry practices can be reproduced and refined into formal school chemistry science [2]. The educational environment in Zambia and elsewhere is characterized by various cultural and historical practices and values [23]. Many ethnic groups possess their unique cultural chemistry, practices, and values, while others cut across cultures. Therefore, the school chemistry curriculum and the teacher should consider such features when designing instruction. It may suffice to state that traditional practices in all cultural groups are different. However, every ethnic group has some fundamental concepts, goals, and values. Teachers have to teach students not the particular cultural perspective and experience but the amalgamation of multicultural, many historical perspectives, and traditional practices [24]. The essence of such education is to produce a student who interacts with a society based on common principles, worldviews, and values. In ethnopedagogy, set goals and objectives reveal the essence of this science [25].

While ethnopedagogy and ethnochemistry are related, they are not the same thing and the two differ on many of fronts. Firstly, it should be noted that the latter is broader than the former, as the latter teaches the upcoming generation whole aspects of life, such as civic consciousness, societal values, and the primary principles of life for the ethnic group or the nation [25]. Ethnopedagogy can be used to enhance student learning through ethnochemistry by integrating indigenous knowledge and cultural practices related to scientific phenomena into the curriculum [22]. Thus, ethnochemistry focuses narrowly on integrating chemistry cultural concepts and principles into chemistry lessons to make chemistry content familiar to the students. Secondly, ethnopedagogy effectively bridges the gap between culture and science and connects the two, whereas ethnochemistry is the vehicle through which meaningful chemistry learning is attained [26]. In addition, the priority of ethnopedagogy is the application of the traditions of various ethnic groups living in a country to formal school, thereby developing children's abilities and encouraging their talent and self-expression [23,24]. In this sense, therefore, ethnochemistry can be viewed as a branch of ethnopedagogy. Further, ethnopedagogy aims to prepare learners for the future, such as marriage, future vulnerabilities, family relationships, and so on [27]. However, the direction of ethnochemistry is to use the chemistry cultural knowledge as local examples so that the students can easily grasp the new chemistry knowledge they are learning. Finally, the task of ethnopedagogy is to teach both children and their parents. Therefore, ethnopedagogy leans more toward being a cultural activity, whereas ethnochemistry is a formal chemistry schooling activity.

2.4. Ethnochemistry as an ethnically responsive teaching approach

According to Rychly and Graves (2012), culturally responsive teaching is defined as using ethnically diverse students' cultural experiences, characteristics, and perspectives as a channel for teaching them more effectively [28]. Ethnochemistry teaching is a culturally responsive teaching approach. There are five fundamental components of any culturally responsive teaching approach [29]. These are: showing care and building learning communities; developing a culturally diversified knowledge base; communicating with ethnically diverse students; the inclusion of ethnic and culturally diversified content in the curriculum; and responding to ethnic diversity during teaching. The teaching approach assumes that when skills and knowledge are situated within the frames of reference and lived experiences of students, they are more personally meaningful to the learner, tend to exhibit higher interest appeal, and are learned more easily and thoroughly. Consequently, the academic performance and achievement of ethnically diverse students will be enhanced and improved when they are taught through their own cultural and experiential filters [24–29].

Today, there is a grave risk that enormous and invaluable indigenous knowledge acquired through hundreds of years of experience will be lost. Consequently, this study would establish the groundwork for enriching the chemistry knowledge base by integrating ethnochemistry knowledge and practices into it, which will enhance students' performance in and attitude towards the subject. For instance, it was demonstrated that the integration of ethnochemistry practices in secondary school chemistry lessons enhances students' attitudes toward chemistry [2]. The current study would also catalyze interest in bringing about a paradigm shift from the held view that foreign forms of knowing are better than native peoples' traditional ways of knowing the world, leading to sustainable living [19,20]. Ethnochemistry may offer solutions to economic and sustainability-related challenges and contextualization in teaching secondary school chemistry.

2.5. Ethnochemistry for cultural sustainability

Culture permeates all aspects of life in indigenous communities. In this vein, culture is the basis of sustainability awareness in traditional life. According to UNESCO, culture comprises a world view, way of life, values, beliefs, and traditions, and culture is one of the four core aspects of sustainability in the same category among social, economic, and ecological [30]. Cultural sustainability is the capacity to preserve the identity of a culture, enabling change in line with the values of the culture. Cultural sustainability emphasizes recognizing societal needs while maintaining a progressive understanding of culture [31]. Therefore, ethnochemistry practices should be preserved to assure cultural sustainability, thus enabling the upcoming generations to access cultural knowledge and resources from the old, outgoing generations. It should be emphasized that culture cannot be transmitted biologically but can only be transmitted from one generation to another through learning.

We must emphasize that cultural and natural capital should be preserved for cultural sustainability. Cultural capital encompasses cultural diversity, both tangible and intangible property, support systems, and cultural networks. Natural capital encompasses natural resources, biodiversity, and ecosystems [32]. Ethnochemistry practices fall within the umbrella of tangible property, as do man-made sculpture, landscape, architecture, monuments, painting, and archaeology. Ethnochemistry knowledge falls under the intangible part, as do designs, attitudes, illustrations, skills, and knowledge. Cultural sustainability of both intangible and tangible cultural properties, such as ethnochemistry knowledge systems and practices, would correspond to the definition of sustainable development as development that meets the needs of the current generation without compromising the needs of future generations [33]. Therefore, it is pertinent to document ethnochemistry knowledge and practices to assure cultural sustainability.

3. Methodology

The research design that was used in this study was qualitative particularly ethnography [34,35]. Learning about ethnochemistry practices was achieved mainly through participant observation during the everyday life of the researcher in the Copperbelt Province of Zambia from 2010 to 2022. The researcher acquired enormous knowledge as he immersed himself in the community by observing up-close and actively participating in tasks like any other community member, particularly for some ethnochemistry practices such as alcohol production, salt making, charcoal making, traditional soap, and traditional toothbrushes.

3.1. Target population

Prospective people, that is, people with substantial knowledge of certain ethnochemistry practices, in the Mufulira district of Zambia were included in the study to learn and document ethnochemistry practices from them. Mufulira was chosen because it is cosmopolitan, with people from all provinces of Zambia, and the researcher lived in this district for more than ten (10) years and observed and overtly participated in the everyday life activities of the people. Mainly, people residing in Mufulira possessing sufficient knowledge of specific ethnochemistry practices were included for participation in the study.

3.2. Sample and sampling procedure

The snowball sampling method was used to select the research participants. These were people who possessed the knowledge of how certain ethnochemistry practices were done either in ancient or in modern times. The snowball technique was utilized by first establishing contact with one or two initial participants from the sampling frame. Then, the initial participant was requested to identify more. Further, the new participants were asked to identify other participants whom they thought had relevant knowledge of a particular ethnochemistry practice [35]. The process only stopped after interviewing the required sample. In the end, twenty (20) participants took part in the study.

3.3. Data collection and analysis

During Bitwell Chibuye's immersion in the community setting, data collection was achieved by triangulation. Firstly, during participant observation, field notes detailing the observations, conversations, and preliminary analysis formed the basis for the documentation of ethnochemistry practices. In addition to field notes, photos were taken, and some figures were drawn detailing the observed phenomena. In some instances, in addition to participant observation, documentation of certain ethnochemistry knowledge was achieved through unstructured interviews conducted with the research participants that were identified through a snowball sampling to observe, participate, and learn certain ethnochemistry from them, such as iron smelting and the preservation of meat and seeds. The following were the unstructured questions that were asked of the research participants.

1. Please explain the named process, for example, alcohol production.
2. What are the materials required for the process?
3. Give the optimum conditions for the production of the intended product.
4. What are the precautions to take during the process?
5. Explain the importance of the process in your culture.

However, depending on interview responses, different follow-up questions were asked to learn more about a particular ethnochemistry practice.

During data analysis, pieces of information were put together to present a picture of a particular ethnochemistry practice. Analytic memos, in vivo, and process coding led to thematic analysis [34,35].

Ethical approval

The Department of Chemistry, School of Mathematics, and Natural Sciences of the Copperbelt University (CBU) approved all data collection procedures performed in this study. Written informed consent was secured and signed by each research participant before being interviewed and after fully explaining the data collection procedure.

4. Results

4.1. Some ethnochemistry practices in Zambia

Some ethnochemistry practices that this study documented included the following.

4.2. Foods and crops

4.2.1. Production of alcohol (Vernacular name: kachasu)

Three factors make alcohol production significant in indigenous society. First of all, the alcohol produced is consumed for celebrations such as weddings and customary rites. Second, it fosters camaraderie among the village's older men. They would gather at a homestead in the evenings, usually around a fire, and share stories and local brews. They would come from various households. The purpose of these get-togethers was to improve the ties that bound the families in the neighbourhood. Lastly, pure alcohol was once employed in the traditional healthcare system for functions such as wound sterilizing and as a solvent to extract phytochemicals, mostly from medicinal plants [36]. Elders or traditional healers would use pure alcohol to sterilize an injured person's wound, which would inhibit the growth of germs and hasten the healing process. Furthermore, for some herbs, the leaves, stem bark, or roots would be steeped in a solvent with a high alcohol content rather than water to extract therapeutic phytochemicals by maceration [36]. The patient would then take the extract orally.

The process of making alcohol involves certain chemical aspects. There are primarily two steps involved in the making of alcohol, or kachasu as it is known locally. The initial step in the ethnochemistry - based traditional practice of brewing kachasu in Zambia's Bemba speaking region, which is located in the Northern and Luapula Provinces, and other parts of the country, is the fermentation of grains that contain carbohydrates, including sorghum, finger millet, or maize grain. Until the seeds germinate, the grain is first immersed in fresh, clean water in a closed container. To serve as an enzyme, the dried and germinated millet or maize seeds are then crushed into flour. Ground seeds contain enzymes that are activated during fermentation [37]. The enzymes are generated in seeds during germination and function as a catalyst in the fermentation process, converting glucose to ethanol according to the following equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} \xrightarrow{enzyme} \underset{\text{ethanol}}{2C_2H_5OH} + \underset{\textit{Carbon dioxide}}{2CO_2}$$

After that, the dried corn or maize is pounded into flour and cooked in a large pot over a traditional stove to make a thick porridge. The receiving bole and the large pot were made of clay in the past (Fig. 1).

Subsequently, the thick porridge is combined with the ground-germinated seeds to initiate the fermentation process. The reaction pot is placed close to the traditional stove to continuously supply the ideal warmth for the good activity of the enzymes. It is well covered to prevent air (oxygen) from reacting with the thick porridge. Soured alcohol would result from the ethanol produced during fermentation being oxidized to ethanoic acid if air were permitted to enter the pot. The formation of foam stops after roughly five to seven days, suggesting that carbon dioxide (CO_2) production has ended. This signifies that the fermentation process is finished. The fermented porridge is now prepared for the next step, which is distillation to purify the resulting alcohol.

Previously, the distillation arrangement (depicted in Fig. 1) included a large aluminum container filled with cold water, which was positioned on top of another aluminum pot. The bottom of the pot had holes and held a clay vessel for collecting the alcohol (distillate). The sieve-like saucepan is positioned above the large clay pot filled with fermented porridge. The three large stones provided support for the distillation pot. This represented the traditional stove. This fire assembly was fuelled by burning wood.

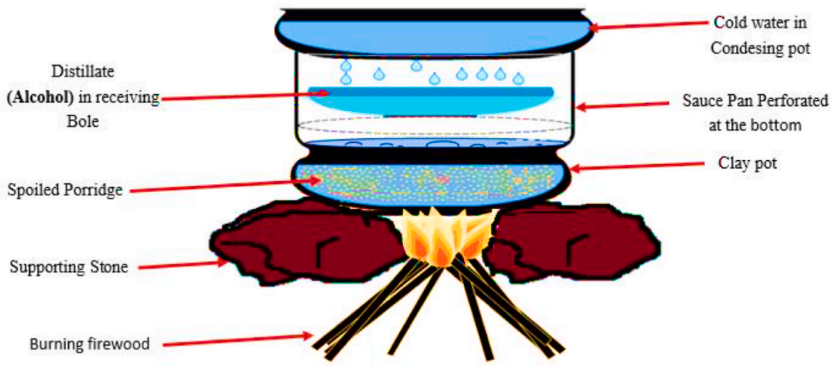

Fig. 1. Ancient traditional setup.

The distillation apparatus (Fig. 2) has been modified and improved in the present day. The traditional stove is used to boil the fermented porridge in a sealed cylindrical metal vessel known locally as a "drum," which is supported by three large stones. Firewood or twigs are used to fuel the stove.

A small aluminum pipe connected near the top of the sealed drum passes through a big plastic or metallic containing vessel filled with cold water to act as the condenser and is supported on either a wooden table or a hollow metallic drum. The evaporated distillate is condensed around this region, and the distillate is collected in the receiving vessel placed on the same table. The following Fig. 3 shows a photograph of one of the various modern-day setups.

A small aluminum pipe connected near the top of the sealed drum passes through a big plastic or metallic vessel filled with cold water to act as the condenser and is supported on either a wooden table or a hollow metallic drum. The vapour is condensed around this region, and the distillate is collected in the receiving vessel placed on the same table. The following Fig. 3 shows a photograph of one of the various modern-day setups.

Fig. 3 is a photograph of the modern day traditional set up.

4.2.2. Traditional salt making in Zambia

Salt that is made in traditional communities in Zambia finds multiple uses. For example, it is utilized as a seasoning to enhance the flavor and improve the taste of food, specifically when preparing meals. Additionally, it is employed for medical reasons. A solution containing a small amount of salt is applied to cleanse the wounds in order to promote rapid healing. Also, conventional salt is utilized for the treatment of either swollen or painful lower limbs and feet. The individual would submerge their feet or legs in warm salt solution until the solution cools down. This procedure is done three times daily until the situation gets better. Moreover, there is a belief that by spraying a salt solution on charms such as malevolent amulets, their impact can be nullified, effectively making them harmless.

Sodium Chloride, chemically called NaCl, is commonly referred to as common salt. Salt production in Zambia is carried out in different salt plains through traditional methods. A salt plain, also known as a salt pan, is a large, flat land filled with a high concentration of salt. Traditionally, this area is used for the production of salt. In the Kaputa district, there are over ten salt plains such as Kabwe, Chichenchelebwe, and Shikayamba. On the other hand, Kasempa district only has one large salt plain called Kaimbwe, which spans across a distance of 10 km. In Kaputa, the local community engages in various economic activities such as fishing, rice farming, and salt making. The indigenous inhabitants claim that they have been carrying out salt production for over two centuries. However, in Kasempa, individuals also participate in subsistence farming alongside the production of salt. The Kaimbwe hot spring, along with its related salt plain, as well as the Kaputa springs and their linked salt plains, serve as a significant source of salt for the local population in those areas as well as the neighboring districts [38].

The salt is obtained by scraping off the effloresce on the surface of the salt plain when it is dry, which occurs during the production season between July and October. The scrapped raw materials are transported to suitable sites within the salt plain where purification of the salt takes place. On the other hand, it is noteworthy that salt production also involves burning salt-rich marsh grasses and then extracting the salt from the resulting ash through leaching. The scrapped effloresce of salt mixed with dirt and sand is then put in proportionate quantities on a filtration stand. The filtration stand is made up of four tree branches that are the same length and act as poles. These poles are securely placed in the ground to form a rectangle. The legs of the table are linked together by four additional branches, resembling aprons, in order to make a structure similar to that of a table, without the tabletop. A large porous sack is tied around the aprons in a warped design to form the top (Fig. 4).

A small amount of water is poured onto the mixture of salt effloresce, dirt, and sand that is placed on the filtration stand. The process of salt dissolving in water occurs through dissolution, and filtration is accomplished using a sack that is permeable. The high

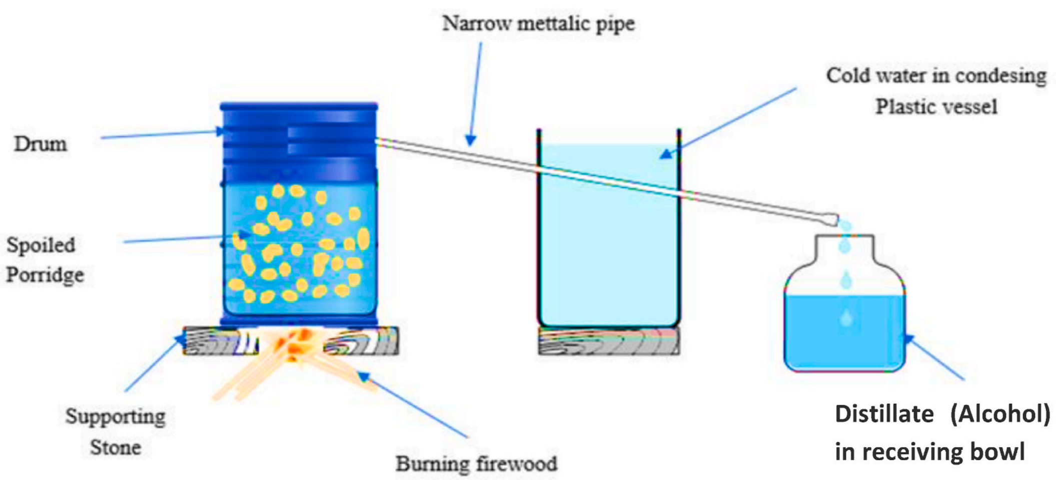

Fig. 2. Modern-day traditional set up.

Fig. 3. A Photograph of modern-day traditional setup.

salt concentrated filtrate, is collected in a large aluminum pot placed at the bottom of the filtration stand. In Kaputa, the locals often refer to this filtration process as Ukuchemeka (Fig. 5).

The same mass of the salt effloresce, dirt, and sand mixture is usually filtered by adding a controlled amount of water from 6.00 a.m. to 5.00 p.m. About 15 to 30 L of concentrated salt solution (filtrate) is collected depending on the size of effloresce added. After going through the process of filtration, the concentrate is then heated until it is nearly completely dry. Heating is typically carried out in the evening, preferably around 8:00 p.m. until around 3 in the morning likely due to its convenience. Once there is only a small quantity of water remaining, the salt is placed under the sunlight to evaporate and form crystals. However, the salt produced is non-iodized and may not prevent goitre, as iodized salt does [39,40]. It must be emphasized that iodized salt is table salt mixed with a minute amount of various salts of the element iodine. The ingestion of iodine prevents iodine deficiency, which is the leading preventable cause of intellectual and developmental disabilities worldwide [41]. Iodine deficiency also causes thyroid gland problems, including endemic goitre [39,40].

4.2.3. Preservation of meat

In ancient times, prior to modern refrigerators, and other methods of meat preservation such as salting, people would wrap meat in papaya or pawpaw leaves. The meat would be kept fresh for a day or two without spoiling. This allowed the individuals to access fresh meat for a certain period of time. After that, the meat would undergo either smoking or sun-drying processes. This specific leaf might possess mild antibacterial qualities that can help inhibit meat from decaying. Pawpaw leaves contain bioactive compounds that play a role in preserving the meat. According to literature, it is suggested that certain plant compounds, specifically polyphenols such as tannins, flavonoids, and anthocyanins, as well as essential oils such as terpenes, are highly beneficial and bioactive secondary

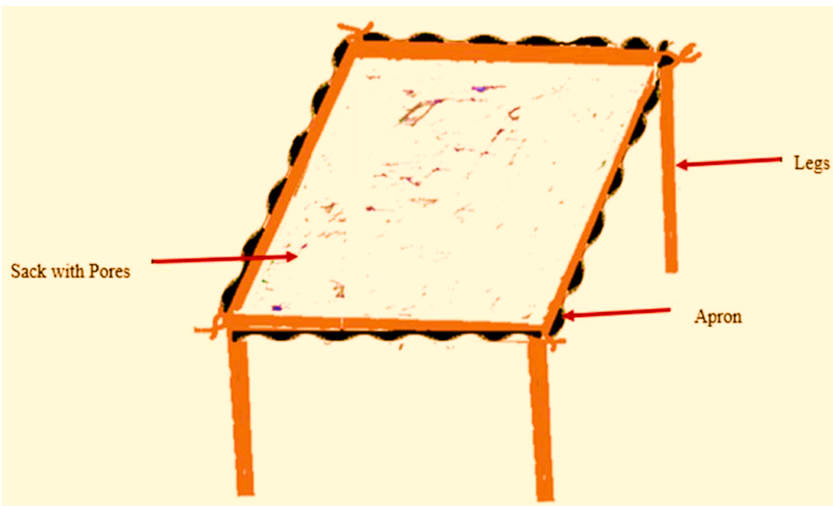

Fig. 4. Filtration stand.

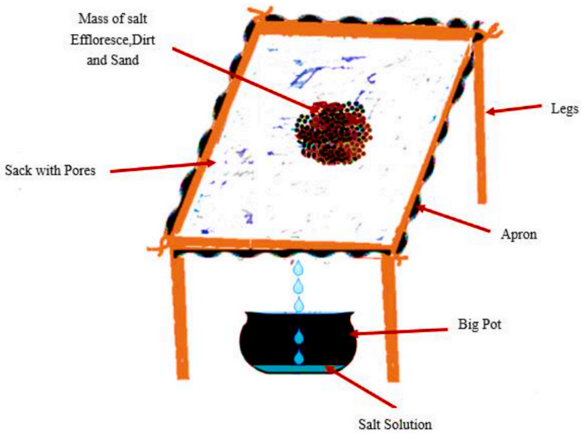

Fig. 5. Filtration stand during filtration.

metabolites found in plants and can be utilized by the meat industry for meat preservation purposes [42,43]. The reason why pawpaw leaves are effective for preserving meat is due to their antimicrobial properties, specifically their ability to fight against bacteria [44].

4.2.4. Pesticides

Whenever pests infested plants or vegetables, locals would extract a natural plant poison known as Ubuuba. This poison was derived from the roots or leaves of a tree called Tephrosia vogelli. The extraction involved soaking the roots or leaves in water and allowing the solution to concentrate over a few hours. Afterward, the solution was sprayed onto the leaves of the plants in order to combat the insects. The extracts were used in the control of lice, fleas, termites, aphids, stem-borers, and ticks in agriculture and on domesticated animals such as goats and cattle. Currently, there is scientific evidence that T. vogelli does possess pesticidal properties based on the presence of rotenoid [45].

Additionally, indigenous Zambian farmers, who are typically small-scale farmers, have devised a chemical approach to safeguarding and storing seeds, particularly maize seeds, for future use in the following agricultural season. They would make a mixture of ashes by burning leaves, twigs, and grass. The specially chosen good grains were then mixed with the ashes, and stored in a dry environment until the following planting season. They held the belief that ashes acted as a safeguard for the seeds, shielding them from pests. This is proven by the consistent excellent germination efficiency of these protected seeds. There is scientific evidence to support the use of ash as pesticide [46].

4.3. Tools and things for everyday life

4.3.1. Iron smelting before modern civilization

The blacksmiths of ancient Zambia, who were skilled in iron smelting, led fulfilling lives and had intriguing ideas. They possessed innovative abilities in enhancing tools used for various tasks such as home improvement, hunting, and gardening. They smelted iron to make hoes that were used in the gardens [47]. This occurred prior to the arrival of Europeans who introduced advanced farming equipment such as hoes and ploughs. Smelting iron brought about a favorable impact on the people's way of life. It served as a source of agricultural tools such as hoes, household tools such as axes and knives, and hunting tools such as spears. The hoes were also utilized as part of a dowry in matrimony.

The initial phase of iron smelting involved gathering high-quality clay soil from an ant mound and combining it with water in order to form mortar. Compared to other soil sources, anthills offer a superior quality of clay soil that is well-suited for constructing a kiln. Additionally, they would construct the Kiln or Furnace using the mortar at a suitable location that was conveniently situated near an ant hill, making it effortless to transport the clay soil. The anthill also has the capability to serve as protection from the wind and aid in the smelting process. The kiln had the appearance of a small hut, with a wide base that tapered towards the top [47]. They made little openings around the bottom of the kiln. The kiln was typically constructed slightly taller than the height of an average person. Due to its height exceeding that of an average individual, the kiln required the construction of scaffolds and supports around it. The scaffolds were utilized to hold the charcoal and the ore. The purpose of the supports was to avert any potential collapse and the subsequent harm to individuals. When the construction of the kiln was completed, they used to wait until it had dried and become sufficiently solid.

The following step was to locate the ore. These were occasionally discovered in a location within a village that had been deserted or relocated several years prior. However, it was common for the ore to be present in various locations. Previously, when they found the site, they would excavate the ore from the ground by specifically choosing the high-quality ones. The assessment of the ore's quality was based on the varying colours of the soil, which ranged from dark grey to reddish rust. Another factor that was considered to assess the ore's quality was its weight, with a higher weight being indicative of better quality. Iron ore may occasionally be found in intricate and shallow marshlands.

A significant quantity of ore was gathered and piled next to the furnace. A significant quantity of charcoal was also collected.

Afterward, both the ore and charcoal would be stacked in alternating layers inside the kiln until it reached maximum capacity. Then, they would patiently wait for the wind to blow in the direction of the vent holes of the kiln before igniting the ingredients with fire. People took the lead in utilizing multiple bellows made from goatskin bags to inject air into the kiln through the lower ventilation holes. They would persist in supplying air through the vent holes until they were confident that the fire in the kiln was sufficiently strong to melt the iron. Afterward, they would seal up all the openings in the kiln using a clay-based mortar.

After waiting for some time, and ensuring that the ore was molten, a stick was wedged or poked into the bottom to make a hole. Then the 'red' hot molten liquid gushed out of the kiln and solidified as it cooled. When the molten liquid flowed out, a chunk of iron was removed. The whole process was repeated again. Each time retrieving a lump of iron. The molten substance similar to slag was referred to as excrement (Amafi), while the act of the liquid flowing out was called "Ukunya," which translates to defecation in English. The piece of iron retrieved was known as "Cuma" which means wealth in the English language.

Chemical analysis was not performed to determine the iron content of the ore during the selection process. At times, the poor choice of ore resulted in the kiln not being able to produce iron. In the past, it was commonly said that the kiln had "vomited" (ukuluka), and they would subsequently remove everything from it. These iron chunks were transported to a different location to undergo additional processing. At this location, they once again utilized animal skin bags as bellows to supply air, and they reheated the iron in the fire once more. Using special hammers, they made knives, hoes, spears, and axes out of the iron. These hammers were round or oval-shaped hard stones. The pieces of iron could also be kept as wealth.

4.3.2. Charcoal (vernacular – amalasha) making in Zambia

In Zambia's indigenous communities, charcoal serves multiple functions. The primary and most crucial application of charcoal is its role as an energy source, particularly for cooking purposes. Moreover, charcoal is employed in communities for its medicinal properties. The substance is crushed until it becomes a fine powder, and a specific quantity is mixed with warm water and ingested by a patient who is experiencing stomach infections such as diarrhoea or abdominal pain. In addition, a small chunk of charcoal is positioned alongside currency, cornmeal, or other valuable items to deter their unexplained vanishing. In traditional African societies, it is commonly believed that witches have the ability to steal valuables in a mysterious manner. To safeguard against such thefts, charcoal is used as a preventive measure.

Charcoal is produced from wood by a process called carbonization or pyrolysis [48,49]. The process occurs when there is no oxygen or limited air flow to the charcoal kiln. If the charcoal kiln is well closed using soil, it will result in incomplete combustion, leading to a significant production of carbon (charcoal). However, in case there are multiple vents (tiny openings), a combination of ashes and charcoal is produced because of complete combustion, resulting in a small amount of charcoal produced.

The process of burning wood into charcoal involves numerous chemical reactions because wood is not a pure substance but a combination of various organic compounds, predominantly cellulose. When wood is burned with plenty of oxygen, it produces carbon dioxide, water, and volatile gases. The gases that are formed can react with oxygen to produce carbon dioxide and water. The chemical reaction representing the complete and ideal burning of wood is approximately denoted as:

$$CH_2O \text{ (dry plant matter)} + O_2 \longrightarrow CO_2 + H_2O + \text{VOCs} + \text{heat}$$

Where CH_2O (dry plant matter) consists of CxHyOz and VOCs. CxHyOz represents mainly cellulose and lignin, whereas VOCs represent the volatile organic compounds. This reaction ensues when there is an unlimited supply of oxygen, and no charcoal is formed in this case. However, the chemical equation changes during pyrolysis, a process that takes place in an oxygen-starved environment that

Fig. 6. Logs piled into a clamp.

produces charcoal. During pyrolysis, wood is broken down into solid carbon and volatile gases. The solid black carbon is the charcoal, which is used for energy as it can also burn if enough oxygen is available during cooking. The following is the reaction equation that produces charcoal during pyrolysis.

$$CH_2O \text{ (dry plant matter)} + O_2 \longrightarrow \text{black carbon} + H_2 + CO + CH_4 + \text{hydrocarbons}$$

In Zambia, charcoal is made by wood carbonization using the earth clamp method. The process of charcoal production involves felling indigenous hardwood trees, such as Muombo (B. longifolia). Then, the trees are cut into sufficient short logs of similar length, which are piled into a clamp. The number of logs cut depends on the expected amount of charcoal to be produced. The logs are ferried to a pre-selected site where they are piled into a clamp (Fig. 6).

The ideal location for the kiln should be in close proximity to where the logs are sourced to minimize the distance needed for hauling. Then the clamp of logs is covered with grass and plenty of soil lumps. Depending on the direction of the prevailing wind, a small portion of the kiln in the direction of the wind is left uncovered. This is the ignition point. Firing is done by the “charcoal burner”, at the ignition point. The charcoal burner starts the fire with some level of precision, ensuring the fire is well established in the kiln in about 15 min, but without burning a considerable amount of wood. (Fig. 7).

The ignition point is then covered, and the carbonization of wood ensues. After, closing the ignition point, smoke reduces, giving a false impression that the kiln is “dead”. However, the kiln adjusts itself to insufficient oxygen levels to facilitate incomplete combustion (Fig. 8).

This process of combustion transforms wood into charcoal, carbon monoxide, and water. After a few days, charcoal is collected and put into bags for packaging. The entire procedure is physically demanding and primarily involves the use of basic instruments such as axes and hoes.

4.3.3. Traditional “soap”

Prior to the advent of modern soap making in Zambia, the indigenous population relied on the utilization of the leaves of Eucalyptus camaldulensis and the fruit of Sapindus Saponaria for cleansing purposes. The process involves gathering a significant quantity of plant leaves and then pulverizing them. The pulverised leaves were combined with the right amount of water in order to obtain the concentrate. Foam formation occurred, and a filtration process was performed to obtain the "soapy" filtrate. After that, the soiled garments will be soaked in the resultant soapy solution. The clothes were cleaned and the dirt was eliminated after being washed. This tradition persisted whenever the community members were unable to purchase contemporary soap due to financial constraints. The reason why certain plants have soap-like properties is because they contain specific natural compounds known as saponins. When agitated in water, saponins easily form a soapy lather and produce froth. The name saponins, derived from the Latin prefix ’sapo’, means soap because they have foaming properties in water similar to soap [50]. Another good example is the plant S. officinalis (soapwort), which is native to Europe and is used as soap by native people in that part of the world, even in the modern-day [50].

4.3.4. Traditional toothbrush

Small fresh stems of a plant, particularly the Diospyros mespiliformis, locally known as Muchenja plant, about the size of a pencil, were used as toothbrushes, without any toothpaste. The stems had a whitening effect on the teeth besides making the teeth healthier. The plant may have anticavity properties and may contain bioaccumulation of metal or nonmetal ions with teeth-protecting properties.

Fig. 7. Fire starting at the ignition point.

Fig. 8. Kiln adjusting itself to insufficient oxygen supply.

For instance, copper ions and other metals may bioaccumulate in the stem of D. mespiliformis. According to Xu et al. (2022), copper nanoparticles easily blend and bond to other metal ions, polymers, and ceramics, and display physiochemical stability within compounds [51]. In this way, copper nanoparticles are frequently used in dentistry to boost the chemical and physical properties of many dental materials, including restorative cement, adhesives, obturation materials, dental amalgam, resins, endodontic-irrigation solutions, dental implants, brackets and orthodontic archwires [51,52]. Other than cations, anions with tooth decay-protecting properties may bioaccumulate in D. mespiliformis. For example, fluoride has been found to prevent tooth decay and makes the enamel resistant to acid attack [53]. The bioaccumulation of tooth-protecting cations and anions such as copper and fluoride may be the scientific reason for using the small plant stems as toothbrushes in some traditional Zambian societies.

There are literature reports of natural toothbrushes. The most widely favored and extensively utilized among these options are the branches of the Salvadora persica tree called Miswak twigs. The natural toothbrush is an effective oral hygiene tool due to its numerous phytochemicals. Bacterial plaque is the main factor responsible for the development of dental caries and periodontal diseases. Treating gingivitis is highly successful when dental plaque is removed [54]. There are different ways to keep dental plaque under control and maintain good oral health, including mechanical and chemical methods. The double benefit of using natural toothbrush for oral hygiene comes from both its mechanical action, which removes plaque through friction between the plant fibres and teeth, and its chemical properties, which help control plaque due to its natural compounds. The natural toothbrush effectively eliminates plaque from both hard-to-reach areas between teeth and easier-to-access spots [55]. Regardless of gender and ethnicity, the subgingival microbiota exhibits similarity. Utilizing the natural toothbrush offers a method for gradual improvement in dental hygiene [55]. In 1986 and 2000, the World Health Organization (WHO) supported the utilization of natural toothbrush, that is, Miswak twigs in a global agreement on oral cleanliness for areas where it is traditionally used. However, the WHO acknowledged that additional research was needed to understand its effects [56]. Multiple studies have indicated that natural toothbrushes such as Miswak possesses numerous valuable properties from a medical standpoint, such as being antiseptic, astringent, abrasive, detergent, enzyme inhibiting, and fluoridative [55–59]. Natural toothbrushes from plants are preferred as they do not require toothpaste, are cheap to obtain, easy to maintain, and can even tackle bad breath [60]. Therefore, although there has been a shift to using modern brushing techniques in Traditional African societies, natural toothbrushes are still popular in many countries [60]. Therefore, it would be beneficial to popularise the use of natural toothbrushes, as they are more beneficial for our oral hygiene.

5. Discussion, conclusion, and recommendations of the study

5.1. Discussions of the study

The various ethnochemistry practices documented in this study might have educational, economic, agricultural, and social importance. For instance, in chemistry education, some ethnochemistry practices might be integrated into chemistry lessons to make the subject more interesting and familiar to students. For example, it was found that integrating ethnochemistry practices in chemistry lessons enhanced secondary school students' attitudes toward chemistry [2]. In the same vein, integrating ethnochemistry into the curriculum was found to bring about meaningful learning in addition to appreciation and preservation of cultural heritage [61]. Further, it was concluded that ethnochemistry learning experiences positively affect cognitive learning. Moreover, the application of Ethnochemistry in chemistry lessons leads to contextualized learning, making the learning challenging and more interesting to the students [62]. Furthermore, it was demonstrated that the ethnochemistry teaching approach enhances secondary school students' retention and achievement in separation techniques of mixtures [63]. Moreover, it was determined that incorporating ethnochemistry into chemistry education can serve as a practical laboratory and educational tool to enhance the engagement and relevance of chemistry lessons to students' everyday experiences (contextual-based learning) [64].

Indeed, wherever the teacher lives, there should be a particular conception of the world, civilization, indigenous knowledge, and a way of doing things that can be blended into an institutionalized formal chemistry curriculum [61,65]. The Zambian secondary school chemistry curriculum typically contains the following main topics: the particulate nature of matter, atomic structure and bonding, acids, and bases, the periodic table, stoichiometry and the mole concept, metals and non-metals, electrolysis, and organic chemistry.

The ethnochemistry teaching approach involves the integration of cultural chemistry practices in chemistry lessons. For example, the processes involved in the traditional practice of making alcohol could be used and discussed as local examples when teaching ethanol production by fermentation and distillation in chemistry lessons. Under the topic, of metals, the process of ancient iron smelting could be used when teaching the extraction of iron in the blast furnace. Hammering a chunk of iron into hoes, axes, knives, and other domestic implements could be used as a local example when describing the malleability and ductility of metals. Further, charcoal making may be used as an example when teaching complete and incomplete combustion. It may suffice it to add that integrating ethnochemistry practices, as local examples, in chemistry lessons might positively enhance learners' appreciation of chemistry.

In the economic sphere, some ethnochemistry practices have had economic benefits. For example, the ethnochemistry practices of making salt, iron smelting, and brewing alcohol would bring wealth in terms of money to the last denomination of society. Additionally, finding the active ingredients in the abovementioned applications of ethnochemistry would lead to the discovery of chemicals, which may have immense economic benefits. This might lead to reciprocal benefits to the community from which the knowledge came. Such benefits might be in terms of technology transfer and training [65,66]. Furthermore, the ethnochemistry methods of making pesticides and hoes have agricultural importance.

Our conception of culturally and linguistically responsive teaching is grounded in constructivist views of learning. From this perspective, learners use their prior knowledge and beliefs to make sense of the new ideas and experiences they encounter in school. A central role of the culturally and linguistically responsive teacher is to support students' learning by helping them build bridges between what they already know about a topic and what they need to learn about it.

The urgency of preserving ethnoscience, such as ethnochemistry through documentation, must be emphasized. There is rampant erosion of indigenous Zambian cultural knowledge in particular and African knowledge in general [67]. There are mainly two causes of the erosion of indigenous science knowledge. The first cause conforms with the African proverb, "When an elder dies, a library burns down." This is because, generally, Africans do not document knowledge by storing it either in a print format such as books, or in electronic format such as audio or video. Africans in indigenous communities rely on passing knowledge to the younger generations through storytelling and learning by doing [68]. Due to the encroachment of the urban way of life into many indigenous communities, there is the erosion of traditional knowledge. This is exacerbated by the erosion of the culture where elders previously used to sit, talk and work with the young, in order to pass on valuable indigenous knowledge [69]. The documented ethnochemistry practices in this study will contribute to the assurance of the preservation of the African knowledge systems. Secondly, indigenous African knowledge is being lost due to globalization [69,70]. Africans are embracing the Western way of life, especially the younger African generation, through the institutionalized Western education system in African countries such as Zambia [69–71]. In this way, the cycle of indigenous knowledge transmission is truncated as the younger generation learns the Western way of life at the expense of indigenous education. Further, Africans are inundated with Western culture and values through the internet, social media, and satellite televisions, thereby captivating the minds of the youth to the extent that the youth deem their own traditions, rituals, and cultures as old-fashioned, barbaric, and inferior [69,71]. The biggest challenge in this regard then is the demystification of indigenous knowledge, skills, and practices.

5.2. Conclusion

The findings of this study emanated from the study encompassing the geographical area of the Mufulira district of Zambia. A few ethnochemistry practices only have been documented in this study. Most of these have been practiced since ancient times, and many are still used. For instance, the traditional method of iron smelting was practiced even before the Europeans introduced the Western methods of iron smelting. In addition, the traditional method of producing alcohol is still practiced in communities nationwide. There is a myriad of invaluable ethnochemistry practices resulting from hundreds of years of experiences of ancestors that could be documented at the local and global levels. These ethnochemistry practices can potentially be used to grow the national economy, enrich the teaching of Secondary School Chemistry to ethnically diverse students, and generate secondary school students' interest and better familiarity with Chemistry.

5.3. Recommendations of the study

i. Only a few ethnochemistry practices have been documented in this study for use in teaching secondary school chemistry to ethnically diverse students. More research merits attention in this field to identify and isolate chemical compounds responsible for the observed chemical activity of the mentioned traditional substances. This could lead to the formation of chemicals.
ii. The potential for research in this field seems to be immense. If given due attention and consideration it may lead to the evolution of a totally new field of ethnochemistry in chemistry.
iii. There is a need to integrate ethnochemistry practices in secondary school chemistry lessons. This will lead to contextualized teaching of ethnically diverse students thereby enabling students to learn meaningfully.

5.4. Limitations of the study

i) The Ethnochemistry practices documented in this study are not exhaustive and merit further work to enrich the Ethnochemistry knowledge base.
ii) The study carried out was limited to only one small part of a district, it can be extended to the whole country to further concretize the findings of this study.

Notes

This initial work formed the basis and catalyzed the interest for the doctoral dissertation work in medicinal plants phytochemical profiling, polyphenolic content, antioxidant, antibacterial, metal, and in silico molecular docking studies by Chibuye Bitwell and supervised by Professor Singh Indra Sen, who was assisted by Professor Maseka Kenneth Kakoma and Professor Chimuka Luke.

Data availability statement

Data included in article/supp. material/referenced in article.

CRediT authorship contribution statement

Bitwell Chibuye: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Indra Sen Singh:** Writing – review & editing, Visualization, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] I.T. Horváth, Introduction: sustainable chemistry, Chem Rev 118 (2018) 369–371, https://doi.org/10.1021/acs.chemrev.7b00721, 2018.
[2] I.S. Singh, B. Chibuye, Effect of ethnochemistry practices on secondary school students' attitude towards chemistry, J. Educ. Pract. 7 (17) (2016) 44–56. ISSN, Online, 2016, www.iiste.org.
[3] M. Rosa, D.C. Orey, Ethnomathematics: the cultural aspects of mathematics, Etnomatemática: os aspectos culturais da matemática 4 (2) (2011) 32–54. http://www.revista.etnomatematica.org/index.php/RL.
[4] R. Timol, Ethno-religious socialisation, national culture and the social construction of British Muslim identity, Contemporary Islam 14 (2020) 331–360, https://doi.org/10.1007/s11562-020-00454-y, 2020.
[5] G. Geneva, Preparing for culturally responsive teaching, J. Teach. Educ. 53 (2) (2002) 106–116, https://doi.org/10.1177/0022487102053002003.
[6] P.W.U. Chinn, Preparing science teachers for culturally diverse students: developing cultural literacy through cultural immersion, cultural translators and communities of practice, Cult. Stud. Sci. Educ. 1 (2006) 367–402, https://doi.org/10.1007/s11422-006-9014-0, 2006.
[7] F. Ducarme, D. Couvet, What does 'nature' mean? Palgrave Commun 6 (2020) https://doi.org/10.1057/s41599-020-0390-y, 2020.
[8] B. Latour, D. Milstein, I. Marrero-Guillamón, I. Rodríguez-Giralt, Down to earth social movements: an interview with Bruno Latour, Soc. Mov. Stud. 17 (2018) 353–361, https://doi.org/10.1080/14742837.2018.1459298, 2018.
[9] F.P. SariMaryati, I. Wilujeng, Ethnoscience studies analysis and their integration in science learning: literature review, Jurnal Penelitian Pendidikan IPA (JPPIPA) 9 (3) (2023) 1135–1142, https://doi.org/10.29303/jppipa.v9i3.2044.
[10] L.J. Slikkerveer, The indigenous knowledge systems' perspective on sustainable development, Differential-Algebraic Equations Forum (2019) 33–66, https://doi.org/10.1007/978-3-030-05423-6_2.
[11] N. Barter, The perception of the environment: essays on livelihood, dwelling and skill, Social and Environmental Accountability Journal 32 (2012) 121–123, https://doi.org/10.1080/0969160x.2012.718920, 2012.
[12] W. Larner, Globalising knowledge networks: universities, diaspora strategies, and academic intermediaries, Geoforum 59 (2015) 197–205, https://doi.org/10.1016/j.geoforum.2014.10.006, 2015.
[13] R. Jannah, F. Festiyed, Y. Yerimadesi, L. Lufri, S. Putra, Ethnoscience in learning science: a systematic literature review, Scientiae Educatia 11 (2) (2022) 75–184, https://doi.org/10.24235/sc.educatia.v11i2.11488.
[14] I.M.S. Eldeen, M.A.W. Effendy, T.S. Tengku-Muhammad, Ethnobotany: challenges and future perspectives, Res. J. Med. Plant 10 (6) (2016) 382–387, https://doi.org/10.3923/rjmp.2016.382.387.
[15] K.O. Obiero, S. Klemet-N'Guessan, A.Z. Migeni, A.O. Achieng, Bridging Indigenous and non-Indigenous knowledge systems and practices for sustainable management of aquatic resources from East to West Africa, J Great Lakes Res 49 (1) (2023) 128–137, https://doi.org/10.1016/j.jglr.2022.12.001.
[16] M. Mbah, S. Ajaps, P. Molthan-Hill, A systematic review of the deployment of indigenous knowledge systems towards climate change adaptation in developing world contexts: implications for climate change education, Sustainability 13 (9) (2021) 1–24, https://doi.org/10.3390/su13094811.
[17] R.B. Angayuqaq, O. Kawagley, Indigenous knowledge systems and Alaska native ways of knowing, Anthropol. Educ. Q. 36 (1) (2005) 8–23, https://doi.org/10.1525/aeq.2005.36.1.008.
[18] R. Zidny, J. Sjöström, I. Eilks, A multi-perspective reflection on how indigenous knowledge and related ideas can improve science education for sustainability, Sci. Educ. 29 (2020) 1–41, https://doi.org/10.1007/s11191-019-00100-x, 2020.
[19] W. Menski, Comparative Law in a Global Context: the Legal Systems of Asia and Africa, second ed., Cambridge University Press, 2006, pp. 1–499, https://doi.org/10.1017/CBO9780511606687.
[20] E.O. Wahab, S.O. Odunsi, O.E. Ajiboye, Causes and consequences of rapid erosion of cultural values in a traditional african society, J. Anthropol. (2012) 1–7, https://doi.org/10.1155/2012/327061.
[21] R. Arsenault, C. Bourassa, S. Diver, D. McGregor, A. Witham, Including indigenous knowledge systems in environmental assessments: restructuring the process, Glob Environ Polit 19 (3) (2019) 120–132, https://doi.org/10.1162/glep_a_00519.

[22] Y. Rahmawati, A. Ridwan, U. Cahyana, T. Wuryaningsih, The integration of ethnopedagogy in science learning to improve student engagement and cultural awareness, Universal Journal of Educational Research 8 (2) (2020) 662–671, https://doi.org/10.13189/ujer.2020.080239.
[23] J.H. Hendrawan, The inculcation of Sundanese local wisdom values in millennial generation (Ethno-pedagogy on social studies learning at the pasundan middle school, cimahi), Proceedings of the International Conference On Social Studies, Globalisation And Technology (ICSSGT 2019) 458 (1) (2020) 307–314, https://doi.org/10.2991/assehr.k.200803.038.
[24] X. Meyer, B.A. Crawford, Teaching science as a cultural way of knowing: merging authentic inquiry, nature of science, and multicultural strategies, Cult. Stud. Sci. Educ. 6 (3) (2011) 525–547, https://doi.org/10.1007/s11422-011-9318-6.
[25] Z.A. Khusainov, R.I. Gaisin, N.M. Biktimirov, M.R. Valiev, I.R. Gilemhanov, Formation of ecological culture in the aspect of ethno pedagogy, Mediterr. J. Soc. Sci. 6 (1) (2015) 126–130, https://doi.org/10.5901/mjss.2015.v6n1s3p126.
[26] Y. Rahmawati, A. Ridwan, A. Mardiah, W. Sandryani, P.C. Mawarni, A. Setiawan, Student engagement in science learning through the integration of ethnopedagogy in wastewater treatment project, J Phys Conf Ser (2019) 1–6, https://doi.org/10.1088/1742-6596/1402/5/055052.
[27] H.D. Pingge, N. SupriatnaSapriya, A.A. Wahap, R.M. Haingu, Ethnographic study of the umma kalada values of the indigenous people of loura and its application in elementary social studies learning, in: Proceedings of the 6th International Conference on Education & Social Sciences (ICESS 2021), 2021, pp. 154–159, https://doi.org/10.2991/assehr.k.210918.030.
[28] L. Rychly, E. Graves, Teacher characteristics for culturally responsive pedagogy, Multicult. Perspect. 14 (1) (2012) 44–49, https://doi.org/10.1080/15210960.2012.646853.
[29] Y. Rahmawati, A. Ridwan, Empowering students' chemistry learning: the integration of ethnochemistry in culturally responsive teaching, Chemistry: Bulgarian Journal of Science Education 26 (6) (2017) 813–830.
[30] N. Zugravu-Soilita, R. Kafrouni, S. Bouard, L. Apithy, Do cultural capital and social capital matter for economic performance? An empirical investigation of tribal agriculture in New Caledonia, Ecol. Econ. 182 (2021) 1–15, https://doi.org/10.1016/j.ecolecon.2020.106933, 2021.
[31] A. Escobar, Culture sits in places: reflections on globalism and subaltern strategies of localization, Polit. Geogr. 20 (2) (2001) 139–174, https://doi.org/10.1016/S0962-6298(00)00064-0.
[32] P.Y. Tan, J. Zhang, M. Masoudi, J.B. Alemu, P.J. Edwards, A. Grêt-Regamey, D.R. Richards, J. Saunders, X.P. Song, L.W. Wong, A conceptual framework to untangle the concept of urban ecosystem services, Landsc Urban Plan 200 (2020) 1–11, https://doi.org/10.1016/j.landurbplan.2020.103837.
[33] M. Hajian, S.J. Kashani, Evolution of the concept of sustainability. From Brundtland Report to sustainable development goals, Sustainable Resource Management: Modern Approaches and Contexts (2021) 1–24, https://doi.org/10.1016/B978-0-12-824342-8.00018-3.
[34] M. Hammersley, Ethnography and education ethnography: problems and prospects, Ethnogr. Educ. 1 (1) (2006) 3–14, https://doi.org/10.1080/17457820500512697.
[35] M. del Rio-Roberts, A guide to conducting ethnographic research: a review of ethnography: step-by-Step, in: third ed., in: David M. Fetterman (Ed.), Qualitative Report, vol. 15, 2012, pp. 737–739, https://doi.org/10.46743/2160-3715/2010.1174, 3.
[36] C. Bitwell, S. Sen Indra, C. Luke, M.K. Kakoma, A review of modern and conventional extraction techniques and their applications for extracting phytochemicals from plants, Sci Afr 19 (2023) 1–19, https://doi.org/10.1016/j.sciaf.2023.e01585, 2023.
[37] R. Joshi, Role of enzymes in seed germination, International Journal of Creative Research Thoughts 6 (2) (2018) 1481–1485. www.ijcrt.org.
[38] F.K. Sakungo, Geothermal resources of Zambia, Geothermics 7 (2–3) (1988) 503–514, https://doi.org/10.1016/0375-6505(88)90079-X.
[39] Y. Yu, G. Li, Q. Liu, Different concentration of iodized salt for preventing iodine deficiency disorder: a systematic review, Chin. J. Endemiol. 28 (6) (2009) 579–582, https://doi.org/10.3760/cma.j.issn.1000-4955.2009.05.034.
[40] T. Wu, G.J. Liu, P. Li, C. Clar, Iodised salt for preventing iodine deficiency disorders, Cochrane Database Syst. Rev. 2002 (2010) 1–22, https://doi.org/10.1002/14651858.CD003204.
[41] A. Hatch-McChesney, H.R. Lieberman, Iodine and iodine deficiency: a comprehensive review of a Re-emerging issue, Nutrients 14 (2022) 1–11, https://doi.org/10.3390/nu14173474.
[42] P.E.S. Munekata, G. Rocchetti, M. Pateiro, L. Lucini, R. Domínguez, J.M. Lorenzo, Addition of plant extracts to meat and meat products to extend shelf-life and health-promoting attributes: an overview, Curr. Opin. Food Sci. 31 (2020) 81–87, https://doi.org/10.1016/j.cofs.2020.03.003.
[43] G. Olvera-Aguirre, Á.T. Piñeiro-Vázquez, J.R. Sanginés-García, A. Sánchez Zárate, A.A. Ochoa-Flores, M.R. Segura-Campos, E. Vargas-Bello-Pérez, A.J. Chay-Canul, Using plant-based compounds as preservatives for meat products: a review, 1-12, Heliyon 9 (2023) e17071, https://doi.org/10.1016/j.heliyon.2023.e17071.
[44] C. Baskaran, V.R. bai, S. Velu, K. Kumaran, The efficacy of Carica papaya leaf extract on some bacterial and a fungal strain by well diffusion method, Asian Pac J Trop Dis 2 (2) (2012) S658–S662, https://doi.org/10.1016/S2222-1808(12)60239-4.
[45] A.G. Mkindi, Y. Tembo, E.R. Mbega, B. Medvecky, A. Kendal-smith, I.W. Farrell, P.A. Ndakidemi, S.R. Belmain, P.C. Stevenson, Phytochemical analysis of tephrosia vogelii across east africa reveals three chemotypes that influence its use as a pesticidal plant, Plants 8 (12) (2019) 1–11, https://doi.org/10.3390/plants8120597.
[46] R. Avasthe, A. Yadav, S. Babu, R. Gopi, R.K. Avasthe, H. Kalita, C. Kapoor, S.K. Das, Traditional pest and disease management practices in Sikkim himalayan region, International Journal of Bio-resource and Stress Management 7 (3) (2016) 471–476, https://doi.org/10.5958/0976-4038.2016.00072.5.
[47] B. Fagan, The iron age of Zambia, Curr. Anthropol. 7 (4) (1966) 453, https://doi.org/10.1086/200752.
[48] C.E. Byrne, D.C. Nagle, Carbonization of wood for advanced materials applications, Carbon 35 (2) (1997) 259–266, https://doi.org/10.1016/S0008-6223(96)00136-4.
[49] A. Demirbas, W. Ahmad, R. Alamoudi, M. Sheikh, Sustainable charcoal production from biomass, energy sources, Part A: recovery, Utilization and Environmental Effects 38 (13) (2016) 1882–1889, https://doi.org/10.1080/15567036.2014.1002955.
[50] M. Mohlakoana, A. Moteetee, Southern african soap plants and screening of selected phytochemicals and quantitative analysis of saponin content, Resources 10 (96) (2021) 1–18, https://doi.org/10.3390/resources10100096.
[51] V.W. Xu, M.Z.I. Nizami, I.X. Yin, O.Y. Yu, C.Y.K. Lung, C.H. Chu, Application of copper nanoparticles in dentistry, Nanomaterials 12 (2022) (2022) 1–15, https://doi.org/10.3390/nano12050805.
[52] X. Ma, S. Zhou, X. Xu, Q. Du, Copper-containing nanoparticles: mechanism of antimicrobial effect and application in dentistry-a narrative review, Front Surg 9 (2022) 1–21, https://doi.org/10.3389/fsurg.2022.905892.
[53] C. Robinson, S. Connell, J. Kirkham, S.J. Brookes, R.C. Shore, A.M. Smith, The effect of fluoride on the developing tooth, Caries Res. 38 (2004) 268–276, https://doi.org/10.1159/000077766.
[54] P.D. Marsh, Dental plaque as a biofilm and a microbial community - implications for health and disease, BMC Oral Health 6 (1) (2006) 1–7, https://doi.org/10.1186/1472-6831-6-S1-S14.
[55] M.M. Haque, S.A. Alsareii, A review of the therapeutic effects of using miswak (Salvadora Persica) on oral health, Saudi Med. J. 36 (5) (2015) 530–543, https://doi.org/10.15537/smj.2015.5.10785.
[56] C. Sejal, T. Lisa, W. Stuart, The miswak toothbrush: incorporating traditional knowledge into contemporary product design, Design: Reinventing Design Modes (2022) 1815–1822, https://doi.org/10.1007/978-981-19-4472-7_117.
[57] P. Dahiya, R. Kamal, R. Luthra, R. Mishra, G. Saini, Miswak: a periodontist's perspective, J. Ayurveda Integr. Med. 3 (4) (2012) 184–187, https://doi.org/10.4103/0975-9476.104431.
[58] H.A. Mir, M. Sharif, A. Asif, M. Shamim, M. Qureshi, A. Akhtar, Effectiveness of miswak as compared with toothbrush: a cross-sectional study, Pak Armed Forces Medical Journal 71 (5) (2021) 1582–1584, https://doi.org/10.51253/pafmj.v71i5.7295.
[59] F. Niazi, M. Naseem, Z. Khurshid, M.S. Zafar, K. Almas, Role of Salvadora persica chewing stick (miswak): a natural toothbrush for holistic oral health, Eur J Dent 10 (2) (2016) 301–308, https://doi.org/10.4103/1305-7456.178297.
[60] S. Sagar, Role of natural toothbrushes in containing oral microbial flora-a review, Asian J. Pharmaceut. Clin. Res. 8 (4) (2015) 29–33.

[61] N.K. Said-Ador, Ethnochemistry of Maguindanaons' on the usage of household chemicals: implications to chemistry education, J. Soc. Sci. 6 (2) (2017) 8–26, https://doi.org/10.25255/jss.2017.6.2S.8.26. http://centreofexcellence.net/J/JSS/JSS%20Mainpage.htm.
[62] H. Sutrisno, D. Wahyudiati, I.S.Y. Louise, Ethnochemistry in the chemistry curriculum in higher education: exploring chemistry learning resources in sasak local wisdom, Universal Journal of Educational Research 8 (12) (2020) 7833–7842, https://doi.org/10.13189/ujer.2020.082572.
[63] V.O. Ajayi, E.E. Achor, P.O. Agogo, Use of ethnochemistry teaching approach and achievement and retention of senior secondary students in standard mixture separation techniques, ICSHER Journal 3 (1) (2017) 21–30.
[64] H. Sutrisno, D. Wahyudiati, I.S.Y. Louise, Ethnochemistry in the chemistry curriculum in higher education: exploring chemistry learning resources in sasak local wisdom, Universal Journal of Educational Research 8 (12) (2020) 7833–7842, https://doi.org/10.13189/ujer.2020.082572.
[65] L.K. Duffy, A. Godduhn, C.E. Fabbri, M. van Muelken, L. Nicholas-Figueroa, C.H. Middlecamp, Engaging students in science courses: lessons of change from the arctic, Interchange 42 (2) (2011) 1–5, https://doi.org/10.1007/s10780-011-9151-6, 136.
[66] I. Abramova, A. Greer, Ethnochemistry and human rights, Chem. Biodivers. 10 (9) (2013) 1724–1728, https://doi.org/10.1002/cbdv.201300211.
[67] K. Konadu, Indigenous medicine and knowledge in African society, Choice Curr. Rev. Acad. Libr. 272 (2007), https://doi.org/10.4324/9780203941393.
[68] A. Chikonzo, The potential of information and communication technologies in collecting, preserving and disseminating indigenous knowledge in Africa, Int. Inf. Libr. Rev. 38 (3) (2006) 132–138, https://doi.org/10.1016/j.iilr.2006.06.006.
[69] J.W. Friesen, Strong helpers' teachings: the value of indigenous knowledges in the helping professions by cyndy baskin, Can. Ethnic Stud. 45 (1) (2013) 285–287, https://doi.org/10.1353/ces.2013.0021, review.
[70] C. Quigley, Globalization and science education: the implications for indigenous knowledge systems, Int. Educ. Stud. 2 (1) (2009) 76–88, https://doi.org/10.5539/ies.v2n1p76.
[71] A. Jedlowski, Matthias Krings, African Appropriations, Cultural difference, mimesis, and media, Anthropos 111 (2016) 1–297, https://doi.org/10.5771/0257-9774-2016-2-720.