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Cultural, nutritional and microbial perspectives of *tuak*, a traditional Balinese beverage

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Abstract

Palm wine (*tuak*) is a traditional drink recognized worldwide as the traditional drink of Africa, Southeast Asia, and Central America. The history of alcoholic beverages in Indonesia is from the prehistoric era and is recorded in Borobudur, the largest Buddha temple in Indonesia, built in the eighth century. Although Indonesian society has experienced many social and cultural changes, the tradition of *tuak* production for daily drinks and ceremonies is strong and widespread and has been introduced as a tourism commodity in regions of Indonesia, especially in Bali. However, there are significant challenges in improving this traditional drink's quality and economic value. In this review, we conducted a desktop study and field survey to learn how *tuak* is part of Indonesian fermented beverage history, especially in Bali, linked to daily life in most traditional communities and supported by local regulators for the existence of this traditional heritage in society and economy. The nutritional composition of *tuak* comprises monosaccharides such as glucose and fructose, disaccharides including sucrose and maltose, organic acids, and bioactive compounds encompassing saponins, phenols, terpenoids, alkaloids, and flavonoids. Additionally, *tuak* contains minerals, alcohols, and essential aromatic compounds. The microorganisms engaged in the fermentation process predominantly comprise ambient air microbes and plant-associated microbes, with a significant prevalence of *Saccharomyces cerevisiae*, *Saccharomyces chevalieri*, and *Zymomonas mobilis*. Additionally, *Candida tropicalis* yeast is present in the microbial consortium involved in the fermentation. This understanding will provide comprehensive information from a socio-economic perspective to preserve production, celebrate culture and to further develop the value of traditional beverages.

Keywords *Tuak* Bali, Palm wine, *Tuak* function, Traditional drink, Indonesian fermented beverage, Cultural heritage, Socio-economic development, *Tuak* ceremony, *Tuak* chemical composition

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Introduction

The tradition of drinking alcoholic beverages can be found in almost all societies. This habit reaps the pros and cons due to the positive and negative impacts [1]. Indonesia has a large and diverse culture, with many traditions and religions, and a particular place of palm wine/*tuak* production and consumption. The island of Bali was selected for this study as ancient and modern tradition highly prize *tuak* production in daily life, religious and cultural ceremonies and in tourism. To enhance our understanding of the socio-economic value and diversity of microorganism of *tuak*, we conducted both desktop and field surveys of palm wine production.

People consume alcoholic beverages for socializing, relaxation, cultural and traditional reasons, enhanced enjoyment, escapism, and curiosity. In Indonesia, although most people are Muslims and do not consume alcoholic beverages, on some islands such as Bali, drinking alcohol is typical [2]. Yet, the practice of consuming alcoholic beverages in Indonesia has both advantages and disadvantages, given its adverse consequences [3].

Tuak, a well-known traditional alcoholic beverage, is derived from the sap of various palm tree species rich in sugar, which varies depending on the geographical location. *Tuak* contains ethanol content of approximately 4% and is classified as an alcoholic beverage. Fermented palm sap beverages are found globally, especially in Africa, Asia, and Central America, and are given different names (for example, bandji, taberna, toddy) [4]. Within diverse regions of Indonesia, *tuak* has several specific names in local languages (Fig. 1). *Tuak* is primarily produced from the sap of Palmae genus plants such as aren (*Arenga pinnata* Merr), nipah (*Nypa fruticans*), and siwalan (*Borassus flabellifer*). Furthermore, *tuak* can be produced from rice, corn, and *gadung Dioscorea hispida* Denns. The variation of *tuak* prepared from rice is named as liquid *brem* (in Bali) and *baram* (among the indigenous ethnic groups of Borneo). The word "*tuak*" is inscribed as "twa" or "twak" in ancient Javanese inscriptions and is devoid of comparable linguistic evidence in past cultures of other nations. Thus, it is highly plausible that the word "*tuak*" originates within the archipelago [3, 5].

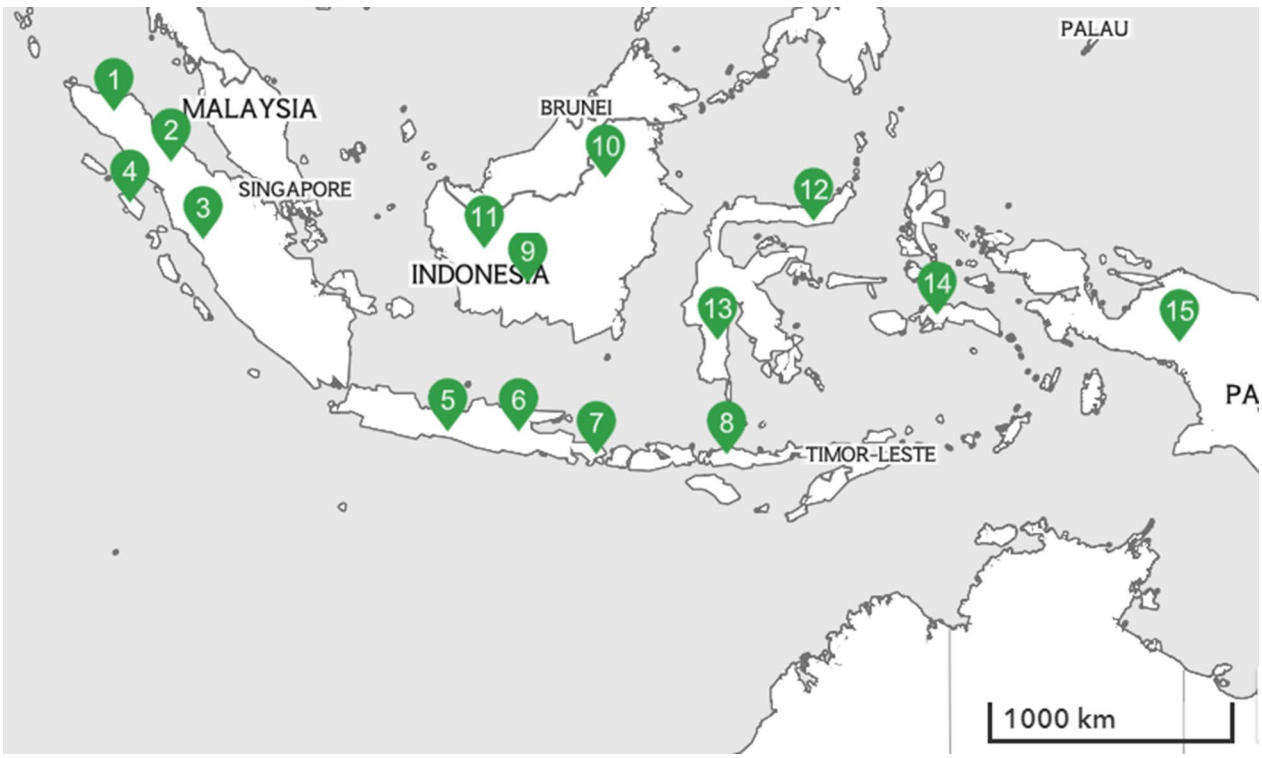


Fig. 1 Geographic Distribution of *tuak* Terminology in Indonesia. This map highlights the diverse names for *tuak*, a fermented beverage with similar attributes, throughout Indonesia. It offers valuable insights into the local terminology and prevalence of this traditional drink, aiding readers in understanding its regional distribution. List of marks: 1. Arak; 2. *tuak*; 3. *tuak*; 4. Tuo Mbanua; 5. Legen, *tuak*; 6. *tuak*; 7. Brem, *tuak*; 8. Moke; 9. Baram; 10. Baram; 11. Beram; 12. Saguer, sageru; 13. Ballo; 14. Saguer, sageru; 15. Khewphu, saguer, ballo. The map is sourced and edited from National Geography Map data

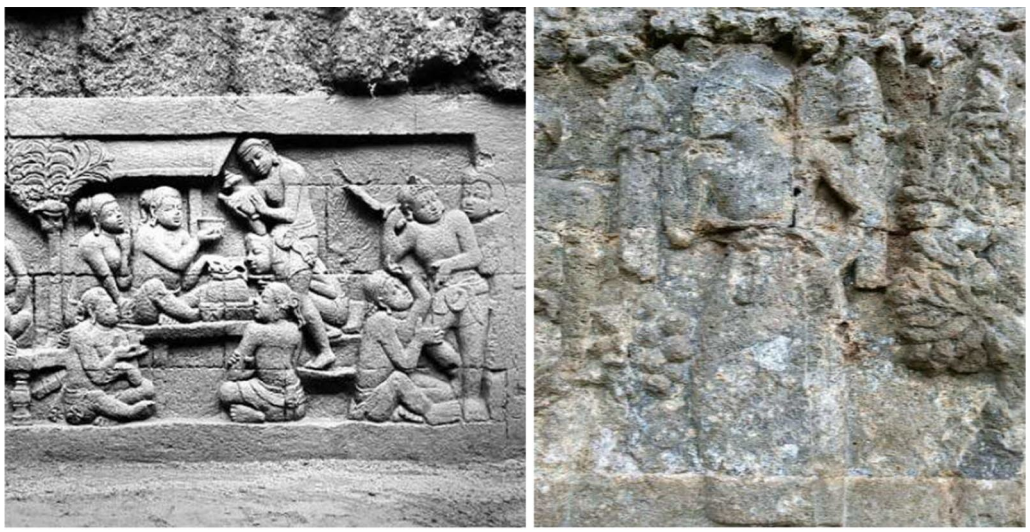
Tracing the origin of *tuak* in Indonesia

It is challenging to estimate when *tuak* was produced and became popular among ancient Indonesians, whether imported or indigenous knowledge. There are two arguments; the first is that a fermented drink was known in Africa and then transferred to Asia by the colonialists and then developed in Indonesia. A strong base does not support this argument. Based on the inscriptions and pictures of the fermented drink, *tuak* is represented in the reliefs of the Borobudur and Prambanan temples, where these temples were constructed in 800 AD, well before the start of the colonization of Asia. There is a firm belief that *tuak* is the indigenous knowledge of peoples in this region (as indicated by old and ancient script on Well-Known Conserved Temples) [6].

Temple reliefs in Fig. 2a, b describe the habit of drinking fermented beverages carried out by all levels of society, from the lowest class to the king. Based on historical records, people around Borobudur and Penataran Temple generally embraced Buddhism and Hinduism [6]. Over subsequent periods, both Hindu and Buddhist communities migrated eastwards to regions such as Bali and the Lesser Sunda Islands. The modern practice of consuming fermented beverages is observed in Bali and the eastern regions of Indonesia [7].

Many inscriptions provide substantial evidence regarding the utilization of alcoholic beverages within diverse ceremonial and ritual contexts, particularly in the context of *sima* establishment by ruling monarchs spanning the realms of Hinduism, Buddhism, and Shiva-Buddhism. Noteworthy examples include early documented records, as inscribed in Taji (901 AD) and Pangumulan (902 AD), detailing the offering of alcoholic beverages (*tuak*) during the formal designation of *sima*. Beyond the stone inscriptions, historical substantiation regarding the prevalence of alcoholic beverages in the Nusantara region, specifically Java, can be derived from various written sources encompassing indigenous works like Negarakertagama (1365), Babad Tanah Jawi (1722), Serat Centhini (1814), as well as foreign accounts [5]. The historical narrative, coupled with an examination of the linguistic and terminological aspects portrayed in the inscriptions and chronicles, suggests that diverse ethnic groups inhabiting the Nusantara (Indonesia) were exposed to alcoholic beverages through the cultural influence exerted by India [3, 5].

In addition to Java and Sumatra, ancient inscriptions from the ninth-eleventh century mention *tuak* can also be found on the island of Bali, such as the Batur Pura Abang A inscription (1011 AD; sheet IIIb 1–2). This inscription refers to the customs followed by the local population during the ceremonial marriage of a male and female horse. Specifically, it offers three baskets of rice, fish as available, and three pots of sweet toddy as the beverage, along with three fruits and five bunches of fruits [3]. Various inscriptions dating from the 8th to eleventh century contain references to the word "twak." One notable example describing *tuak* in the ancient Javanese



(a) **(b)**

Fig. 2 Iconographic representation of: **a** Communal assembly beneath the Arenga Palm (*Arenga* sp.) with service of the traditional fermented sap beverage (*tuak*); **a** an artistic relief from Borobudur Temple; **b** Relief depicting an adult male bearing palm wine: contextualized by adjacent palm and fruit flora: a relief from Penataran Temple. These iconographic representations give valuable insights into the historical and cultural importance of *tuak* at communal gatherings in Indonesia. (retrieved from: Private documentation of Prihardhyanto Keim)

language can be found in the Gulung-Gulung Inscription from the Singasari Kingdom era, dated back to the ninth century, which loosely translates to "and there are sweet desserts, and *tuak*, and suddenly they add more." Another inscription mentioning *tuak* is the Taji Inscription, written during the ancient Mataram era in the ninth century. Most of these inscriptions were created during the "Sima" period, from the 8th to eleventh century [8].

Tuak is frequently mentioned in Sima Era Inscriptions, which document significant events in the political history of ancient Javanese dynasties. These inscriptions serve as valuable sources of information for understanding the broader social, economic, and religious history of the period. Sima inscriptions address the establishment of freeholds (sīma) for temple complexes, their governance and provisioning, rituals, and the social structure of the associated communities. From a geoarchaeological perspective, *tuak* played a crucial role in shaping the archaeological-agricultural landscape of Java during the Sima era [9].

Through archaeological and geoarchaeological analysis, it can be concluded that *tuak* holds significance as a symbol of cultural identity and local culinary innovation. Furthermore, the use of *tuak* as an "official drink" in important celebrations or religious rites showcases the positive perception of this ancient traditional beverage, which may have later evolved due to the influence of new cultural values on how people perceive, think, and engage with traditional practices [3, 5, 6].

The *Cocos nucifera* and *Arenga pinnata*, the primary sources of *tuak*, are widely distributed throughout the Austronesian-Melanesian Tropical Archipelago. However, these plants are typically absent in high-altitude regions within volcanic mountain ranges and thrive in wetland areas, with notable examples found in the wetland basins of Sumatra. Historically, the domestication of both plants can be traced back to the era of Sriwijaya, as evidenced by the Talang Tuo Inscription from the sixth century. This predates the emergence of significant commodities in the modern world, such as rubber and palm oil [3].

Tuak is part of tradition, culture, and religion

In the presence of alcoholic beverages in traditional customs in Indonesia, several indicators can be utilized, including the values and norms that apply to a particular activity, the rules of production, the rules of presentation, the actors involved (ritual leaders or beverage makers), and the recipients of the beverage (deities/ancestors, social structures within the ritual, social structures, and others) [6]. There are four main activities in which traditional alcoholic beverages are present in society, namely as a function in rituals, ceremonies, social functions, and environmental adaptation functions. In practice, these four functions often co-occur, especially in communal customary activities involving many people. The intended customary activities encompass all human activities within the scope of community life, including survival activities (acquiring food and beverages), the life processes of individuals from birth, childhood, adolescence, family life, parenthood, old age, and death, as well as their belief practices.

Ritual functions of *tuak*

As a ritual function, alcoholic beverages are sometimes used as offerings to deities or ancestors, or they may be consumed by specific individuals who act as intermediaries, facilitating communication between the spiritual and earthly realms as part of a ritual [10, 11]. In such rituals, these individuals, often known as shamans or spiritual leaders, enter altered states of consciousness, such as possession or trance by consuming traditional alcoholic beverages and psychoactive plants [12, 13]. During these states, they serve as channels, conveying messages and insights between the spiritual entities and the people participating in the ritual [12]. This practice is deeply rooted in various cultural and religious traditions and is believed to establish a connection between the human world and the divine. Indeed, the influence of *tuak* gradually reduces human control over the physical and mental aspects as the influence of *tuak* lowers the frequency of all brain waves [14]. In normal conditions, humans have a high frequency, and the influence of *tuak* reduces that frequency. When encountering the same frequency as another dimension, humans can communicate with the inhabitants of the spiritual realm. Furthermore, humans may encounter a state of emptiness beyond that point [3, 5].

Rituals, such as the *kalok* and *roko molas poco* of the Flores people, incorporate the traditional alcoholic beverage, *moke*, derived from the *enau* tree (*Arenga pinnata*). This tree is chosen through offerings and prayers. In the *kalok* ritual, tribal leaders and elders consume *moke*, symbolizing cooperative commitment [15]. Conversely, the *roko molas poco* ritual involves villagers collecting construction materials; upon return, they are offered *moke* before constructing a new house [16]. This ritual underscores the selective production and consumption of alcoholic beverages [3, 5]. Among the Dayak Ngaju tribe in Central Kalimantan, the production of *baram*, a fermented rice beverage, involves intricate rituals exclusive to women [17]. The consumption or offering of *tuak* underpins rituals and culture in many places in Indonesia.

Ceremonial uses of *tuak*

In ceremonies, the presence of alcoholic beverages is intended as an expression of gratitude to the creator or ancestors for achievements attained by an individual or the community as a whole [3, 5]. The traditional Batak culture in North Sumatra considers *tuak* as an offering for ancestral spirits, deceased individuals, and similar entities. *Tuak* comes from sugar palm tree/*mayang bagot*, the origin of this *bagot* stem is celebrated by the Toba Batak people from folklore that has been passed down from generation to generation. In this folklore, a princess named Sorbajati, also known as Boru Sorbajati, was forced by her parents to marry a lizard man she did not love [18]. However, due to the pressure exerted by her parents, who had accepted a large sum of money, Boru Sorbajati requested that drums be played while she danced, and her actions would determine her stance for the wedding. While dancing inside the house, she suddenly leaped into the courtyard and disappeared into the ground. Later, Sorbajati transformed into a *bagot* tree, leading to the *tuak* being called Sorbajati water [19, 20]. Since the suicide act was deemed forbidden, *tuak* was not included as an offering to the deities/Gods but presentation of *tuak* has expanded to various events of mourning and celebration [19, 20]. Initially, *tuak* was used as a traditional drink in official traditional ceremonies, funerals, weddings, and births [19].

In everyday life, *tuak* finds prominent usage in the religious ceremonies of the Hindu community. Seputra [21] explains that within these religious ceremonies, *tuak* is employed for *metabuh* (devotional prayers), serving not only as an offering to the divine entity *Ida Sang Hyang Wasa Widhi* but also as an essential complement in the *mecaru* (sacred sacrificial offering to *bhuta kala*) ceremony. This utilization aims to foster harmony within the cosmic order, establishing a harmonious relationship between *bhuana alit* (the human body) and *bhuana agung* (the grand universe). Beyond its role as a religious ceremonial component, *tuak* also fulfills the function of an alcoholic beverage, often consumed during religious ceremonies and customary practices and even served as a refreshing beverage [22, 23].

After the funeral ceremony for someone who has grandchildren, the customary ceremony of *manuan ompu-ompu/raja ni duhutduhut* is held the following day. This ceremony involves planting various types of plants on top of the grave [24]. During this ceremony, water and *tuak* must be poured onto the plants on the grave, but nowadays, only water is usually poured [19].

In the Batak Toba society, there is a traditional ceremony called *manulangi*, a formal event for offering food to the parents [25]. Descendants of the parents, children and grandchildren offer traditional food to their parents. The descendants who offer the food seek blessings and advice from their parents, and during this occasion, the parents distribute their wealth to their descendants. The series of *manulangi* ceremonies are witnessed by extended family members and traditional leaders. When offering food to the parents, the descendants must also serve drinking water and *tuak*. In the belief of the Batak Toba society, water and *tuak* carry symbolic meanings [25]. Water is called *tio* (clear) and signifies that the descendants who offer food to their parents will have clear thinking and good offspring. *Tuak*, on the other hand, is called *tonggi* (sweet) and signifies that the descendants who offer food to their parents will receive a good livelihood from God [19]. Further, the "*tuak tangkasan*" ceremony involves the groom's family presenting the finest *tuak*, traditionally unmixed with raru, to the revered bride's family during a dance ritual [26]. Historically, this *tuak*, gifted by the *boru*, was pure, but contemporary preferences lean toward a mixed version. During these ceremonies, the groom's family also provides money to purchase sweet *tuak* from the bride's side. [19].

Social uses of *tuak*

For social functions, *tuak* has fostered social ties, promoted social harmony, strengthened brotherhood, and instilled cultural values [27]. Initially, *tuak* was sold under the tree where it was produced, and later it was sold at the *tuak* tapper house. Over time, *tuak* stalls (*tuak* shops) emerged. The presence of *tuak* stalls has various economic and social functions in the Toba Batak community, as people usually drink *tuak* at these *tuak* stalls. *Tuak* serves individuals as well as the general community. For individuals, *tuak* is believed to be a beneficial beverage for health and relieves the mind from the life burden [27]. In contrast, for the general community, *tuak* serves as a tool for socializing and is served at every event as a way to entertain guests in the Toba Batak community [19]. *Tuak* is a multifunctional product of ancestral heritage representing the local wisdom of the Toba Batak community.

Karangasem is the largest producer of *tuak* in Bali, where the tradition of *metuakan* (drinking *tuak*) has been well-known since ancient times. In almost every village, residents who work as *tuak* makers and traders can be found. Karangasem *tuak* is shipped and sold in other regions, including Denpasar [28]. Karangasem is also known for its traditional arts *Genjek* and *Cakepung*, in which *tuak* plays a significant role. The performers of Genjek and Cakepung take turns drinking *tuak* while singing with mouth music and dancing in circles.

These arts are vibrant and full of festive atmosphere [28]. Consuming *tuak* is considered a unifying social activity among community members in their shared social interactions and other ceremonies.

Other uses of *tuak*

Alcoholic beverages are consumed to maintain body warmth. This condition applies mainly to those who engage in activities in relatively cold or windy environments. Most ethnic groups in Indonesia do not have layered daily clothing like the Chinese or Japanese, to provide protection against cold air. The activities of communities in highland regions can be observed in the practices of Minahasa farmers in Amurang, where they walk long distances in the early morning to tend to gardens and return in the afternoon. The distance between their homes and the gardens can reach up to 5 km. To adapt to the cold weather, they consume a flask of Cap Tikus (sopi or saguer) before departing to the gardens and another flask before returning [3].

In contrast to the farmers in Amurang, who consume alcohol in flask-sized portions, Balinese fishermen may just take a gulp. In the past, bamboo was the standard container used to carry and store *tuak*. Of course, all these community activities cannot be carried out if performed under the influence of alcohol. This local wisdom sets an example that there are limits or boundaries in consuming alcoholic beverages to avoid reaching a state of intoxication [3, 5].

Types of *tuak*

T*uak* can be defined as the result of the spontaneous fermentation of the sweet sap liquid extracted from *Coco nucifera* and *Arenga pinnata*, widely distributed plants in the Austronesian and Melanesian tropical regions. *Tuak* has continued its historical journey from ancient times in areas less influenced by Islam in Indonesia. In Islamic contexts, the sweet sap of palm trees is primarily transformed into palm sugar, serving as an essential source of sucrose [5, 29]. *Tuak* production is renowned in the North Sumatran and Bali regions of Indonesia. Where, the production of *tuak* involves a natural fermentation process where one or more types of wood bark or root, commonly referred to as *raru* (*Xylocorpus* wood bark or a variety of forest mangosteen), are introduced to the sap water obtained from the inflorescence of the sugar palm or other types of palms for some time. *Tuak* fermentation thrives in tropical environments characterized by ample sunlight and warm temperatures throughout the day. The best *tuak* is obtained by harvesting sugar sap during the early rainy seasons. However, it can be collected throughout the year, ensuring a consistent taste profile with a rich, full-bodied fruity-sour–sweet flavor [5].

Tuak Bali

In Bali, *tuak* is made from the sap of jake (*Arenga pinnata*/palm sugar) flowers, *nyuh* (coconut), and *ental* (*Borassus flabellifer*) trees. Various types of *tuak* are produced, such as *tuak jake*, *tuak nyuh*, and *tuak ental*. *Tuak Jake* is predominantly made in Tenganan, Gumung, and Bebandem. *tuak nyuh* is made in areas with many coconut trees, such as Pikat, Pidpid, and Gunaksa. On the other hand, *tuak ental* is well-known in areas abundant with ental trees (*Borassus flabellifer*), such as Merita, Culik, Tianyar, and Kubu [21, 28, 30].

Tuak jake has a pleasant taste and neutral characteristics and is quickly processed in the body, leading to frequent urination. *Tuak nyuh* has a higher alcohol content than *tuak jake*, and drinkers tend to feel dizzy quickly. *Tuak ental* has a higher alcohol content than *tuak nyuh*, a richer taste, and can quickly induce intoxication [28].

The production of *tuak jake* is time-consuming and can take up to 21 days. Production starts with "ngayunan," where the *jake* flowers are swayed for about an hour. This is followed by the "notok" process, where the jake flower stalks are repeatedly pounded every day for an hour, lasting for two weeks (Fig. 3a). When it is considered mature enough, the "nimpagang" process begins, involving slicing the flower stalk and checking for the presence of sap (Fig. 3b) [28].

Then, the process continues with "nadah," where the jake flower stalks are tapped using a brengkong, a container made from the sheath of a betel palm tree (*Areca catechu*). Each jake flower stalk can produce one brengkong each time the sap is collected, done twice a day, in the morning and afternoon. Up to ten liters of *tuak* can be obtained in a day and one jake tree can produce *tuak* for up to three months. Collecting nyuh and ental *tuak* is similar to the process for jake *tuak* [28].

Freshly collected *tuak* from the tree tastes sweet (*tuak manis*). To enrich flavor *tuak* is mixed with a unique concoction called "lau." Lau generally influences the taste and alcohol content of *tuak*. The best *lau* is made from the powdered wood of the *kutat* tree (*Ganophyllum falcatum*) mixed with the powdered bark of the tabia bun chili tree (*Piper retrofractum*). If the preparation of *lau* is not done correctly, the *tuak* can taste urine-like or sour [28, 31]. *Tuak* is most enjoyable when consumed immediately after being collected from the tree. People in Karangasem are familiar with the taste of "nasak badung" *tuak*, which is slightly bland and slightly sour. There is *tuak* with a more neutral taste, not too old and not too sour, which is still enjoyable to drink called "semedah." *Tuak* wayah refers to *tuak* that has been stored for one to two days. If *tuak* has been stored for two to three days, it is called *tuak bayu*. However, *tuak* stored for more than three days will turn into vinegar [28, 32].

Fig. 3 Photographic documentation of a *tuak* tapper in Bali undertaking the **a** *Notok* and **b** *Nimpagang* processes. This visual representation offers readers an insightful glimpse into the meticulous and time-honored art of *tuak* production in Bali, underscoring the dedication and expertise of the tapper. (retrieved from: Private Photographic Documentation)

Tuak artisans introduce additional *laru* (yeast) to the *tuak*, enhancing the fermentation process and facilitating the conversion of more sugar into alcohol. After two days of delicate and extensive fermentation and aging, the resulting *tuak* (Fig. 4), with its heightened potency, can be subjected to distillation using traditional equipment such as earthenware and bamboo distillation apparatus to produce arak [5, 32]. The graphical representation delineating the procedural steps involved in the production of *tuak* and arak is illustrated in Fig. 4.

Development of palm wine knowledge in terms of nutritional and microbial composition

Palm wine's distinctive whitish hue, effervescence, and sweet-acidic flavor profile can be attributed to the lactic-alcoholic-acetic fermentation processes that occur when the sugary sap of palm trees is collected [33]. This fermentation sequence encompasses three primary stages: lactic acid fermentation, alcoholic fermentation, and acetic fermentation [34]. An interplay and exchange of metabolites among the involved microorganisms dictate the progression of these stages. As organic acids are produced, there is a marked increase in total acidity and a corresponding pH decline, which subsequently fosters the growth and activity of yeasts. Fermentative yeasts generate ethanol, setting the stage for acetic acid production, facilitated by acetic acid bacteria. This intricate microbial cooperation shapes the final character of palm wine [4]. Jagadhita et al. [35] describe the composition of coconut sap with bioactive compounds such as saponins, phenols, and terpenoids identified. Meanwhile, coconut *tuak* possesses a greater number of bioactive compounds compared to coconut sap, including saponins, phenols, terpenoids, alkaloids, and flavonoids.

Palm sap is a clear liquid with a sugar content between 10 and 18% w/v, predominantly consisting of sucrose [4]. In a representative study, the sap collected from *Arenga pinnata* had a pH 6.285 ± 0.007, total phenolic content of 2432 ± 32 µg/g (as gallic acid equivalents), and free radical scavenging activity (measured as IC_{50}) of 0.6 mg/ml. Notably, sucrose was the predominant sugar component in the sample [36]. The consistency, color, and composition of palm wine undergo significant changes as the tapping process progresses. Initial secretions are characterized by a sugary content with minimal alcohol presence, predominantly comprising sugars like sucrose, maltose, glucose, and fructose. As tapping advances, the sugars xylose and cellobiose are found, coupled with a general decline in sugar levels, which can be attributed to the tree's reduced sugar reserves after felling and leaf

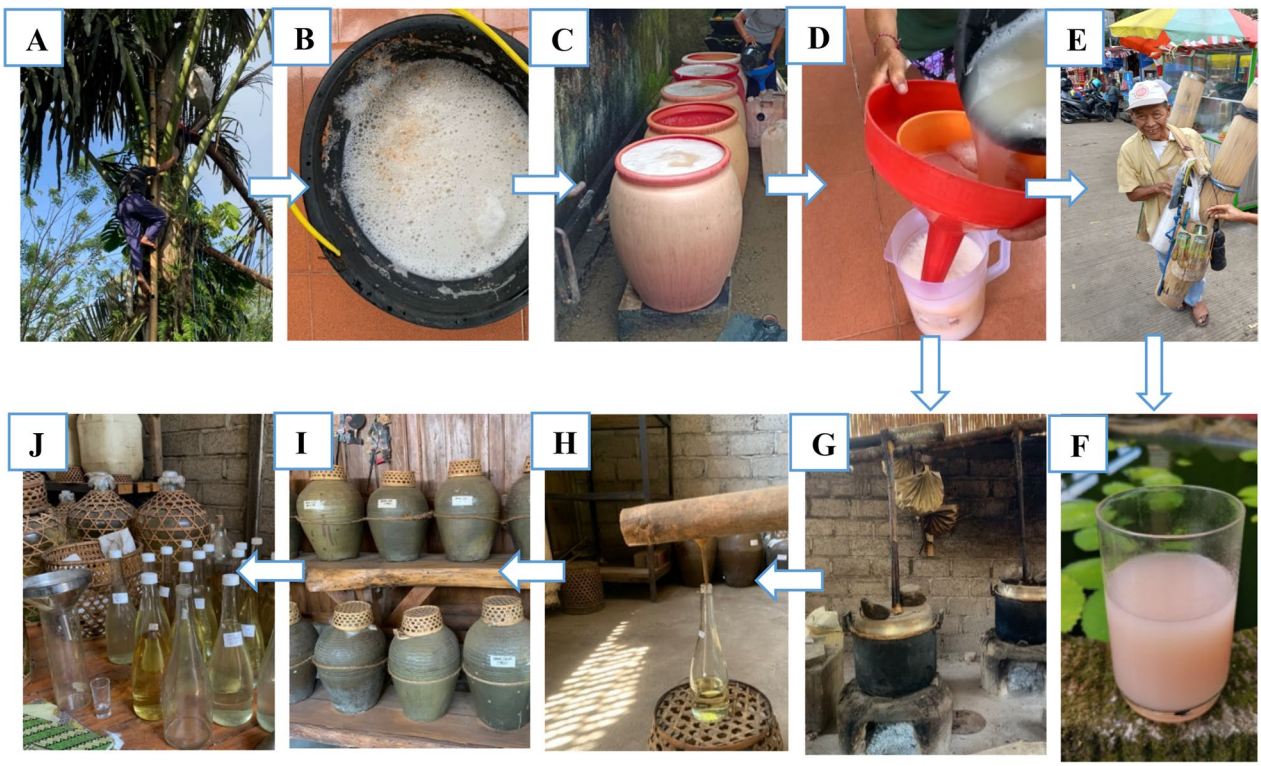


Fig. 4 The traditional process of making palm wine in Bali, particularly in the Karang Asem area, involves several steps. It begins with tapping sap from the aren tree (*Arenga pinnata*) (**A**). The collected sap is then stored in a bucket called *Tuak Manis* (**B**). To enhance the fermentation process, laru (usually coconut fiber) or plant bark *Pterospermum javanicum* is added (**C**). After fermenting for 10–24 hours, *tuak wayah* is produced (**D**). Tuak manis and Tuak wayah are then sold by traditional traders (**E**). Tuak wayah with additional laru': The drink had lovely soft pink and white colors. (**F**). To create arak with varying alcohol content (18–40%), tuak wayah undergoes distillation (**G**). Using bamboo, tuak mist is condensed (**H**). Arak palm wine can gracefully age within earthern jars, maintaining its rich flavors and character for a delightful span of two years (**I**). The final product is set for distribution in sleek glass bottles (**J**). The quality of arak palm wine depends on distillation and condensation techniques, as well as the type of firewood used. Notably, arak kelor has a unique taste attributed to the use of Moringa oleifera bark as firewood. (retrieved from: Private Photographic Documentation)

extraction. In another study, the sap of *A. pinnata* was close to pH 8. Within a 12-h duration, there is a noticeable decline in pH, registering values ranging between 6 and 5 [37]. Alterations in pH can be ascribed to the synthesis of organic acids, a consequence of microbial metabolic processes. Lactic acid, produced by lactic acid bacteria, has been identified as the primary acid responsible for the acidic condition in palm wine [38]. There is much variation in palm wine composition given the specific palm species; the timing of sampling and the method of tapping play crucial roles in dictating the sugar dynamics during the tapping process [4].

Numerous methods have been employed to enhance the shelf life of palm sap. Traditional preservation methods have often hinged on unhygienic and partially fermented sap collection techniques. Contemporary approaches have delved into utilizing extracts from various trees [39], thermal processing such as pasteurization and sterilization [40], and the incorporation of both natural [41] and chemical preservatives [42]. While thermal treatments, especially pasteurization, have shown efficacy in extending sap's shelf life and preserving key nutrients, these processes impact the flavor or color of the sap [43]. Natural preservatives, while promising, need to be judiciously selected to prevent unfavorable changes to the sap's taste or appearance. Additionally, advanced methods, including the use of chitosan and nisin, have proven effective and safe in extending shelf life [44, 45]. Techniques that employ a combination of pasteurization, clarifying agents, and low-temperature storage seem to be the most promising, ensuring a prolonged shelf life without sacrificing quality [46].

The ethanol content in palm wine is determined by an interplay of factors. These include the type of microorganisms present, the intrinsic sap composition, the specific species of the palm tree, prevailing environmental conditions, and the methodologies employed in tapping and sample analysis. Among the microorganisms,

Table 1 Characteristics of local Indonesian beverages and their components

Beverages names	Characteristics	Plant names	Plant parts	Additional ingredients	Distillation	Alcohol percentage	Area	Fermentation time	Type of production	Additional treatment	Belief health benefit	References
Tuo Mbanua	Sweet, whitish	*Arenga pinnata, Cocos nucifera*	Flower sap	Natural starter from air and plant part	None	4–5%	Nias Island	1 day	Home production			[52]
Tuo Nifaro	Clear colorless	*Arenga pinnata, Cocos nucifera*	Flower sap	Natural starter from air and plant part	1x	> 10%	Nias Island	1 day	Home production		Diabetes, stroke	[53, 54]
tuak Batak	Sweet, bitter	*Borassus flabellifer, Arenga pinnata, Cocos nucifera*	Flower sap	Raru (*Cotylelobium* sp.), coconut husk	None	5–10%	Sumatra	1–1.5 day	Home production			[20]
tuak Bali	Sweet, bitter whitish	*Borassus flabellifer, Arenga pinnata, Cocos nucifera*	Flower sap	Powdered wood of *Ganophyllum falcatum*, bark of *Piper retrofractum*	None	5–10%	Bali	1–3 days	Home production, industry			[28]
Moke Mi	Sweet, white color and cloudy	*Borassus flabellifer, Arenga pinnata, Cocos nucifera*	Flower sap	Leaf of *Arenga pinnata*	None	< 10%	Flores	6 h	Home production			[55, 56]
Moke Ba'i	Bitter, colorless	*Borassus flabellifer, Arenga pinnata, Cocos nucifera*	Flower sap	Leaf of *Arenga pinnata*	1–5x	> 30%	Flores	7 days	Home production			[55, 56]

Table 1 (continued)

Beverages names	Characteristics	Plant names	Plant parts	Additional ingredients	Distillation	Alcohol percentage	Area	Fermentation time	Type of production	Additional treatment	Belief health benefit	References
Baram	Sweet, bitter, hard	*Oryza sativa, oryzasativa* var. *glutinosa*	seeds	Store bought starter, fresh dry spices (*Alpinia galanga, Cinnamomum verum, Cinnamomum* sp. leaf, Cloves, *Capsicum*, *Nicotiana tabacum*), and white sugar, fresh clean water	None	1–80%	Katingan, Central Borneo	10–15 days to months	Home production			[57, 58]
Legen	Sweet	*Borassus flabellifer*	Flower sap	Natural starter from air and plant part	None	< 1%	Tuban, East Java	none	Home production	Pasteurization	Gastritic	[59, 60]
Tuwak	Bitter, sour	*Borassus flabellifer*	Flower sap	Anacardium occidentale bark, coconut husk, Syzygium cumini fruit skin	None	> 10%	Tuban, East Java	> 10 days	Home production		Low blood pressure, kidney stone, kidney problem	[60, 61]
Ara'	Clear, bitter	*Arenga pinnata*	Flower sap	Natural starter from air and plant part	1x	> 20%	Buton	3 days	Home production		Increase stamina, diabetes	[62]
Saguer	Sweet, sour, tasty	*Arenga pinnata*	Flower sap	Natural starter from air and plant part	None	5–10%	Minahasa	6–12 h	Home production	Filtering by arenga leaf fiber		[63]

Table 1 (continued)

Beverages names	Characteristics	Plant names	Plant parts	Additional ingredients	Distillation	Alcohol percentage	Area	Fermentation time	Type of production	Additional treatment	Belief health benefit	References
Sopi/Cap Tikus	Sweet, soft, fresh	*Arenga pinnata*	Flower sap	Natural starter from air and plant part	Once	40–80%	Minahasa	3–4 days	Home production, industry		Stamina, increase blood, virus disinfectant	[64, 65]
Khewphu	Whitish, sweet	*Cocos nucifera*	Flower sap	*Lansium domesticum* roots	None	3–5%	Jayapura, Papua	1–2 days	Home production	Mantra		[66]
Ciu Bekonang	Colorless, bitter, throat burn	*Saccharum officinarum*	Sugarcane juice, molasses	Previous fermented liquid, starter	1–3x	30–90%	Java	5–7 days	Home production	Filtering with rice sack	Stamina enhancer	[67]
Ciu Banyumas	Clear with a tint of yellow	*Manihot esculenta*	Starchy root tuber	Palm sugar, starter (*Enterococcus, Brochothrix, Lactobacillus, Pediococcus, Leuconostoc, Listeria, Saccharococcus, Streptococcus, Saccharomyces cerevisiae*) and water	1–3x	20–70%	Java	7 days	Home production		Stamina enhance	[68]
Arak Jowo	Clear, bitter	*Saccharum officinarum, Oryza sativa* var. *glutinosa*	molasses, seeds	Palm sugar	1x	15–30%	Ngawi, Java	5–7 days	Home production	Distillation by burning using *Switenia mahagoni* wood		[69, 70]
Ballo (nipa, inru, ase, tala)	Sweet, soft	*Nypa fruticans, Arenga pinnata, Oryza sativa, Oryza sativa* var. *glutinosa, Borassus flabellifer*	Flower sap, rice seeds	Natural starter from air and plant part	None	5–30%	South Sulawesi	Days—months	Home production		Stamina enhancer	[71, 72]

Saccharomyces cerevisiae, *Saccharomyces chevalieri*, and *Zymomonas mobilis* play pivotal roles in driving the fermentation process, leading to the production of ethanol in the palm wine [4]. *Candida tropicalis* yeast also has been recognized as an important microbe responsible for the fermentation process in *tuak*. Notably, fermentation tests have revealed that these *C. tropicalis* isolates can generate 6.55% (v/v) and 4.58% ethanol at 30℃ and 42℃, respectively [47]. The alcohol content in *tuak* varies from 1–60%, depending on the ingredients and place of production [2, 48, 49].

The mineral composition of palm wine varies notably across different species. For instance, *Elaeis guineensis* palm wine showcases significant concentrations of magnesium and phosphorus [50], along with several other minerals in varying amounts, while *Phoenix dactylifera* palm wine is especially rich in potassium, in addition to magnesium and phosphorus [51]. Furthermore, the fermentation process in palm wine, facilitated by microbial activities, introduces a range of organic acids and alcohols which are not innately present in the sap. These metabolites significantly influence the wine's aroma, with research identifying key aromatic compounds that give palm wine its distinctive scents, such as ethanol, 2–3-methylbutanol, and earthy and fruity undertones. Collectively, these studies underscore the rich and diverse mineral and aromatic profiles inherent [4]. Tuak is a diverse traditional beverages (Table 1), made from various plant species and involving many microorganism for the fermentation.

It is clear that palm wine has an important meaning in people's lives, especially in Bali. Here, *tuak* is an inseparable part of traditional and modern community life. However, there should be much effort to reduce the negative nosion of palm wine. Palm wine has strengthened family and community relations in Bali and helps the lives of poor people, especially people who live on dry land with limited resources. Their sole source of income is derived from tapping various types of palms, including coconut, palmyra, and sugar palm. The farmer are the main victims in this limited resources area, since most farmer own only 0.2 ha land, with a maximum 12 palm trees. For daily life, they only dependent on palm tree, to produce palm wine. However, tuak production system still faces many problems, one of which is lack of hygiene and unstable product quality. Visitor that come to palm wine production areas is blessing for the local community. Visitors not only interested in witnessing the traditional life that is still preserved, but also wish to taste good quality of palm wine. Hence, we can expect visitor contribute to local economic development. This paper describe the history of tuak and its socio-economic benefit will help us to give more value to palm wine *tuak* and wish support of all stake holders on enriching socio-economic value of tuak.

Conclusion and future directions

Traditional beverage, Palm wine *tuak*, predominantly made in Bali has been well assimilated into local culture and tradition contributing to livelihood of poor communities, especially in North and East Bali. Further quality improvement needed for increasing its social and economic benefit. More studies into its chemical, microbiological, and fermentation properties are vital. Understanding the role of microbes and additives, such as *laru* and palm bark, is essential, as is using sanitized equipment to prevent wine degradation. Enhanced distillation and fermentation can reduce methanol levels, elevating wine quality. Governmental interventions are pivotal in guiding traditional communities and framing legal regulations for socio-economic growth. Exploring various bark amendments could standardize *tuak* production. Emphasizing bioethanol from sugar palm offers socio-environmental benefits. Addressing *tuak*'s limited shelf life through research can extend its trade potential. Enhancing the taste and aroma of *tuak,* with *solid* scientific understanding, will allow promotion and celebration of *tuak* to support the traditional practices and economic stability of life in Indonesia.

Abbreviations

IC50 Half maximal inhibitory concentration
GAE Gallic acids equivalent

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Author contributions

IMS collected information, drafted the manuscript, proofreads English; AK collected the information on *tuak* microbiology, maintains the *tuak* microorganism collection; TP, KH contributed information on the biochemical properties of *tuak* and edited the manuscript; INS collected information about *tuak* from local communities in Bali and took pictures; LW designed manuscript content, discussion and future direction; AP was involved in discussion and field survey; All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication
The individuals whose photographs were included in Figures 3 and 4 provided written informed consent for these images to be published.

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All authors declare there is no competing interest regarding this publication.

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