The Invisible Tropical Tuber Crop: Edible Aroids (Araceae) Sold as "Tajer" in the Netherlands

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Abstract: Edible aroids (plants from the family Araceae) are among the top five most cultivated tuber crops globally, but their consumer acceptance is hindered by acridity. Aroids contain sap that severely irritates the throat and lips if not properly processed. However, no in-depth studies exist on acridity in edible aroids and how to diminish it. We used ethnobotanical methods to document the diversity of edible aroids available in the Dutch marketplace and how consumers handle acridity. We grew corms in a greenhouse to obtain additional morphological information and used flow cytometry to assess ploidy. We collected 73 samples and interviewed 71 people. At least three species, *Colocasia esculenta*, *Xanthosoma violaceum*, and *Caladium bicolor*, were sold under the generic name "tajer." Different plant parts with various forms of processing were imported from diverse geographic origins and sold mainly to immigrant customers. Interviewees mentioned various processing methods to avoid and reduce acridity. We distinguished nine cultivar groups of *Colocasia esculenta* and four of *Xanthosoma violaceum*. Both *Colocasia esculenta* and *Xanthosoma violaceum* were also cultivated in Dutch greenhouses. We present the first report on edible aroids cultivation in northern Europe and draw attention to the lack of labeling and cooking instructions.

Keywords: Acridity, Araceae, Food processing, *Caladium bicolor*, *Colocasia esculenta*, *Xanthosoma*, Taro

Introduction

Among edible aroids (plants in the family Araceae) taro, *Colocasia esculenta* (L.) Schott is historically the most widespread, being present in Asia, Africa, and the Pacific since ancient times, and entering the Americas in recent centuries (Grimaldi 2016; Matthews and Ghanem 2020). Similarly widespread are two or more edible species of *Xanthosoma*, originating in tropical America, and now spreading across Asia, Africa, and the Pacific. Taro is a perennial herb, 1–2 m tall, with multiple edible parts, including starchy tubers (commonly referred to as corms and side corms), leaves, and other parts. The leaf is comprised of a tall and thick petiole, supporting a large heart-shaped blade. Edible aroids are among the top five most important tuber and root crops worldwide, and therefore significant carbohydrate sources, only second to cereals globally (Lebot 2019; Oke et al. 1990). Edible aroids are normally cultivated in

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the tropics and subtropics, mostly for food, but also for medicinal and ornamental uses (Lebot 2019; Matthews and Ghanem 2020). Their palatable underground tubers, a starch storage organ, are rich sources of carbohydrates while the aerial parts provide proteins, minerals, and vitamins (Lebot 2019). However, the statistics on their global production, trading, and consumption are lacking, which may be one of the reasons why this group is relatively neglected and less studied (Oke et al. 1990; Matthews and Ghanem 2020).

Examples of known edible aroid species are *Colocasia esculenta* (L.) Schott, *Alocasia macrorrhizos* (L.) G.Don, *Xanthosoma sagittifolium* (L.) Schott, *Amorphophallus paeoniifolius* (Dennst.) Nicolson, *Amorphophallus konjac* K. Koch, and *Cyrtosperma merkusii* (Hassk.) Schott (Bradbury and Nixon 1999; Vaneker 2019).

Taro (*Colocasia esculenta*) is probably the best known and most widely cultivated edible aroid. This perennial herb, domesticated in Southeast Asia, is one of the oldest food crops (Ahmed et al. 2020; Grimaldi 2016; Matthews and Ghanem 2020). Taro is a common part of the diet in the Pacific, the Americas, Africa, and Asia and is widely cultivated throughout the tropics, subtropics, and temperate areas (Grimaldi et al. 2018a; Lebot and Ivančič 2022; Matthews and Ghanem 2020). Direct production data is lacking for most countries known to produce taro, and the global number of people consuming taro is also underestimated, though it probably exceeds the 3.9 billion people suggested for Asia alone in 2013 (Matthews and Ghanem 2020).

Depending on the variety, taro blades, petioles, corms, and side shoots (young corms with starch, or stolons as a vegetable) are consumed (Matthews 2004; Rao et al. 2010). Taro cultivars differ in ploidy: both diploid and triploid taros are grown throughout the tropics and subtropics (Chaïr et al. 2016). The relationship between ploidy and varieties is not yet clear (Lebot et al. 2004). Two major cultivar groups are distinguished in literature (Lebot et al. 2004; Plucknett 1983): the *dasheen* group with a large central corm and few or no side corms, and the *eddoe* group, in which the central corm has multiple smaller side corms. There are many commercial cultivars and traditional landraces within each group: some *dasheen* varieties may produce stolons of various length and thickness, or have fused side corms (also viewed as branched corms); while *eddoe* varieties differ in the shape and number of primary and secondary side corms. Varieties in each group also vary greatly in the size, shape, and color of leaves and petioles (IPGRI 1999). Dasheen and eddoe are commonly used terms, but there are no studies on the acridity variation or consumers' perception or preference within these two major groups. Edible species of *Xanthosoma* spp. have similar morphology to taro and are often misidentified as taro, especially in markets where only the corms are present. They are generally dryland crops.

Despite the global significance of taro and other edible aroids, acridity is one of the factors that limit its consumption, which is thought to have a natural function in the biochemical defense of aroids in general (Konno et al. 2014; Lawrie et al. 2023). Acridity has been linked to calcium oxalate, which appears as fine needle-like crystals or raphides that may penetrate soft skin under the pressure of chewing and swallowing (Bradbury and Nixon 1999). These raphides and accompanying acridity factors irritate the throat and lips if taro is not cooked properly, or the skin when raw slime or sap from corms and leaves touches hands or arms during harvest or preparation (Bradbury and Nixon 1999; Paull et al. 1999). Studies have been done on the morphology and raphide content in different aroids, but the relationship between raphides, raphide-associated acridity, and degree of acridity is still not known (Bradbury and Nixon 1999; Paull et al. 1999, 2022). Different taro cultivars vary significantly in acridity and other physical, chemical, and morphological traits (Lebot et al. 2004; Paull et al. 2022). Taro consumers therefore need to know which parts they can eat from which varieties and how to prepare them to remove acridity (Matthews 2004; Matthews and Ghanem 2020). However, variation in acridity among different taro cultivars and other edible aroids has not been studied in detail and is difficult to measure other than through human sensory tasting panels. Without knowledge of the varietal differences in acridity, consumers cannot make informed choices for purchase and preparation. Cases of oral swelling and pain after consumption of raw leaves of *Colocasia esculenta* have been reported in Canada (Omura et al. 2014) and in Hong Kong after consumption of a common ornamental aroid, *Alocasia cucullata* (Lour.) G. Don (Yuen 2001). In Taiwan and South Korea where taro is commonly consumed, it is reported as a common allergen for children (Li et al. 2022) and associated with cross-allergenicity between pollen and foods (Kim et al. 2018). Throughout the world, ornamental aroids are widely sold for their showy leaves or inflorescences. Buyers of ornamental aroids may misidentify certain ornamental aroids (especially *Colocasia* spp. or *Alocasia* spp.) as edible or "taro" and attempt to eat them with or without cooking. Common wild aroids can also attract attention: *Arum palaestinum* is known as one of the most common causes of plant poisoning among children in Israel (Maree et al. 2020). Negative reactions to taro and other aroids are likely to be more frequent around the world than is apparent from published reports. A few examples of accidental poisoning from ornamental aroids have been published, mostly affecting children and animals (Bertero et al. 2020; Knight 2007; Nițescu et al. 2024).

Another reason for confusion about taro and its preparation, in addition to variation between species and cultivars, is that other similar-looking aroids are often traded as food or ornamentals under the same vernacular names ("taro" or "cocoyam"), including *Leucocasia gigantea* (Blume) Schott (Matthews 2014), *Alocasia macrorrhizos*, *Alocasia cucullata* (Nauheimer et al. 2012), and *Xanthosoma sagittifolium* (Grimaldi et al. 2018b). This is also the case in the former Dutch colony of Suriname, where several varieties of *Colocasia esculenta* and *Xanthosoma sagittifolium* are cultivated for their edible leaves and corms. Wild aroids are also collected for medicinal, ritual, and ornamental purposes, and all are often grouped under the generic Surinamese name "tajer" (Van Andel and Ruysschaert 2011).

In the Netherlands, the number of people with an immigrant background was over 4.3 million in 2021, accounting for one-quarter of the Dutch population (Statista 2022). In 2022, 360,000 people had a Surinamese background (https://allecijfers.nl/migratie-nationaliteiten-geboortelanden/suriname/), and after persons born in Turkey, those born in Suriname are the largest migrant group in the Netherlands (CBS 2022). Other major source areas of migrants are Syria, the Dutch Caribbean, Indonesia, and India, all areas where taro is commonly consumed and/or grown (Matthews and Ghanem 2021, Rao et al. 2010). As a result, the number of migrant food entrepreneurs and "tropical" groceries, also known as *tokos*, have increased in the past decades (Huss 2022; Schösler 2014). No reliable information is available on the cultivars of *Colocasia esculenta* and other aroid species or varieties sold as "tajer" in the Netherlands, their levels of acridity, and how consumers handle this acridity.

In this paper, we aim to clarify the diversity of "tajer" sold in the Netherlands and how consumers reduce its acridity. We posed the following questions: (1) What types of fresh and processed "tajer" products are sold and consumed in the Dutch market? (2) Where do these products come from? (3) What species and varieties of "tajer" can be identified based on their morphology and ploidy? (4) How do consumers in the Netherlands process "tajer" to reduce acridity?

Previous casual observation by the authors indicated that the most commonly sold "tajer" products would be *Colocasia esculenta* corms and *Xanthosoma sagittifolium* leaves. We assumed that "tajer" products would be imported from multiple countries and regions, but mostly from Suriname, due to the strong connection between this country and the Netherlands. We also predicted that the cultivars sold would vary in morphology and ploidy, given the reported global diversity in this crop (Chaïr et al. 2016; Rao et al. 2010). Since most people favor foods that are familiar to them (Fischer and Frewer 2009), we also hypothesized that people who bought "tajer" would know how to deal with acridity and would use special cooking methods for "tajer" products with higher acridity levels. Our study is the first on edible aroids sold in Western Europe, their morphological diversity, ploidy, and use. We hope to contribute to a better awareness of edible aroids and offer suggestions to promote safer consumption.

Materials and Methods

Interviews and Sample Collection

Ethnobotanical fieldwork was carried out between May 2022 and August 2023 and included specimen collection, semi-structured interviews with vendors and consumers, and market surveys (Martin 2004). We visited 30 different locations (shops and markets) in Dutch cities with substantial migrant populations (CBS 2019): Amsterdam (8 locations), Rotterdam (4), The Hague (7), and Utrecht (2), and also some smaller cities such as Almere (2), Groningen (1), Wageningen (5), and De Kwakel (1 location). The shops self-identified as Surinamese groceries and market stalls (6 shops), Hindostani groceries and market stalls (4), African groceries and market stalls (3), Nigerian groceries and market stalls (2), Uganda groceries (1), Ghanaian market stall (1), Caribbean market stall (1), Asian-Caribbean grocery (1), Turkish supermarket (2), Pakistan groceries (1), Indian groceries (1), Indian-Nepalian groceries (1), Chinese supermarket (1), Hong Kong grocery (1), wholesaler (2), horticultural center (2), Dutch flower stall (1), Dutch supermarket (1), community garden (1), and individual farmers who also sold products from their garden in the market (2 persons). Interviewees were selected among "tajer" vendors and consumers who sold, shopped for, and/or purchased "tajer" and "tajer" products during our visits to these stores. Before purchasing corms or interviewing vendors and consumers, we explained our research and asked for their oral informed consent. We followed the ISE Code of Ethics (ISE 2006) during our study and paid for all "tajer products" that we collected. Informants were interviewed on the spot in the markets and shops. An interview lasted for 1–10 min on average. Most people accepted to be interviewed, except a few (around 3) who declined our interview. When consumers told us that "tajer" was also grown in Dutch greenhouses and sold in garden shops, we visited two greenhouses in Almere (https://onzevolkstuinen.nl/) and Amsterdam, and two ornamental plant centers (in Almere and Wageningen). We interviewed 71 people, all with a migrant background, including 43 vendors, 22 customers, and nine farmers (three farmers also sold what they cultivated in their garden). Our interviewees had a background from Suriname (30), India (29), Uganda (2), Nigeria (3), Pakistan (2), China (3, including 1 from Hong Kong), and St. Maarten (2), while 42 were male and 29 were female (ESM Table 2).

We also informally talked to some native Dutch shop visitors, but they were not part of our ethnobotanical data collection. We collected the following information: species, plant parts, local names (including languages), country of origin, and processing method before sale. We also asked consumers and vendors about their perceptions of acridity (very/somewhat/not acrid), specific processing steps used to reduce acridity, and other ingredients added to reduce acridity. We decided that we had surveyed a representative sample of shops and participants when we did not find any new "tajer" products and did not hear different recipes anymore.

Leaves, inflorescences, and corms were collected in the shops, market stalls, and greenhouses, and numbered consecutively (e.g., FQ1, FQ2). For fresh leaves and inflorescences, herbarium vouchers were made from the materials purchased. Fresh corms were purchased and grown in the Wageningen University and Research (WUR) Unifarm greenhouse under conditions of 16 h of daylight, a temperature of 18–25 °C, and a humidity between 50 and 90%, for several months to more than a year during 2022–2024. Herbarium specimens were made from the plants that produced by these corms, including inflorescences if present. Vouchers (number range FQ1-FQ83, ESM Table 1) were deposited at Naturalis Biodiversity Center, Leiden (L.), and voucher numbers will soon be available online at https://bioportal.naturalis.nl/ (search term: "Fang, Q." in the collector field). A young leaf of each variety (if available) was collected and stored in a freezer (− 80 °C) for later molecular studies (DNA analysis). Photographs were made of all the plant parts of each specimen.

Specimens were identified at the genus level or the species level based on the authors' experience and by referring to taxonomic literature (Croat et al. 2017; Gonçalves 2011; Li and Boyce 2010). Within species, cultivars and cultivar groups were distinguished and described according to morphological characters and traits indicated in the descriptors for *Colocasia esculenta* (IPGRI 1999; Whitney et al. 2016) and *Xanthosoma sagittifolium* (IBPGR 1989) and based on our own observations and criteria. To distinguish cultivars and cultivar groups,

Table 1. Cultivar groups of *Xanthosoma* cf. *violaceum* based on morphological traits

Group number	XG1	XG2	XG3	XG4
Specimen number	FQ61, FQ32, FQ63, FQ75	FQ42, FQ53	FQ23-27, FQ31, FQ36, FQ83	FQ13
Vernacular names	Rode cocoyam, cocoyam, aroei	Nigeria cocoyam, Uganda cocoyam, okumo, yautia	Tajerblad	"*Xanthosoma sagittifolium*"
Ploidy level	*2n*	*2n*	*2n*	*2n*
Petiole color	Green and purple	Green and purple	Green and purple	Purple
Blade orientation	Slightly downwards	Slightly downwards	Slightly downwards	Slightly downwards
Leaf cupping	Umbrella	Flat	Flat	Cup
Blade shape	Sagittate	Sagittate	Sagittate	Sagittate
Lower veins color	Green with purple	Green	Green	Purple
Leaf margin	Slightly undulate	Slightly undulate	Entire	Entire
Piko color	Green	Green	Green	Green
Petiole base color	Green with purple	White to green	White to green	Pink to purple
Basal ring color	Pink	Pink	White	Pink
Main bud color	Pink-green to purple	Purple	n.d	Pink
Accessory buds	Multiple	Multiple	n.d	Multiple
Accessory bud color	Pink to purple	Purple	n.d	Pink
Corm flesh color	Pink	White	n.d	White
Corm fiber	Purple	Yellow	n.d	Yellow

we used petiole color, leaf shape and position, leaf edge color, corm flesh and fiber color, buds color, basal ring color, and floral characters if inflorescences were available (Fig. 1). We did not use leaf size or plant height as characters because plants were grown from pots, so we did not know their natural height when grown in open (unconfined) ground, which is the usual field context for agronomic observations of plant size and yield. While blade shape is relatively constant among mature (fully emerged) leaves that vary in size, petiole length and overall plant size differ greatly according to the environment (Matthews 2014).

Ploidy Level Analysis

To further identify varieties within species, we sent fresh leaf material of the specimens to the company *Iribov B.V.* (Heerhugowaard, the Netherlands) for flow cytometry (FC) to measure their ploidy level. The principle for ploidy testing via FC is detecting the number of stained nuclei and measuring the relative fluorescence intensity in each sample, with reference to a standard. The nuclei were extracted from the samples with a razor blade and nylon mesh, modified from Zonneveld (2003), and stained with DAPI (4′,6-diamidino-2-phenylindole). DAPI binds to AT-rich regions of DNA and emits fluorescent signals when excited with UV light (365 nm). Fluorescence was measured using optical channels (filters). A filter was used that only allowed emissions greater than 435 nm to pass through. Based on the fluorescence signals, the DNA C-values of each sample were calculated with reference to an internal standard (*Nicotiana tabacum* L.) that was included in the analysis (Doležel et al. 2007; Zonneveld 2003). We used *Nicotiana tabacum* because there is no internal standard available yet for *Colocasia* or *Xanthosoma* species.

The relative DNA C-values were calculated following the equation:

$$Spg = (Rpg/Rpp)^{S}pp$$

S_{pg}, pg of sample; R_{pg}, pg of reference, R_{pp}, peak position of reference; S_{pp}, peak position of sample; pg, picogram.

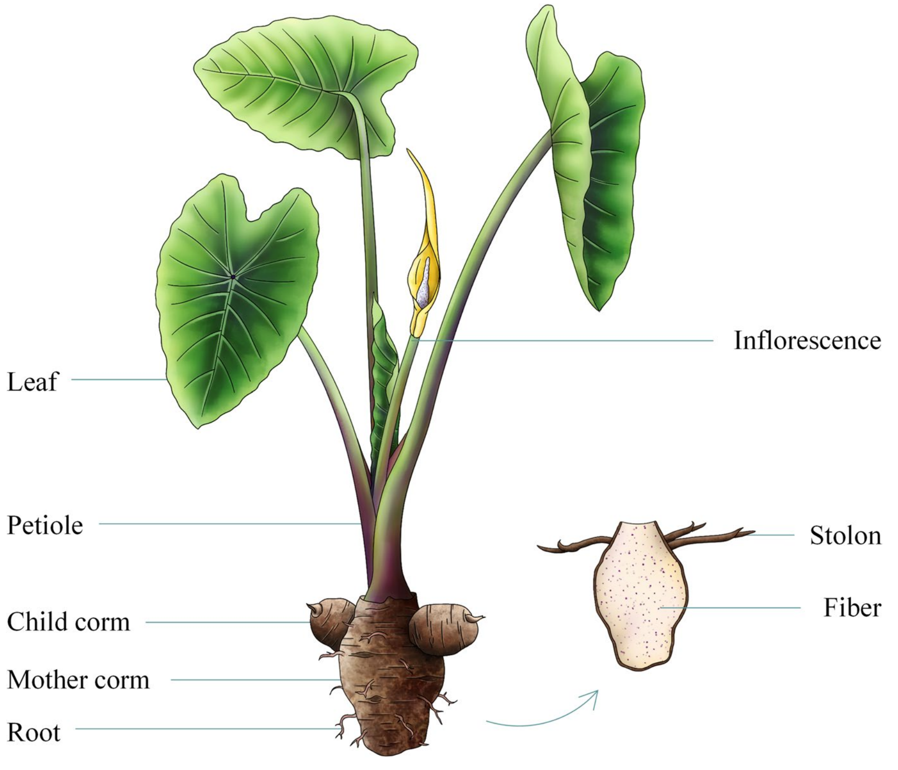

Fig.1. Plant parts of *Colocasia esculenta* that were observed for morphological traits. Illustration by C. Villard adapted from Whitney et al. (2016)

C-values for *Xanthosoma sagittifolium* and *Colocasia esculenta* were double-checked with the Plant DNA C-values Database (https://cvalues.science.kew.org/) and literature (Coates et al. 1988; Ramachandran 1978). As a control measure, we also conducted chromosome counting as follows: actively growing root tips from small lateral corms were collected in the early morning (9:00 am), because mitotic activity is highest after sunrise for most plants (Kantama et al. 2017), incubated in 0.2 mM 8-hydroxyquinoline, followed by fixation in freshly prepared acetic acid ethanol. Cell spread preparations were made after pectolytic digestion and acetic acid maceration. The air-dried preparations were stained in DAPI and studied under a fluorescence microscope with UV/Blue filters as described in Kantama et al. (2017) and de Jong et al. (2023).

Results

Diversity of Plant Species and Plant Parts Sold

We collected a total of 73 samples from 27 different locations in the Dutch cities of Amsterdam, Rotterdam, Den Haag, Almere, Utrecht, Groningen, and Wageningen (Fig. 2). These are all cities with relatively large immigrant populations. The share of residents with a non-Western immigrant background is largest in Rotterdam (38%) followed by Amsterdam (35%) and The Hague (35%) (CBS 2022). We identified three different species sold under the name of "tajer" in the Netherlands: the domesticated crops *Colocasia esculenta* and *Xanthosoma violaceum* and the wild species *Caladium bicolor* (Fig. 3). We collected 50 specimens of *Colocasia esculenta*,

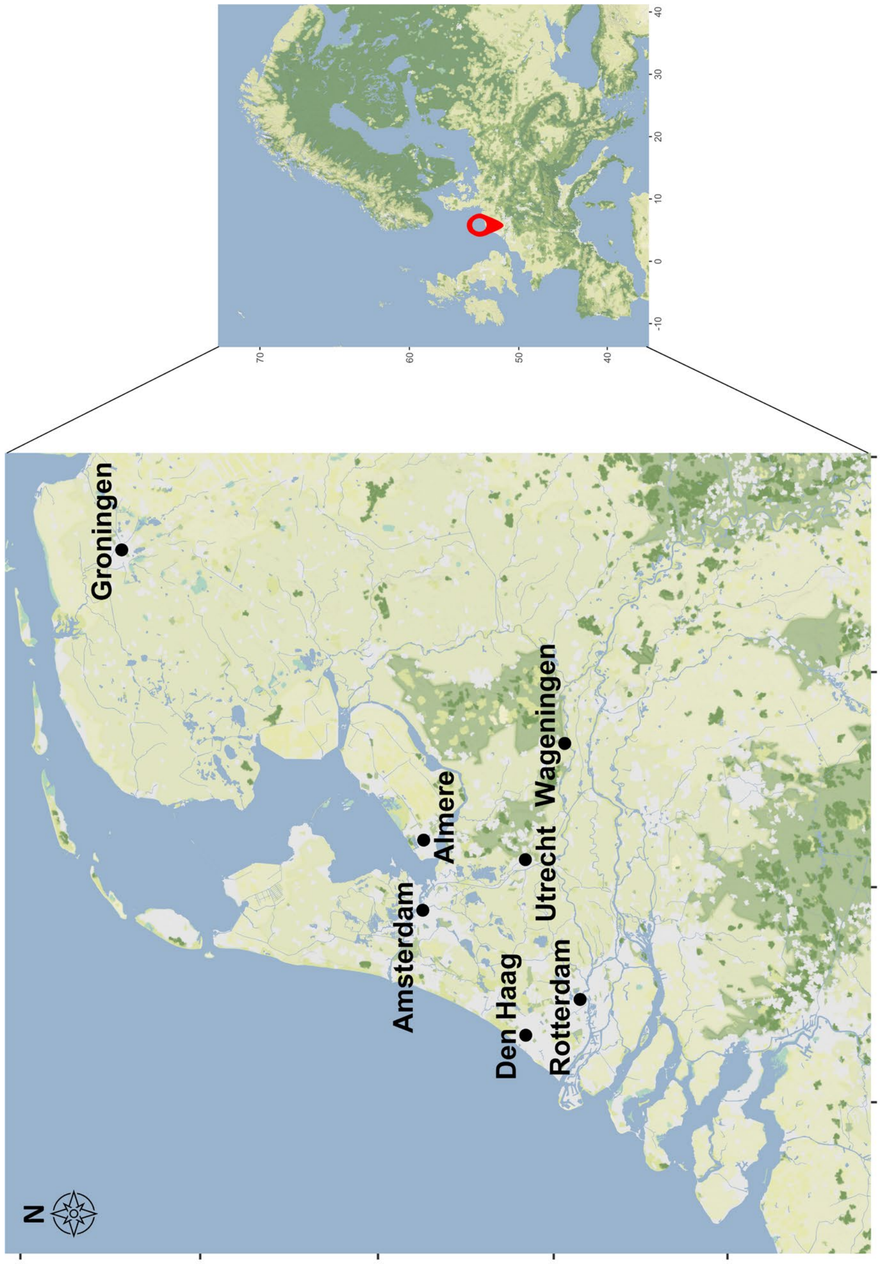

Fig. 2. Map of the Netherlands, with fieldwork locations in black

Fig. 3. Different species and plant parts sold often under the name “tajer” in the Netherlands. **a** “eddoe,” corms of *Colocasia esculenta* (FQ50). **b** “bandroeya,” inflorescences of *Caladium bicolor* (FQ58). **c** “tajer-blad,” leaves of *Xanthosoma violaceum* (FQ31). **d** Young plants of *Xanthosoma violaceum* (FQ83). Photographs: Qiong Fang

21 of *Xanthosoma violaceum*, one of *Caladium bicolor*, and one product from an unknown species (most likely *Colocasia esculenta* or *Xanthosoma* spp.). Detailed information (e.g., species, variety group, plant part sold, perceived acridity) is given in ESM Table 1. Four individuals of *Colocasia esculenta* (FQ2, FQ29, FQ49, and FQ60) flowered in the greenhouse after approximately 4 months. One individual of *Xanthosoma violaceum* (FQ61) flowered after approximately 7 months. In general, the *Xanthosoma* corms were sold in a bad state for eating, with partly rotten corms: 16 survived and five died in the greenhouse. The quality of purchased corms of *Colocasia esculenta* was better: they grew faster under the same conditions: 40 survived and five died.

The *Xanthosoma* individuals we collected were either cultivated for food or ornamental purposes. We identified them as *Xanthosoma* cf. *violaceum* since they all had a posterior rib that was naked for a few centimeters, and all plants had more or less violet petioles and major veins, which are characteristics for *Xanthosoma violaceum* (Croat et al. 2017; Gonçalves 2011). However, these specimens were not all identical in their vegetative morphology, so the present naming is tentative. The only flowering *Xanthosoma* specimen (FQ61) had a slightly purple peduncle and a spadix with a pink sterile interstice (between the upper male and lower female flowers), consistent with *Xanthosoma violaceum*.

The fresh plant parts of the different types of “tajer” sold included corms, leaves, inflorescences, and living plants (Fig. 3). Of our collected specimens, 63% were sold in the form of corms. “Tajer” products were mostly sold at groceries and market stalls managed by Chinese, Indian, Surinamese, African, and Iranian vendors. Only in large cities the major Dutch supermarkets sold “tajer”: a few fresh corms of *Colocasia esculenta* sold in Jumbo under the name of “eddoe” (FQ28) and in Albert Heijn under the name “Chinese tayer” (https://www.ah.nl/producten/product/wi231671/ah-chinese-tayer). *Xanthosoma* leaves or corms are not sold in Dutch supermarkets.

Surinamese migrants also grow their own “tajer” in greenhouses. In the Almere greenhouse, we found that most people cultivated “tajerblad” (*Xanthosoma* cf. *violaceum*) for home consumption and the market. *Colocasia esculenta* corms were less commonly cultivated and were harvested mostly in mid-summer. One farmer mentioned that he sold *Colocasia esculenta* leaves, but only to Japanese and Indian immigrants, as “they were the only ones who knew how to cook them.” He did not have confidence that people of other descent would know how to deal with their toxicity. The greenhouse in Almere had an official shop where seedlings and young plants of tropical crops were sold, but many farmers had brought their own cuttings and root materials from Suriname and sold their “tajer” discreetly. A greenhouse near Amsterdam also housed large quantities of “tajerblad,” together with other Surinamese vegetables grown for the Dutch market. Garden centers in the Netherlands also sell ornamental varieties of *Colocasia esculenta* and *Xanthosoma violaceum*, of which we collected three specimens (ESM Table 1) because these cultivars might also be grown for consumption.

Cultivar groups within *Xanthosoma violaceum*

We distinguished four cultivar groups (XG1-4) within our *Xanthosoma violaceum* specimens (Table 1): three food groups: the “red cocoyam” (XG1), the “African cocoyams” (XG2), the “tajerblad” group (XG3), and one ornamental group (XG4). The “red cocoyam” group was sold as elongated, edible corms, with pink flesh and purple fibers (ESM Fig. 1, FQ61). The leaves were not sold and not mentioned as edible. They produced quite large plants, of which some (FQ61 and FQ75) had a thick trunk. The young sprouts were dark purple, the young leaf yellowish green with purple veins, and in the older leaves, the secondary veins often branched off at an angle of 90° from the main vein (ESM Fig. 1, XG1).

The “African” group including the “Uganda cocoyam” and “Nigeria cocoyam” was similar to the red cocoyam, but their flesh and fibers were whitish yellow (ESM Fig. 1, XG2, FQ53). They were named after the countries where they were said to be imported from according to the vendors, while there was no label on the package about the country of origin. The “tajerblad” group was sold as a vegetable with relatively small leaves that were somewhat glaucous below, with a winged petiole with purple margins (ESM Fig. 1, XG3). The corms were said to be inedible due to their acridity. The ornamental individual FQ13, sold as a house plant, was wrongly labeled as “*Xanthosoma sagittifolium*” and was almost completely purple. It had small, elongated corms, with a few stolons (ESM Fig. 1, XG4). According to the vendor, it was not edible.

Cultivar Groups Within *Colocasia esculenta*

We distinguished nine cultivar groups within our collection of *Colocasia esculenta*: two ornamental and seven food groups (Table 2). Detailed descriptions are provided in ESM Fig. 2. The seven food groups were distinguished by petiole color, leaf shape and position, corm flesh and color, and numbers and color of the buds. The two ornamental groups were easily distinguishable: “Teacup” (FQ11) was an entirely purple plant with cup-shaped leaves that produced no corms but stolons (ESM Fig. 2, CG8). “Hawaiian Punch” (FQ12) had a red petiole, veins, and roots, and produced stolons, not cormels (ESM Fig. 2).

Ploidy Levels

We measured the ploidy of 50 samples (eight *Xanthosoma violaceum*, 42 *Colocasia esculenta*) from our living collections (grown from the fresh corms) through flow cytometry (FC). Results showed that most *Colocasia* samples were triploid, with a relative DNA content of ~ 6.3 pg; only a few were diploid with a relative DNA content of ~ 4.2 pg (Fig. 4). The ornamental *Colocasia* samples (FQ11, FQ12, and FQ79) were all diploid, but one of the edible specimens (FQ59) was also diploid and fell into a separate cultivar group (Table 2). All our

Table 2. Cultivar groups of *Colocasia esculenta*, based on morphological traits and ploidy level

Groups	CG 1	CG 2	CG 3	CG 4	CG5	CG 6	CG7	CG 8	CG 9
FQ number	FQ5, FQ7, FQ77	FQ6, FQ49	FQ09/54	FQ59	FQ43/48	FQ47	FQ1-4, 8,10,28,29,33–35,37–39,44–46,50–52,56,57,60,64–66	FQ11	FQ12
Vernacular names	Snesie tajer, eddoe	Snesie tajer, Indiase tajer	Indian taro, arbi	Malanga, grote taro	Snesie tajer	Snesie tajer	Snesie tajer, taro, eddoe, taro head, dasheen, aroei(a), arbi	Teacup	Hawaiian punch
Ploidy level	*2n*	3n	3n	*2n*	3n	3n	3n	*2n*	*2n*
Petiole color	Green	Green	Green	Green	Green and purple	Green and purple	Green and purple	Green and purple	Green and purple
Blade orientation	Downward	Horizontal, slightly down-wards	Downwards	Most downwards	Pretty horizontal	Horizontal and downwards	Downwards	Horizontal	Horizontal
Leaf cupping	Cup	Flat	Umbrella	Cup	Cup	Umbrella	Slightly cup	Cup	Slightly cup
Blade shape	Sagittate	Sagittate-ovate	Ovate	Sagittate	Narrow sagittate	Ovate	Sagittate	Sagittate	Sagittate
Lower vein color	Green	Green	Green	Green	Green	Green and purple	Green	Purple	Red
Leaf margin	Entire	Entire	Slightly undulate	Entire	Somewhat undulate	Undulate	Entire	Entire	Entire
Piko color	Purple	Green	Green	Purple	Green	Green	Purple	Purple	Purple
Petiole base color	Green with purple stripes	Green and purple	Green	Green	Green with purple stripes	Green with purple stripes	Purple	Purple	Purple
Basal ring color	Pink to purple	Green	Green	Purple	Green	Green	Pink	Pink	Red
Main bud color	Pink to purple	Green to purple	Green	Purple	Green and purple	Purple	Pink to purple	Pink	Pink
Accessory buds	No	Multiple	Multiple	No	Multiple	Multiple	no	n.d	n.d
Accessory bud color	n.d	White to green	Green	n.d	Green and purple	Purple	n.d	n.d	Pink purple
Corm flesh color	White	White	White	White	White	White	White	White	White
Corm fiber	Yellow	Yellow	Yellow	Purple	Yellow	Yellow	Yellow	Purple	Purple

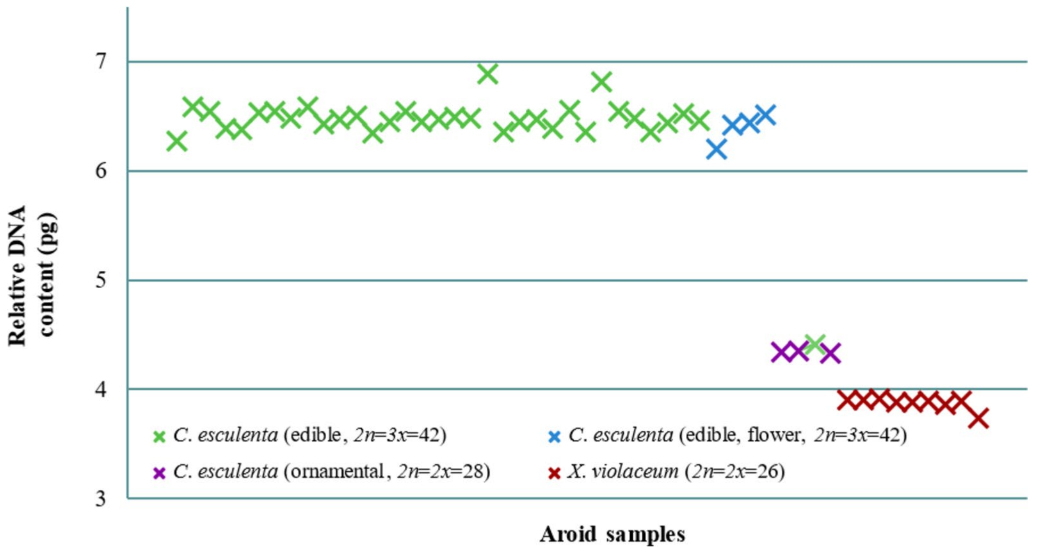

Fig. 4. Flow cytometry measurement on relative DNA content of 42 *Colocasia esculenta* and 8 *Xanthosoma violaceum* specimens sold in the Netherlands. The x-axis represents the sample sequence. *Colocasia esculenta* samples are in green (edible, $2n = 3x = 42$), blue (edible, flowering, $2n = 3x = 42$), and purple (ornamental, $2n = 2x = 28$). *Xanthosoma violaceum* samples are shown in red ($2n = 2x = 26$). For diploid, relative DNA content, C-value is around 4 pg, while for triploid, relative DNA content C-value is around 6 pg

Xanthosoma samples were diploid, with a relative DNA content of ~ 3.9 pg.

To further confirm the ploidy level of our living collections, we also counted their chromosome numbers, which were $2n = 3x = 28$ (diploid) and $2n = 3x = 42$ (triploid) for *Colocasia esculenta* (ESM Fig. 3). Unfortunately, of the ten samples we replanted, only three generated suitable root tips for this measurement. None of the *Xanthosoma* samples generated healthy root tips, so we could not count the number of chromosomes. The $2n$ number for *Xanthosoma* is likely to be 26 (Sotomayor-Rios et al. 1989).

Processed "Tajer" Products on the Dutch Market

Various partly processed products are sold in the Netherlands under the names "tajer," "taro," "taya," and "cocoyam," including frozen and peeled corms, grated corms, dried leaves, and corm flour (Fig. 5). These processed products are labeled with vernacular names only, and sometimes up to three names (Fig. 5a). Although some packages show leaves of either *Xanthosoma* (Fig. 5c) or *Colocasia esculenta* (Fig. 5d), the botanical origin of the material is not mentioned and cannot be verified by the customer.

Highly processed, ready-to-eat food products are also sold in the Netherlands, mainly in Asian groceries, under the English name "taro" or the Chinese name "芋" "yu" (Fig. 6). These products are imported from multiple Asian countries and regions and likely contain *Colocasia esculenta*, not *Xanthosoma*. Even in Asia, where people are more knowledgeable about taro than in Europe, taro is confused with other morphologically similar crops when labels are written in English. Note the "yam cookies" (Fig. 6c), of which the label shows a *Colocasia esculenta* corm, together with its Chinese name "芋" "yu" and "芋头" "yu tou" ("taro" and "taro head"). The English translation here is "yam," which often refers to the starchy underground tubers or aerial bulbils of several species of *Dioscorea* in Mandarin Chinese or other tropic tuber and root crops like *Ipomoea* (sweet potato), *Oxalis* (Lebot 2019), and *Amorphophallus konjac* K.Koch (elephant yam).

During fieldwork, we noticed that native Dutch citizens could not tell the difference between the tubers of yam (*Dioscorea* spp.),

Fig. 5. Edible aroid products sold in the Netherlands under a variety of local names. **a** Frozen peeled corm *Colocasia esculenta*. **b** Dry fufu flour (probably *Colocasia esculenta*). **c** Frozen grated corm of "pomtajer" (*Xanthosoma* sp.). **d** Dried shredded leaves, probably from *Colocasia esculenta*. Photographs: Qiong Fang

cassava (*Manihot esculenta* Crantz), and the corms of "tajer," *Colocasia esculenta* and *Xanthosoma* spp. No scientific names were found on any package, except one bag with frozen corms from India, sold in a Surinamese grocery, that mentioned "*Colocasia* sp."

Vernacular Names and Origins

Many different vernacular names were used for the edible aroids they cultivated, sold, or bought. We recorded names in Sranantongo, Surinamese Dutch and Sarnami (Hindostani Surinamese), English, Hindi (India), Nepalese, Chinese, and Caribbean Spanish (ESM Table 1). Local names were not restricted to specific species or varieties, except for "bandroeya," the Sarnami name for the inflorescences of *Caladium bicolor* (Fig. 3b).

Although the Surinamese-Dutch name "tajer" was used as an umbrella term for all aroids on the Dutch market, especially by consumers of Surinamese descent, we also documented vernacular names referring to the country of origin of the product (e.g., "Nigeria cocoyam"), the (morphology of the) plant part, and on the geographical and ethnic background of the consumers and vendors (ESM Table 1). The

Fig. 6. Various processed food products sold under the name “taro” in the Netherlands. **a** Chips from Vietnam. **b** Energy sticks (taro flavor) from Taiwan. **c** Cookies (with the wrong name “yam”) from Malaysia. **d** Mochi (sticky rice cake with taro flavor) from Taiwan. **e** Cake from Japan. **f** Sticky balls from China. **g** Bubble tea (taro flavor) from China. **h** Instant milk tea (taro flavor) from Taiwan, **i** Taro ice bar from Thailand, **j** Taro ice cream from Thailand, **k** Jelly pudding (middle top row) from Taiwan, **l** Buns from Taiwan. Photographs: Qiong Fang

Fig. 7. Four types of fresh "tajer" corms sold in the Netherlands, **a** snesie tajer (FQ35, *Colocasia esculenta*). **b** aroei, with most hair removed (FQ54, *Colocasia esculenta*). **c** cocoyam (FQ61, *Xanthosoma violaceum*). **d** grote taro (FQ59, *Colocasia esculenta*). Photographs: Qiong Fang

official name "taro" was hardly ever used for fresh produce, while the frequently used trade names "tannia" and "malanga" for *Xanthosoma* spp. were never heard (Giacometti and León 1994). No scientific names, labels, or cooking instructions were provided with any of the fresh material. On some packaged products (fufu flour and frozen pomtajer), recipes were provided in Dutch.

Fresh corms of *Colocasia esculenta* (Fig. 3a, Fig. 7a) were the major "tajer" product sold in the market, followed by fresh "tajerblad," the leaves of *Xanthosoma* cf. *violaceum* (Fig. 3c). Less frequently, we observed "aroei," corms of *Colocasia esculenta* from which the hairs had been removed (Fig. 7b), and corms of *Xanthosoma violaceum* (Fig. 7c). Although they are edible, the leaves of *Colocasia esculenta* were not encountered at the market but said to be sold occasionally in greenhouses. The local names did not clearly distinguish between species or varieties: the most commonly used specific name for the corms of *Colocasia esculenta* was "snesie tajer," which literally means "Chinese taro" (Table 1).

The provenance of the fresh material was recorded from interviews with vendors, from product labels, and boxes in which products were put up for sale. Products were reportedly imported from China, India, Ghana, Nigeria, Uganda, Suriname, Costa Rica, the Dominican Republic, and Honduras. According to the vendors, frozen "tajerblad" leaves came by air from Suriname, fresh "tajerblad" was imported from Suriname in winter and spring, but in other seasons from Spain and Italy or from Dutch greenhouses in summer. Inflorescences of *Caladium bicolor* also came by air from Suriname. Corms themselves were never labeled, and their boxes could have been used previously for other products, so we could not verify the countries of origin with certainty.

Processing Methods and Acridity

When vendors and consumers were asked about the acridity of "tajer" products, most said they were not very acrid, which was consistent across different groups of immigrants. However, because our interviewees were not selected randomly, they cannot be viewed as representatives for the entire migrant population in the Netherlands. We did not observe any Dutch natives buying "tajer" products. Only one native Dutch family sold *Colocasia esculenta* corms on a tropical vegetable market, but they had never eaten it nor knew how to process it (ESM Table 2). For the few products that were considered acrid (fresh *Colocasia* leaves, petiole, and corm; inflorescences of *Caladium bicolor*), different methods of acridity reduction were used. These included tactics to avoid getting into contact with fresh juice, such as peeling fresh corms with gloves or peeling corms after boiling or steaming. Other methods were adding specific spices, milk or coconut milk, or sour fruits like lemon, tamarind, lime, green mango, and kokum (*Garcinia indica* (Thouars) Choisy). Processing methods varied among the consumers' country of origin: tamarind and kokum were only mentioned by Indian consumers, lime was mostly used by Surinamese, and lemon and coconut milk by Asian customers. The African vendors we interviewed mentioned a simple recipe: "boil it just like potato and then eat it as a snack." Other African consumers cooked the corms with many vegetables, spices, and meat. "Tajerblad" was said to be "cooked like spinach." However, recipes for corms and leaves varied in cooking methods, cooking time, and ingredients. Recipes for corms varied from simply boiling or steaming to stir-frying with garlic, onion, pepper, and ginger, cooking with fish or meat, or adding spices like turmeric, garlic, cumin, coriander, and masala.

The most complicated recipe is related to the intense acrid inflorescences of *Caladium bicolor*. It started with removing the peduncle and followed by peeling off the spathe. Only the staminate (upper part) of the spadix was used, because the other parts were "too bitter" (acrid). The spadices were rinsed thoroughly with water and stir-fried with garlic, onion, curry, chili pepper, masala, salt, and some green mango "to diminish the bitterness." One male interviewee mentioned that he had never cooked it because only his wife and mother knew how to handle it. These inflorescences were only found in one Surinamese grocery. They were said to be available for only one month per year and imported by air from Suriname directly by the vendor. In Suriname, *Caladium bicolor* is harvested from the wild.

Discussion

Diversity of Products

At least three species of aroids were sold as "tajer" in the Netherlands. The diversity in the provenance of the products, vernacular names, and backgrounds of consumers and vendors makes it complex to correlate different processing methods and people's perceptions to separate cultivar groups. Vernacular names for edible aroids were more indicative of the geographic origin of the vendors and customers than of the specific species or cultivar sold. Apart from the general term "tajer," some single cultivars have multiple names, which makes it confusing for customers not familiar with edible aroids. In general, participants were able to distinguish fresh corms of *Xanthosoma* spp. from *Colocasia esculenta* in the Netherlands and saw the *Xanthosoma* leaves as a different "species," but they lacked information on the biological plant species involved.

We distinguished four different *Xanthosoma violaceum* and nine *Colocasia esculenta* cultivar groups on the Dutch market. We did not encounter *Xanthosoma sagittifolium*, although the frozen and grated "pomtajer" corms may belong to this South American domesticate (Van Andel and Ruysschaert 2011). In the Netherlands, *Xanthosoma violaceum* is the marketed *Xanthosoma* species, although it is still viewed as a synonym of *Xanthosoma sagittifolium* by Plants of the World Online (POWO 2024), just like the other edible *Xanthosoma* species, such as *Xanthosoma mafaffa* Schott and *Xanthosoma robustum* Schott (Croat et al. 2017; Gonçalves 2011; Li and Boyce 2010). Despite being a popular food source, the taxonomy and diversity of domesticated *Xanthosoma* species and their cultivars are understudied (Gonçalves 2011). All cultivar groups of *Xanthosoma violaceum* and ornamental cultivars of *Colocasia esculenta* were diploid; all but one food cultivar of *Colocasia esculenta* was triploid. Further molecular studies are needed to verify whether and how the morphological groups differ genetically.

Although widely sold in the Netherlands as an ornamental, we reported *Caladium bicolor* for the first time as a food plant in Europe. The processing method for this plant was very elaborate because of its acridity. Although not consumed, the surrounding spathe was presumably kept during distribution to help maintain the freshness of the enclosed spadix. This study was also the first to report that edible aroids are grown in Dutch greenhouses for home consumption and the market.

Eddoe Versus Dasheen

Corms of *Colocasia esculenta* were the most common "tajer" product sold on the Dutch market. Commonly mentioned in scientific publications, "eddoe" has a central corm and multiple cormels, while the dasheen type has one large central corm and without side corms (Lebot et al. 2004). As all corms were sold separately, we could not separate the seven food cultivar groups into "eddoe" or "dasheen" groups, nor can this be seen by customers buying the plants. Moreover, the size of the corm is also related to its developmental stage and environmental growth conditions. In previous studies, the dasheen type was named *Colocasia esculenta* var. *esculenta*, and the eddoe type *Colocasia esculenta* var. *antiquorum*. These varietal names were previously used as species names (Hay 1998; Plucknett 1983) but have been synonymized as *Colocasia esculenta* (POWO 2024). No full description and clear distinction between the two types has been reported, and many intermediate types exist, which may have resulted from hybridization (Lebot et al. 2004). While floral characters are useful for distinguishing cultivar groups, floral structures might also include intermediate forms, and the inflorescences of diverse cultivars have not been systematically studied, as the taxonomy of *Colocasia* focuses on wild species. Globally, little visual (photographic) information is available for different cultivars, and few studies have related morphological traits to ethnobotanical uses and processing methods.

The name "eddoe" was more frequently used as a vernacular name on the Dutch market than "dasheen," but these names did not seem to correlate with the descriptions of Lebot et al. (2004). We do not think this division is practical for market surveys as vendors sort separated corms according to their size. We found only a few large corms, from which the only surviving plant in the WUR greenhouse (FQ59) was morphologically different from the other groups. Vendors and consumers preferred smaller corms over larger ones. Vendors said that consumers generally preferred smaller corms due to their texture and flavor, and vendors' preference was based on the relatively easier transport and smaller potential financial loss if they went moldy. Lebot et al. (2004) did not find any correlation between ploidy and eddoe or dasheen groups. Though our findings reveal that some morphological cultivar groups differ in ploidy, further molecular studies are needed on the ploidy level and the genetic differences between the various cultivar groups.

Colocasia Versus *Xanthosoma*

The Netherlands is not the only country in which *Colocasia* and *Xanthosoma* are not distinguished as separate species. Many similarities between these two genera exist: both are marketed for their underground corms and aboveground leaves (Lebot 2019). They are morphologically similar and grown in similar (sub-)tropical environments, although *Colocasia* was domesticated in South-East Asia and *Xanthosoma* in South America (Ahmed 2020). In Africa, both genera are called "cocoyam" (Grimaldi and van Andel 2018), although the term "new cocoyam" is often used for *Xanthosoma sagittifolium*, which is replacing *Colocasia esculenta* in some parts of Africa (Boakye et al. 2018), as it is less susceptible to the taro leaf blight disease (Onyeka 2014). Breeding programs have been set up to develop leaf blight-resistant varieties (Lebot and Ivančič 2022), and some traditional African landraces of *Colocasia esculenta* were reported that were less attacked by this disease (Grimaldi et al. 2018b). Global production, consumption, and trading data on "taro" that clearly distinguish between *Colocasia* and different species of *Xanthosoma* are lacking. For the many other edible aroids, such as *Amorphophallus*, *Cyrtosperma*, *Alocasia*, *Leucasia*, *Lasia*, *Montrichardia*, and *Monstera* species, there is even less data on production and international trade. Edible aroids are understudied and underestimated, despite their significant role in human society for millennia as food, ornamentals, fibers, medicine, and their potential for ensuring food safety under global change (Bown, 2000; Smith 2023).

Trading, Labeling, and Consumption

The multiple processed taro products imported from Asia and sold on the Dutch market reflect taro as a beloved food source on that continent. The processed taro products dramatically illustrate the preference of many consumers for taro corms with colorful purple or violet fibers (Fig. 6). Many processed taro products likely contain anthocyanins, which may be natural or synthetic. This phenomenon could result from Asian consumers' color preference, as a common commercial cultivar there is the "Bun Long," with purple fibers. As some yam (*Dioscorea* spp.) cultivars also have purple fibers, this may be one of the reasons for confusing taro with yam. Imports of ready-to-eat food products may be reported under generic product categories that fail to identify aroids as the source plants. Currently, there is no accurate data available on the international trade in aroids (Boakye et al. 2018; Matthews and Ghanem 2020), but our study suggests the presence of preferential commercial channels.

According to the Dutch food safety rules, instructions for use are required on labels, but this is not required for non-packaged food (https://business.gov.nl/regulation/labelling-food/). We found only one frozen corm from India labeled with the scientific name "Colocasia," frozen "pomtajer" with a recipe in Dutch, and fufu flour (species unknown) with a recipe in multiple languages at the back of the package. The lack of cooking instructions poses a risk of food poisoning if the consumers are unfamiliar with the processing methods.

Limitation and Prospects

Our study was mainly based on the fresh material sold on the Dutch market, where products were mostly sourced from wholesale food centers, so the diversity in cultivars was relatively low. The Dutch market is representative of the wider European market, as the Netherlands exports to many other European countries, and ranks in the top ten countries of *Colocasia esculenta* and top five of *Xanthosoma* spp. importers and exporters globally (https://www.tridge.com/intelligences/taro/NL/export). Tracing the origin of the products was difficult because vendors often did not know, and packages and labels were unclear or lacking. Species identification for *Xanthosoma* was difficult because differentiating morphological traits were lacking from the material. More research on the different cultivars within *Xanthosoma* and *Colocasia* is needed to compare varieties worldwide. Genetic studies such as sequencing and comparing the results to existing databases are needed to further clarify the identities and origins of aroid crops in the Netherlands. Further research on microscopy and phytochemistry could be helpful to understand acridity of aroids better. If products could be identified, named and labeled with species and variety names, confusion among consumers and traders would be reduced, thus improving the public recognition of edible aroids. Cooking instructions for edible aroids should be provided with fresh products, which are more acrid than processed products, to reduce the risk of food poisoning. In the multicultural and botanically diverse Dutch market, consumers are presented with product names from diverse languages without processing instructions. Customers need to be informed on what they are purchasing and how to prepare it properly. In countries like Japan, taro is sometimes sold with clear cooking methods on the label, a practice also observed by the first author in Japanese grocery stores in Germany. Such practices could greatly benefit the Dutch market by enhancing consumer understanding and safety.

Conclusions

We found that three different species, several cultivars, and plant parts were sold, consumed, and grown under the name "tajer" in the Netherlands. Most edible aroids were triploid forms of *Colocasia esculenta*, imported as corms from Costa Rica and sold under the name "snesie tajer," followed by "tajerblad," leaves of diploid *Xanthosoma* cf. *violaceum*. No products were observed that could be identified as *Xanthosoma* *sagittifolium*. As vendors, customers, and products come from different continents and scientific names, labels, and cooking instructions are lacking, there is ample room for confusion and poor consumer experiences. We hope that this study will contribute to a better awareness of the diversity of edible aroids in Europe and suggest approaches that can help consumers enjoy these plants while avoiding toxicity.

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Author Contribution Tinde van Andel, Eric Schranz, Peter J. Matthews, Ilaria M. Grimaldi, and Qiong Fang conceived and designed the study. Tinde van Andel, Hans de Jong, Jose van de Belt, and Qiong Fang collected the data. Tinde van Andel, Peter J. Matthews, Ilaria M. Grimaldi, and Qiong Fang identified the specimens. Qiong Fang cultivated the greenhouse collections. Peter J. Matthews, Tinde van Andel, and Qiong Fang analyzed the data. Qiong Fang wrote the manuscript, and all authors contributed to the revision and approved the final version.

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Data Availability Data used in this research is published as supporting information. Transcripts from interviews are not published to ensure participants' anonymity. Herbarium vouchers of collected specimens are available in the Herbarium of Naturalis Biodiversity Center (L).

Declarations

Ethics Approval and Consent to Participate No ethics approval from the University was needed for this research. In the Netherlands, studies involving human participants only needs an ethics approval when it concerns medical or psychological research. All informants were asked for their free prior informed consent before interviews were conducted. Before purchasing products or interviewing vendors and consumers, we explained our research and asked for their oral free prior informed consent. We followed the ISE Code of Ethics (ISE 2006) during our study and paid for all "tajer products" that we collected.

Competing Interests The authors declare no competing interests.

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