



Article

Curcuma borealis sp. nov. and *C. retrocalcaria* sp. nov. (Zingiberaceae): Two Novel Taxa from Northern Thailand

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Abstract: This study introduces *Curcuma borealis* Saensouk, P.Saensouk, and Boonma and *C. retrocalcaria* Saensouk, P.Saensouk, and Boonma, two newly discovered species within the *Curcuma* genus of the Zingiberaceae family, found in the Mae Hong Son and Chiang Mai Provinces of Northern Thailand, respectively. This research aims to clarify the taxonomic identity of these species, which were initially confused with *C. ecomata* Craib and *C. chantaranothaii* Boonma and Saensouk due to similarities in flower coloration and some morphological characteristics, respectively. Detailed morphological analysis was conducted to distinguish these species. *Curcuma borealis* is differentiated by its unique anthers lacking appendages or projections at the base of the spurs, in contrast to the appendages or projections present in *C. ecomata*, while *C. retrocalcaria* is characterized by anther spurs folding or curving backward under the anther base and with two purple patches at the base of the labellum, distinguishing it from *C. chantaranothaii*. The findings highlight distinct morphological traits that set *C. borealis* and *C. retrocalcaria* apart from existing *Curcuma* species. The pollen morphology of the two new taxa was also studied here for the first time. This research emphasizes the importance of thorough taxonomic scrutiny for accurate species identification and contributes to our understanding of the diversity within the *Curcuma* genus. Accurate identification of these species is crucial for conservation efforts, underscoring the need to protect their habitats and maintain biodiversity in the region.

Keywords: *Curcuma*; *Ecomata*; new species; Thailand; Zingiberales; Zingiberaceae; Zingibereae



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1. Introduction

The genus *Curcuma* L., encompassing diverse plant species within the Zingiberaceae family, holds considerable ecological, economic, and medicinal importance across tropical and subtropical Asia [1]. Thailand, renowned for its rich biodiversity, particularly stands out as a hub for *Curcuma* species diversity, with over 80 species native to the country and at least 61 species recorded in the *Flora of Thailand*, volume sixteen part two [2]. It is followed by India with approximately 30 native species, and China with around 16 native species [3]. However, the accurate identification of *Curcuma* species is challenging due to overlapping morphological traits and superficial similarities among species.

It has been proposed that the genus be classified into three subgenera. The subgenus *Hitcheniopsis* (Baker) K. Schum. is characterized by the absence of epigynous glands, whereas the other two subgenera exhibit the presence of epigynous glands. The subgenus

Curcuma L. typically produces bell-shaped or closed-form flowers, with staminodes generally concealed by the dorsal corolla lobe and well-developed coma bracts. In contrast, the subgenus *Ecomata* Škorničk. and Šída.f. usually produces open-form flowers and inflorescences that generally lack coma bracts [4].

In recent years, taxonomic studies focusing on *Curcuma* species have highlighted the need for clarity and precision in species delineation. Many publications have shed light on the taxonomic complexities within the genus, revealing instances of misidentification and closely related species that are difficult to distinguish [5–9]. Controversies and diverging hypotheses regarding species boundaries and relationships have emerged, emphasizing the necessity for further research to resolve taxonomic ambiguities.

This study aims to address the taxonomic ambiguities within the *Curcuma* genus in Northern Thailand by identifying and describing two newly discovered species. Specifically, we aim to conduct a detailed taxonomic analysis to distinguish new species within the *Curcuma* genus, provide a comprehensive morphological description of each newly identified species, and address the misidentification and marketing issues associated with these new species. We identified the first new species—*C. borealis* Saensouk, P.Saensouk, and Boonma—in the forests of the Mae Hong Son Province and its morphological characteristics often lead to confusion with the closely resembling *C. ecomata* Craib [10]. Additionally, *C. borealis* has been mistakenly marketed as *C. ecomata* under the Thai vernacular name “Krachiao Suthep”.

Moreover, the second new species—*C. retrocalcaria* Saensouk, P.Saensouk, and Boonma—was discovered in the Chiang Mai Province and look superficially similar to *C. chantaranonthaii* Boonma and Saensouk [11].

The similarities in morphological traits among *Curcuma* species and the frequent misidentifications within this genus highlight the critical need for precise taxonomic delineation. This study addresses these challenges by providing a detailed descriptive comparison of newly collected or previously undescribed *Curcuma* specimens against the descriptions in the protologue for related species. The significance of our research lies in its contribution to the accurate taxonomy of the *Curcuma* genus, which is fundamental for developing effective conservation strategies and ensuring the sustainable utilization of these plants. By clarifying species boundaries and documenting previously undescribed specimens, our work aims to enhance the understanding of *Curcuma* diversity and inform future taxonomic and conservation efforts.

By providing comprehensive descriptions and comparative study of these newly discovered species, along with examining their pollen morphology, ecology, phenology, distribution, and conservation status, this study aims to contribute significantly to the accurate taxonomy of the *Curcuma* genus. The recognition of these two new species not only enriches our understanding of regional biodiversity but also emphasizes the importance of preserving their natural habitats.

Accurate species identification is pivotal for biodiversity conservation, ecological research, and sustainable development. This study underscores the necessity for ongoing taxonomic research to resolve uncertainties within the *Curcuma* genus, thereby laying a crucial foundation for future research in related fields.

2. Materials and Methods

Detailed morphological measurements were conducted on 20 specimens from both preserved and living samples of each taxon using a stereoscopic microscope (ZEISS–Stemi 2000-C, Oberkochen, Germany). Specimens of the first taxon (holotype), *Curcuma borealis*, were collected from Thailand, Northern, Mae Hong Son Province, Mae Sariang District (Figure 1), 8 June 2023, Boonma 23618 (Faculty of Forestry Herbarium (FOF!)). Additional specimens examined (paratypes) were collected from Thailand, Northern, Mae Hong Son Province, Sop Moei District, 12 June 2024, Boonma 24008 (MSU!). The holotype of the second taxon, *C. retrocalcaria*, was collected from Chiang Mai Province (Figure 1), 8 August 2023, Boonma 23808 (FOF!), and paratypes from Thailand, Northern, Chiang Mai Province,

8 August 2023, Boonma 24009 (MSU!). All graphic designed in this study used Pixelmator Pro Program (Version 3.6.5 (Archipelago), 2023, Pixelmator Team, Vilnius, Lithuania), on an iPad Air 5 (iPadOS17.5.1 (21F90), 2024, Apple Inc., Cupertino, CA, USA), and MacBook Pro (13-inch, M1, 2020, Apple Inc., Cupertino, CA, USA).

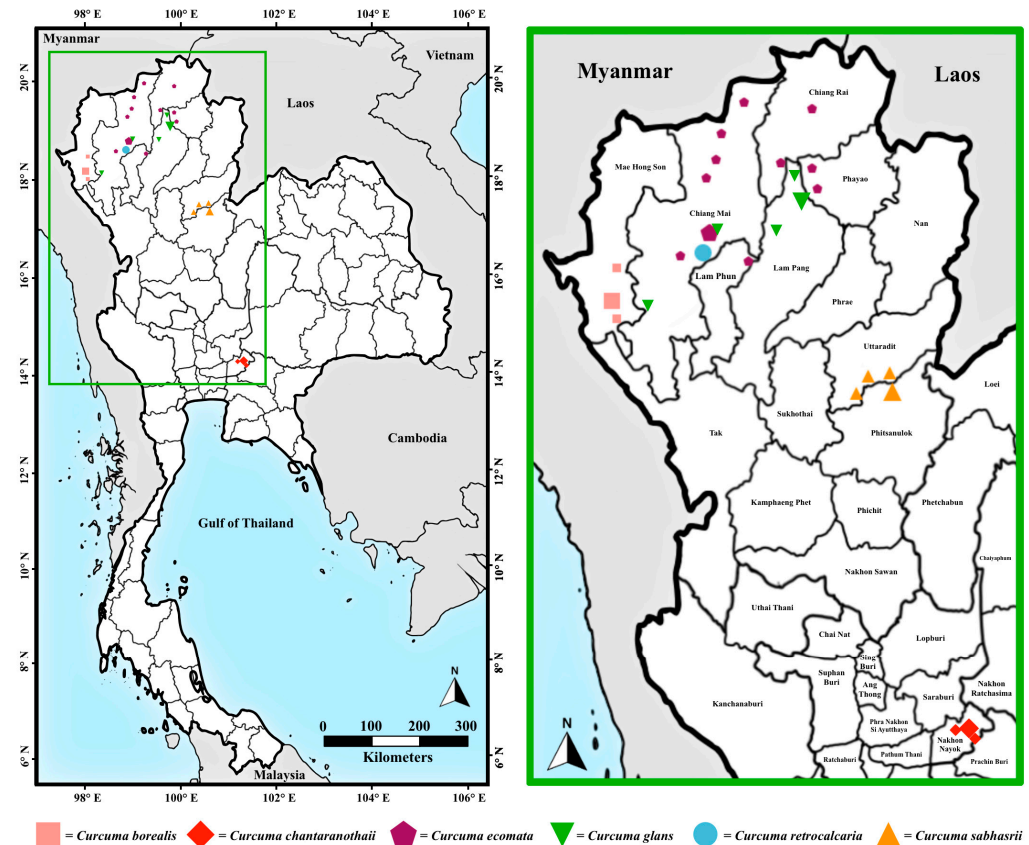


Figure 1. Distribution map of *Curcuma borealis* (pink square) and *C. retrocalcaria* (blue circle) with their ally's species, *C. chantaranothaii* Boonma and Saensouk (red square), *C. ecomata* Craib (purple pentagon), *C. glans* K. Larsen, and Mood (green triangle), and *C. sabhasrii* Saensouk, Maknoi, Wongnak, and Rakarcha (orange triangle). The green square is an enlarged section of the map on the left, providing a clearer view of each species' location along with the names of the provinces.

Additional specimens examined used to refer to a location on a map (Figure 1) including the following details:

C. borealis Saensouk, P.Saensouk, and Boonma: Thailand, Northern, Mae Hong Son Province, Mae Sariang District, Boonma 23618, 8 June 2023 (holotype FOF!). Mae Hong Son Province, Sop Moei District, 12 June 2024, Boonma 24008 (MSU!).

C. chantaranothaii Boonma and Saensouk: Thailand, Central, Nakhon Nayok Province, 29 May 2019, Boonma 15 (KKU!). Thailand, Central, Nakhon Nayok Province, Ban Na District (cultivated), 23 July 2022, Boonma T. NY040 (MSU!). Thailand, Central, Nakhon Nayok Province, Pak Phli District, 15 July 2023, Boonma 23715 (MSU!).

C. ecomata Craib: Thailand, Northern, Chiang Mai Province, Doi Suthep-Pui National Park, Altitude 670 m, 18°48' N, 98°55' E, 2 September 1910, Kerr A.F.G. 1155 (BM!, E!, K!). Chiang Mai Province, Chom Thong District, Mae Ya, 7 May 1921, Kerr 5369 (BK!, BM!, K!). Chiang Mai Province, Doi Chiang Dao, 24 April 1956, Suvarnakoses 1176 (BKF!, C!). Chiang Mai Province, Doi Suthep, 20 April 1958, Sorensen et al. 2919 (C!). Chiang Mai Province, Doi Inthanon, 8 May 1958, Sorensen et al. 3297 (C!). Chiang Mai Province, Fang District, 27 April 1965, Phengklai 1031 (BKF!). Chiang Mai Province, Doi Chiang Dao, Watershed station, Altitude 500 m, 19°23' N, 98°54' E, 6 June 1973, Geesink R., Phanichapol D., and Santisuk T. 5734 (BKF!, C!, E!, P!). Chiang Mai Province, Doi Suthep, 22 July 1978,

Phengkklai et al. 4054 (BKF!). Chiang Mai Province, Doi Suthep, 18 July 1987, Maxwell 87-675 (CMU!). Chiang Mai Province, Doi Suthep, 28 April 1988, Maxwell 88-541 (CMU!). Chiang Mai Province, Doi Suthep-Pui National Park, Altitude 1450 m, 18°48' N, 98°55' E, 8 May 1988, Maxwell 88-591 (CMU!, E!). Chiang Mai Province, Doi Suthep-Pui National Park, east side, trail to Pha Lat Temple, Altitude 550 m, 18°48' N, 98°55' E, 9 July 1988, Maxwell 88-745 (AAU!, BKF!, CMU!, E!). Chiang Mai Province, Doi Suthep-Pui, Pha Lat Temple, 13 May 1993, Phuakam 24 (CMU!). Chiang Mai Province, Doi Suthep-Pui, 10 June 1993, Phuakam 28 (CMU!). Chiang Mai Province, Doi Cham Bah Bih, Mae Jam District, above Mae Jam River, 25 May 1995, Maxwell 95-462 (BKF!, CMU!). Chiang Mai Province, Doi Chiang Dao WS, Chiang Dao, 14 August 1995, Maxwell 95-495 (CMU!). Chiang Mai Province, Mae Taeng District, Doi Sam Liam, 27 May 1997, Maxwell 97-539 (BKF!, CMU!). Chiang Mai Province, Doi Suthep-Pui NP, 9 July 1999, Ngamriabsakul 28 (BKF!). Chiang Mai Province, Doi Suthep-Pui NP, 9 July 1999, Ngamriabsakul 38 (E!). Chiang Mai Province, 12 April 2001, C. Maknoi 145, QBG no. 25644 (QBG!). Chiang Mai Province, San Pan Si, Altitude 600 m, 3 May 2002, C. Maknoi 210, QBG no. 25673 (QBG!). Chiang Mai Province, Sri Sangwan Waterfall, Altitude 500 m, 20 July 2003, C. Maknoi 341 (AAU!, BKF!, PSU!, QSBG!). Chiang Mai Province, 15 May 2012, C. Pitaksantipap 15, QBG no. 59781 (QBG!). Chiang Rai Province, Altitude 1218 m, 27 August 2015, M. Norsaengsri 12523, QBG no. 85870 (QBG!). Chiang Rai Province, Altitude 650 m, 2 June 2016, N. Muangyen 1107, QBG no. 91097 (QBG!). Chiang Rai Province, West side of Doi Luang NP, summit ridge of Doi Muak, Wiang Pa Pao, 24 May 1998, Maxwell 98-565 (BKF!, CMU!). Lamphun Province, Doi Khun Dahn NP, Mae Tha, 3 June 1993, Maxwell 93-538 (CMU!). Phayao Province, 7 May 2015, M. Norsaengsri 12442, QBG no. 83058 (QBG!). Phayao Province, 30 May 2016, N. Muangyen, QBG no. 90995 (QBG!).

C. glans K.Larsen and Mood: Thailand, Northern, Chiang Mai Province, Bo Luang, Ob Luang tableland, 12 June 1968, Beusekom C.F.v. and Phengkklai C. 1157 (BKF!). Chiang Mai Province, Doi Suthep-Pui National Park, 21 June 1958, Sørensen T.J. 3658 (BKF!). Lampang Province, Altitude 810 m, Mood J.D. and Larsen K. 1455B (holotype AAU!). Lampang Province, Chae Son National Park, along Mae Nawn stream, Altitude 475 m, 22 April 1996, Maxwell J.F. 96-555 (BKF!, CMU!). Lampang Province, Wang Nuea, Wang Gayo Falls, Altitude 825 m, Maxwell J.F. 97-237 (BKF!, CMU!).

C. retrocalcaria Saensouk, P.Saensouk, and Boonma: Thailand, Northern, Chiang Mai Province, San Pa Tong District, 8 August 2023, Boonma 23808 (holotype FOF!); Chiang Mai Province, 8 August 2023, Boonma 24009 (paratype at Mahasarakham University Herbarium (MSU!)).

C. sabhasrii Saensouk, Maknoi, Wongnak and Rakarcha: Thailand, Northern, Uttaradit Province, Altitude 221 m, 11 June 2012, Romklao Botanical Garden, 2555 463, QBG no. 62523 (QBG!). Thailand, Northern, Uttaradit Province, Phichai District, 17 August 2018, Boonma 3 (MSU!). Thailand, Northern, Uttaradit Province, Thong Saen Khan District, 17 July 2019, Boonma 197 (MSU!). Thailand, Northern, Phitsanulok Province, Chat Trakan District, 15 May 2021, P. Phaosrichai and M. Wongnak 2641 (BKF!, KCU!, QBG!).

Our study is primarily focused on a descriptive comparison of the morphological characteristics between newly collected or previously undescribed *Curcuma* specimens and the descriptions provided in the protologue for related species. This approach is consistent with traditional taxonomic methods, emphasizing detailed qualitative observations to document and interpret species' traits. Living specimens of these undescribed *Curcuma* species were cultivated in the garden of the Diversity of Family Zingiberaceae and Vascular Plant for Its Applications Unit and the Brio Botanical Research Garden (BBRG!). These specimens were carefully examined to document their morphological features for comparison with protologue descriptions of *Curcuma* species. Comparative analyses were conducted using dried specimens from various herbaria both in situ and online (AAU!, BK!, BKF!, E!, FOF!, HNL!, KCU!, PSU!, QBG!, and US!), as well as consulting the protologues of all *Curcuma* species and available online photographs from resources such as the Zingiber-

aceae Resources Center (<https://padme.rbge.org.uk/ZRC/data/specimens>) accessed on 1 July 2024.

Pollen morphology of the two taxa was examined using Erdtman's method. The samples were dehydrated through a series of ethanol solutions (70%, 80%, 90%, and 100%), with each step lasting 5 min. The dehydrated pollen was air-dried overnight at room temperature and then mounted onto aluminium panels using carbon tape [12]. Pollen grains were analyzed using a scanning electron microscope (SEM) (Hitachi, TM-4000plus, Hitachi High-Tech, Tokyo, Japan) at Mahasarakham University's Laboratory Equipment Center, Division of Research Facilitation and Dissemination. Observations of 30 pollen grains under SEM provided detailed insights into their morphology, employing Erdtman's classification and terminology.

3. Results

3.1. *Curcuma borealis* Saensouk, P.Saensouk, and Boonma sp. nov. (Table 1, Figures 1–5)

Diagnosis: A new species is similar to *Curcuma ecomata* Craib but differentiated by its very pale yellowish-white rhizome (vs. pale brown); elliptic lamina measuring $29\text{--}43 \times 13\text{--}17$ cm, with a glabrous surface except for hair along the veins (vs. oblanceolate, $15\text{--}45 \times 5\text{--}12$ cm, finely hairy); lateral inflorescences (vs. both terminal and lateral); broadly obovate and pubescent fertile bracts (vs. ovate and glabrous); sparsely hairy corolla lobes (vs. glabrous); elliptic-rhomboid staminodes, $1.7\text{--}1.9 \times 0.8\text{--}0.9$ cm (vs. obliquely ovate, $1.3\text{--}1.6 \times 0.6\text{--}0.9$ cm); pubescent labellum (vs. glabrous with glandular hair); filament $5.5\text{--}6$ mm long and c. 4 mm wide (vs. $5\text{--}7$ mm long and $2.5\text{--}3$ mm wide); anther spurs do not produce mucilage and lack prominent appendages or projections (vs. anther spurs mucilage-producing with prominent appendages or projections); and epigynous glands $8\text{--}8.5$ mm long (vs. $7\text{--}8$ mm).

Type: Thailand, Mae Hong Son Province, Mae Sariang District, Boonma 23618, 8 June 2023 (holotype FOF!).

Description: Perennial herb with very pale yellowish-white ovoid rhizomes, slightly aromatic rhizome with vertical branches. *Roots*—fibrous, bearing ellipsoid tuberous structures, and whitish in color internally. *Bladeless sheaths*—3–4 in number, measure $6\text{--}27$ cm in length; they are pubescent and display a green coloration with a reddish tinge at the distal part and exhibit a mucronate apex with hairs. *Leaf sheaths*—distichous, measuring $25\text{--}32$ cm in length, green, pubescent. *Ligule*—membranous, $2\text{--}4$ mm long, bilobed, each lobe apex-rounded. *Leaves*—3–5 in number; *petioles* subsessile to 14 cm long (with the first leaf usually subsessile or with short petiole, and the following next leaves usually longer, while the innermost leaf usually displays the longest petiole), green; *the young leaf*—rolled and erect before unfurling; *laminae*—elliptic, measuring $29\text{--}43 \times 13\text{--}17$ cm, with apex mucronate, and a base rounded to attenuate. The margin is entire with whitish semi-translucent hyaline, an adaxial surface green that is midrib green, and slightly embossed veins with sparse hairs along the veins, the abaxial surface is a paler green and glabrous. *Inflorescence* lateral: *thyrses*—broadly ovoid to subglobose, $6\text{--}8 \times 6\text{--}8$ cm; *peduncle*— $4.5\text{--}7$ cm in length. *Fertile bracts*—number 50 to 70, broadly obovate, and measure $3\text{--}4.5$ cm in length; lower bracts are $4\text{--}5$ cm wide and gradually decrease in size, with the upper bracts measuring $1.8\text{--}2$ cm wide. The distal part of the lower bracts are rounded with a mucronate tip, pubescent, and exhibit various shades of color from whitish to pale green or pale pink to reddish, the upper bract with a more acute apex than the lower bracts. *Coma bract*—absent. *Bracteole*—absent. *Cincinnus*—with 3–4 flowers. *Flower*— $4.9\text{--}5.2$ cm long. *Calyx*—tubular, apex tridentate, $1.5\text{--}1.7$ cm long, with an incision up to 7 mm long. *Floral tube*—slender and tubular, measuring $2.7\text{--}2.9$ cm in length, the distal part is larger in diameter than the basal part and whitish in color, pubescent; *dorsal corolla lobe*—triangular-ovate, $1.65\text{--}1.8 \times 0.65\text{--}0.72$ cm, with mucronate apex (mucro c. 1 mm long), hooded, white or with pinkish tinge and sparsely hairy; *lateral corolla lobes*—oblong-ovate, $1.6\text{--}1.7 \times 0.65\text{--}0.7$ cm, with obtuse apices, hooded, white or with pinkish tinge, and sparsely hairy. *Lateral staminodes*—elliptic rhomboids, $1.7\text{--}1.9 \times 0.8\text{--}0.9$ cm, with obtuse apices and varying shades from very pale pink to ruby, or

pinkish purple but rarely white or pale yellowish orange, pubescent. *Labellum*—obovate, 1.78–1.9 × 1.4–1.5 cm, with an emarginate apex that becomes bilobed at the distal part, a sinus up to 0.8 cm long. The labellum lobes vary in shade from very pale pink to ruby, or pinkish purple but rarely white or pale yellowish orange, usually matching the staminodes' color, with a yellow median band along the mid-lobe of the labellum and divided at the base, pubescent. *Stamen 1*: *filament*—5.5–6 mm long, c. 4 mm wide, white, pubescent; *anther*—11.8–12.3 × 2.5–3.0 mm (including spurs); *anther thecae*—7.6–8.0 mm in length; *anther crest*—longer than the anther lobe, c. 0.5 mm in length and c. 1 mm in width, with a rounded to slightly retuse apex and pubescent; *anther spurs*—conical, 4.6–5 mm long, lack of prominent appendages or projections at the basal of spurs, and anther spurs not producing mucilage. *Epigynous glands*—two in number, slender, 8–8.5 mm long, and yellowish, with sharp apices. The *ovary* subglobose—2–2.5 × 2–2.5 mm, pubescent; *style*—white; *stigma*—ciliate, 1.3–1.5 mm wide, yellowish, and shaped like a slightly flattened inverted cone. *Fruits*—subglobose, 8–9 × 7–8 mm, sparsely hairs. *Seeds*—brownish with white arils.

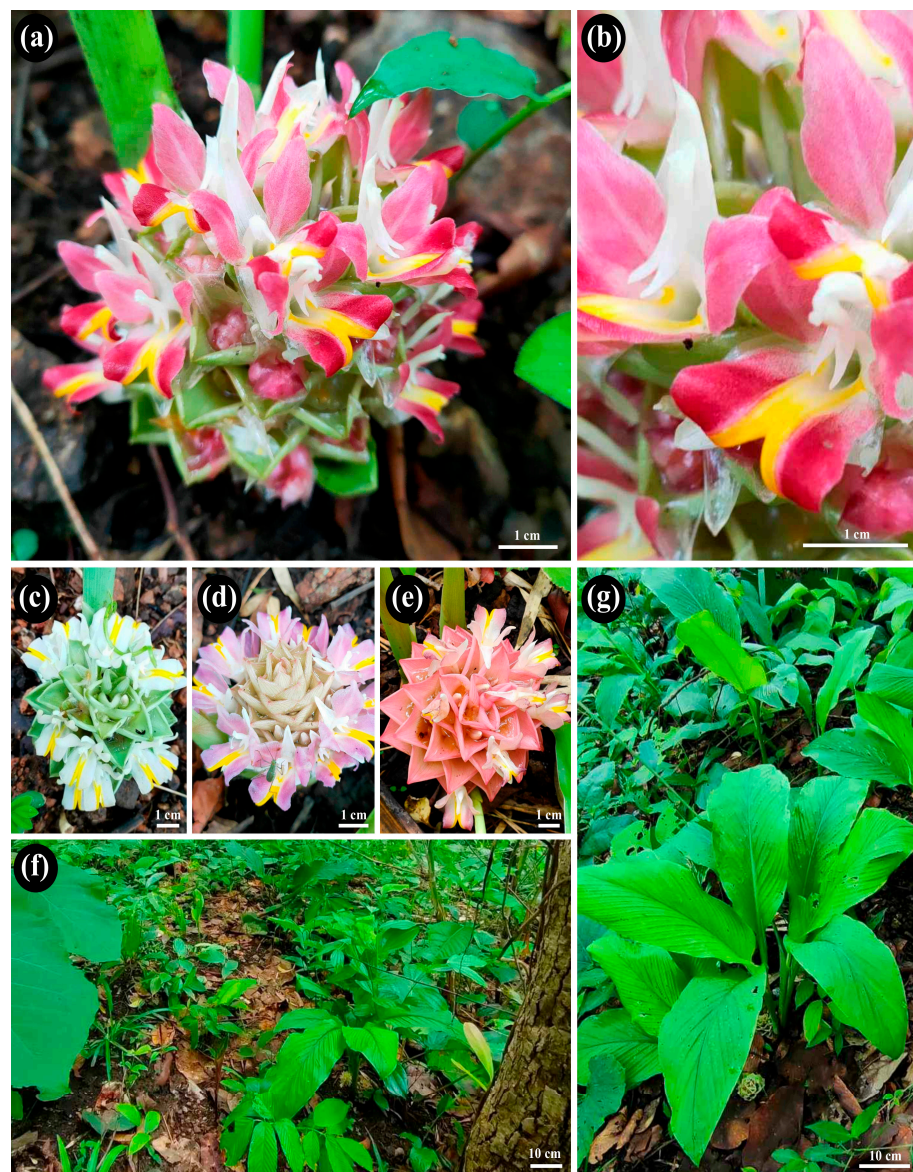


Figure 2. *Curcuma borealis* Saensouk, P.Saensouk, and Boonma sp. nov.: (a) inflorescence with flowers; (b) semi-side view of flower showing the anther spurs without prominent appendages or projections; (c–e) color variation in bracts and flowers; (f) natural habitat; (g) habits. Photographs by Thawatphong Boonma and Payungsak Joipradit.

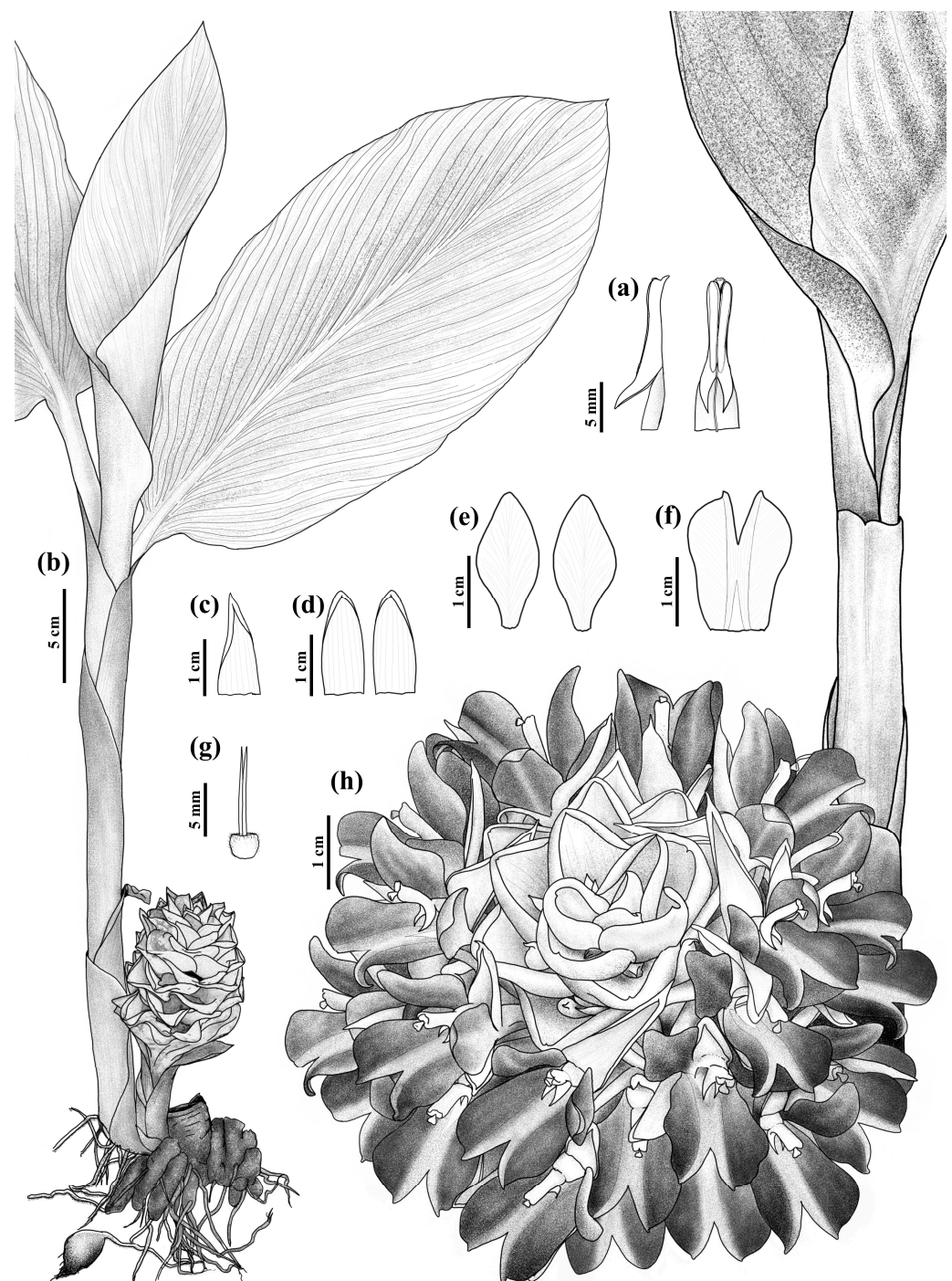


Figure 3. *Curcuma borealis* Saensouk, P.Saensouk, and Boonma sp. nov: (a) side and front view of anther; (b) habit; (c) dorsal corolla lobe; (d) lateral corolla lobes; (e) lateral staminodes; (f) labellum; (g) epigynous glands with ovary; (h) inflorescence with flowers, and new shoot with curling leaf. Drawn by Thawatphong Boonma.

Additional specimen: Thailand, Northern, Mae Hong Son Province, Sop Moei District, 12 June 2024, Boonma 24008 (paratype at Mahasarakham University Herbarium (MSU!)); Mae Hong Son Province, Mae La Noi District, 12 June 2024, Boonma 24010 (paratype at Mahasarakham University Herbarium (MSU!)).

Vernacular name: “*Thep Apsorn*”, this name is derived from the name of Apsara, the most beautiful celestial maiden in Hindu and Buddhist mythology. The name reflects the striking beauty of the species’ inflorescences and flowers, particularly when they

bloom simultaneously from the lower fertile bracts. This blooming pattern, with the upper bracts still without flowers, resembles the traditional depiction of an Apsara, who is often portrayed with a flowing dress that leaves her upper body uncovered.

Etymology: The specific epithet “*borealis*” is derived from the Latin word “*borealis*”, meaning “*northern*”. This name was chosen to reflect the species’ distribution exclusively in the northern regions of Thailand.

Distribution: This newly discovered species has been categorized as endemic to Thailand, meaning it is found exclusively inside the forests of Mae Hong Son Province in Northern Thailand.

Ecology: This species inhabits deciduous forests, thriving in soil composed of sandy loam and pebbles. It prefers habitats with high moisture levels and is typically found at elevations ranging from 300 to 600 m above sea level, growing under the shade of *Tectona grandis* L.f. and other deciduous trees. It is often found alongside other species such as *Globba garrettii* Kerr, *G. schomburgkii* Hook.f., and *Hellenia speciosa* (J.Koenig) S.R.Dutta, which have also been observed in the same natural habitat.

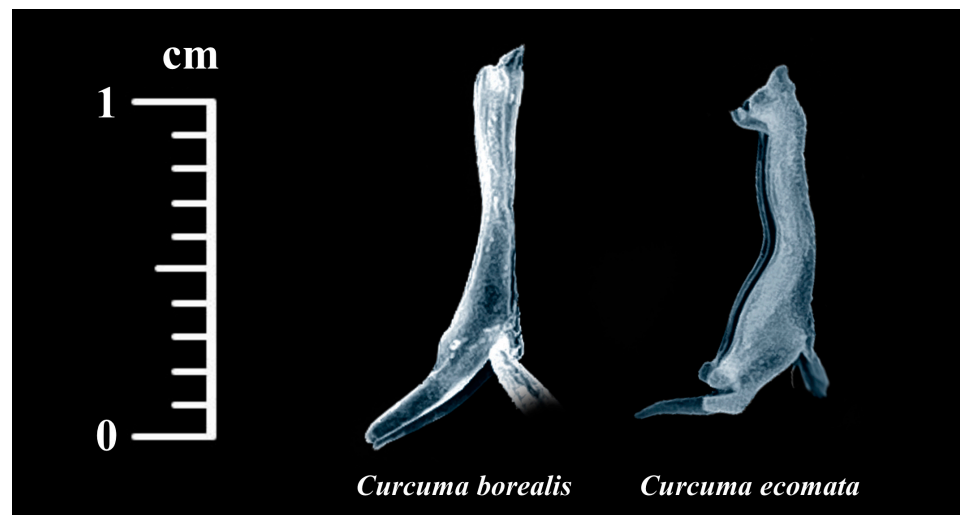


Figure 4. Side view of anther of *Curcuma borealis* Saensouk, P.Saensouk, and Boonma, and *C. ecomata* Craib. Photographs by Thawatphong Boonma.

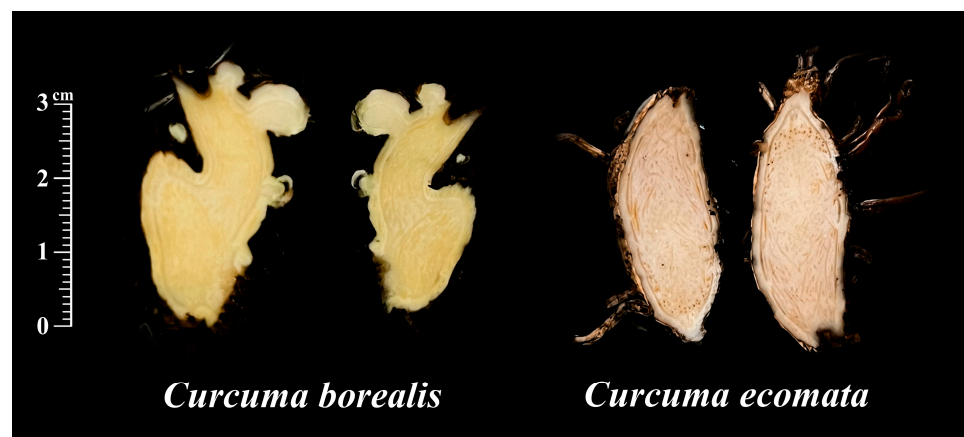


Figure 5. Dissected rhizome to show the internal of *Curcuma borealis* Saensouk, P.Saensouk, and Boonma, and *C. ecomata* Craib. Photographs by Thawatphong Boonma.

Phenology: This species undergoes dormancy from late December to April. Following the first rains, it prepares for flowering, during which lateral inflorescences emerge directly from the primary rhizome. Shoots then arise, either concurrently with or shortly after

the inflorescences appear. Flowering typically occurs between late April and July, with most anthesis events taking place early in the morning. Fruiting occurs between June and August.

Table 1. Comparison of Morphological Characteristics between *Curcuma borealis* and *C. ecomata*.

Characters	<i>C. borealis</i>	<i>C. ecomata</i> [8]
Rhizome	Very pale yellowish white	Pale brown
Lamina	Elliptic, 29–43 × 13–17 cm, Adaxially surface glabrous, except hairy along the veins, Abaxially surface glabrous, Midrib green	Oblanceolate, 15–45 × 5–12 cm, Adaxially surface fine hairy, Abaxially surface fine hairy, Midrib green or with a red patch
Inflorescence	Lateral	Terminal and Lateral
Fertile bracts	Broadly obovate, Pubescent on both surfaces	Ovate, Glabrous on both surfaces
Corolla lobes	Sparsely hairy	Glabrous
Staminodes	Elliptic rhomboid, 1.7–1.9 × 0.8–0.9 cm	Obliquely ovate, 1.3–1.6 × 0.6–0.9 cm
Labellum	Pubescent	Glabrous with short glandular hair along median band
Filament	5.5–6 mm long, c. 4 mm wide	5–7 mm long, 2.5–3 mm wide
Anther spurs	Not producing mucilage Lack of appendages or projections	Producing mucilage With prominent appendages or projections
Epigynous glands	8–8.5 mm long	7–8 mm long

Utilization: This new taxon has high potential for both ornamental horticulture and medicinal use, similar to other species within the same genus. Its beauty and unique characteristics make it an excellent candidate for cultivation as an ornamental potted plant, while its medicinal properties enhance its value in traditional practices.

Conservation status: *Curcuma borealis*, a species with an extent of occurrence (EOO) of less than 2000 km² and an area of occupancy (AOO) of less than 100 km² and found in just three locations, faces significant conservation challenges. With a population of fewer than 250 mature individuals, it is classified as Endangered (EN B1B2ab(iv,v); C2a(i)) according to the Guidelines for Using the IUCN Red List Categories and Criteria Version 16 (March 2024) [13]. This classification underscores the species’ vulnerability to extinction primarily due to habitat loss, degradation exacerbated by global warming, and potential threats from human activities. Recent observations of this plant being sold in markets further highlight the urgency of conservation efforts. Urgent measures are crucial to protect its remaining habitats, mitigate threats, and ensure the long-term survival of *Curcuma borealis*. Strategies such as designating this area as Other Effective Area-Based Conservation Measures (OECMs) and engaging local communities will play pivotal roles in safeguarding this species and preserving its ecological importance within its restricted range.

3.2. *Curcuma retrocalcaria* Saensouk, P.Saensouk, and Boonma sp. nov. (Table 2, Figures 6 and 7)

Diagnosis: A new species closely resembles *Curcuma chantaranothaii* Boonma and Saensouk but can be distinguished by the following characteristics: ligule—3.5–5 mm long, apex rounded (vs. *C. chantaranothaii* with ligule 7–8 mm long, apex acute); staminodes—asymmetrical ovate, apex obtuse, white with a yellow dot at the base and a darker reddish spot inside (vs. rhomboid, apex acute, white with a yellow patch along the center); labellum obovate—white with a yellow band extending from the apex down to about half their length. At the base of the labellum, there are two yellow dots with a darker reddish spot inside, positioned on the side closer to the staminode. Adjacent to these dots, there are two

pale purple patches (vs. labellum broadly obovate, white with an embossed yellow median band extending from tip to base, diverging at the base in a Y-shape, with two paler yellow crescent patches from the apex on each side to the half of the length); anther thecae—c. 4 mm long (vs. c. 6 mm long); anther crest—2.5–2.8 mm long, apex slightly retuse (vs. c. 0.8 mm long, apex rounded); anther spurs—c. 1 mm long, folding or curving backward under the anther base (vs. spurs c. 0.5 mm long, not folding, pointing downwards).

Type: Thailand, Chiang Mai Province, San Pa Tong District, 8 August 2023, Boonma 23808 (holotype FOF!); Thailand, Northern, Chiang Mai Province, 8 August 2023, Boonma 24009 (paratype at Mahasarakham University Herbarium (MSU!)).

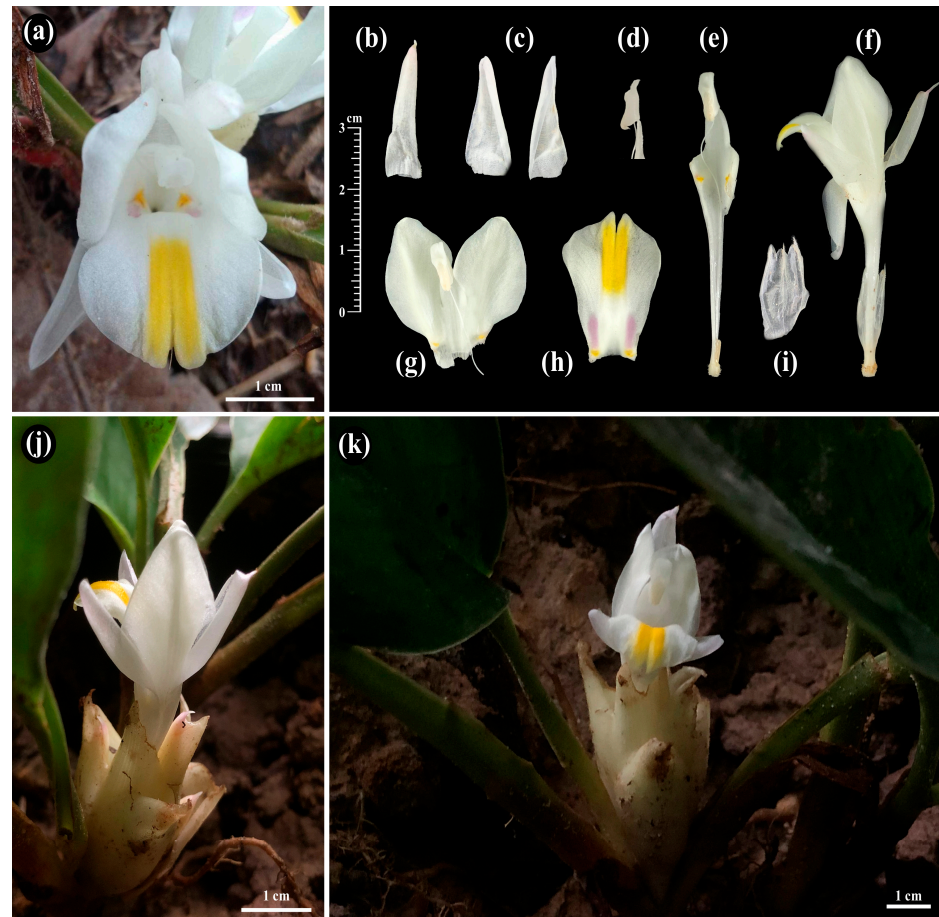


Figure 6. *Curcuma retrocalcaria* Saensouk, P.Saensouk, and Boonma sp. nov.: (a) front view of flower; (b) dorsal corolla lobe; (c) lateral corolla lobes; (d) side view of the anther; (e) dissection of the floral tube showing the epigynous glands; (f) side view of flower; (g) lateral staminodes with filament and anther; (h) labellum; (i) dissection of calyx showing apex's lobes; (j) side view of inflorescence with flower; (k) habit. Photographs by Thawatphong Boonma.

Description: Perennial herb with yellowish-white ovoid rhizomes, slightly aromatic. *Roots*—fibrous, bearing ellipsoid tuberous structures, whitish internally. *Bladeless sheaths*—3–4 in number, 1–6 cm in length, pubescent, green coloration with a reddish tinge at the distal part, usually wilt with age, apex mucronate with hairs. *Leaf sheaths*—distichous, 2–4 sheaths at anthesis, 3.5–6 cm in length, green with a reddish tinge, and pubescent. *Ligule*—membranous, 3.5–5 mm long, bilobed, each lobe apex rounded, ciliate. *Leaves*—2–5 in number; *petioles*—1–4 cm long, green, pubescent; *the young leaf*—rolled and erect before unfurling; *laminae*—elliptic to oblanceolate, 8–20 × 4–8.5 cm, apex acute with mucronate tip, base cuneate. The margin is entire, with whitish semi-translucent hyaline, adaxial surface green, midrib green, the abaxial surface is paler green, and both surfaces are pubescent. *Inflorescence*—terminal; *thyrses*—3–4 × 2.5–4 cm; *peduncle*—1–2 cm in length,

whitish, pubescent. *Fertile bracts*—number 5 to 9, ovate–triangular, $2\text{--}3.5 \times 1.0\text{--}1.5$ cm, apex acute, pubescent and whitish. *Coma bract*—absent. *Bracteole*—absent. *Cincinnus*—with 3–4 flowers. *Flower*— $5.0\text{--}5.5$ cm long. *Calyx*—tubular, apex tridentate, $1.7\text{--}1.74$ cm long, with an incision up to 7 mm long, semi-translucent white, pubescent. *Floral tube*—slender and tubular, $2.7\text{--}2.85$ cm in length, the distal part is larger in diameter than the basal part and is whitish in color, pubescent; *dorsal corolla lobe*—triangular–ovate, $1.7\text{--}2.3 \times 0.7\text{--}0.8$ cm, with mucronate apex (mucro approximately 3 mm long), hooded, white with pale pinkish tinge at the distal part and sparsely hairy; *lateral corolla lobes*—triangular–ovate, $1.6\text{--}2.0 \times 0.65\text{--}0.7$ cm, with very short mucronate apex, hooded, white or with pinkish tinge at the distal part, and sparsely hairy. *Lateral staminodes*—irregularly asymmetrical–ovate, $2.0\text{--}2.2 \times 1.3\text{--}1.4$ cm, with obtuse apices, white with a yellow dot at the base, closer to the side that connects to the labellum, and pubescent. *Labellum*—obovate, pubescent, $2.0\text{--}2.1 \times 1.38\text{--}1.45$ cm, with an emarginate apex, bilobed, with a sinus up to 0.3 cm long, the labellum lobes are white with a yellow band extending from the apex down to about half their length. At the base of the labellum, there are two yellow dots with a darker reddish spot inside, positioned on the side closer to the staminode. Adjacent to these dots, two pale purple patches $4\text{--}5 \times 1.5\text{--}2$ mm. *Stamen 1: filament*—c. 6 mm long, $4.5\text{--}5.0$ mm wide, white, pubescent; *anther*—c. $8.0 \times 2.5\text{--}3.0$ mm (including spurs and crest); *anther thecae*—c. 4 mm in length; *anther crest*—rectangular with curved edges, $2.5\text{--}2.8$ mm in length and $2.5\text{--}2.8$ mm in width, apex slightly retuse, and pubescent; *anther spurs*—short conical, c. 1 mm in length, folding or curving backward under the anther base, lack of prominent appendages or projections at the basal of spurs, and not producing mucilage. *Epigynous glands*—two in number, slender, $4.2\text{--}4.5$ mm long, yellowish, with acute apices not sharp. The *ovary*— $2.7\text{--}3.0 \times 2\text{--}2.5$ mm, white, pubescent; *style*—white; *stigma*—inverted conical, ciliate, c. 1×1 mm. *Fruits*—subglobose, white, $8\text{--}10 \times 7\text{--}9$ mm, pubescent. *Seeds*—brownish with white arils.

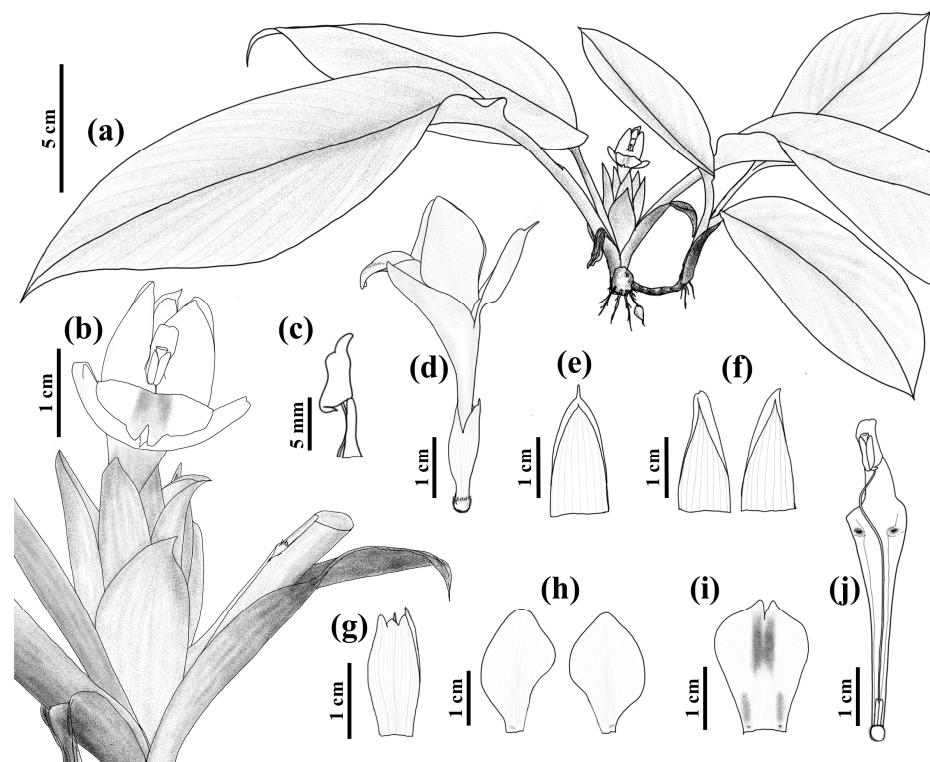


Figure 7. *Curcuma retrocalcaria* Saensouk, P.Saensouk, and Boonma sp. nov.: (a) habit; (b) side view of inflorescence with flower; (c) side view of anther; (d) side view of flower; (e) dorsal corolla lobe; (f) lateral corolla lobes; (g) dissection of calyx; (h) lateral staminodes; (i) Labellum; (j) dissection of the floral tube showing the epigynous glands, and semi-front view of anther. Drawn by Thawatphong Boonma.

Table 2. Comparison of morphological characteristics between *Curcuma retrocalcaria* and *C. chantaranothaii*.

Characters	<i>C. retrocalcaria</i>	<i>C. chantaranothaii</i> [9]
Leaf sheaths	Green with reddish tinge	Pale green
Ligule	3.5–5 mm long, apex rounded	7–8 mm long, apex acute
Petiole	1–4 cm long	6–8 cm long
Laminae	Elliptic to oblanceolate, 8–20 × 4–8.5 cm, Apex acute with mucronate tip, Base cuneate	Elliptic to narrowly elliptic, 12–15 × 4–6.5 cm, Apex acuminate, Base attenuate
Peduncle	1–2 cm in long	4–6 cm long
Thyrse	3–4 × 2.5–4 cm	4–6 × 5 cm
Fertile bracts	Ovate–triangular, 2–3.5 × 1–1.5 cm, Apex acute Whitish	Lanceolate to narrowly ovate, 4–6 × 2–3 cm Apex acuminate–mucronate, Pale green
Floral tube	2.7–2.85 cm long	2.4–2.6 cm long
Dorsal corolla lobe	Triangular–ovate, 1.7–2.3 × 0.7–0.8 cm, White with pale pinkish tinge	Ovate, 2.1–2.3 × 1.5–1.7 cm, White
Lateral corolla lobes	Triangular–ovate, 1.6–2.0 × 0.65–0.7 cm, Apex very short mucronate, White or with pinkish tinge	Ovate, 1.9–2.2 × 1.4–1.6 cm, Apex obtuse, White
Staminodes	Irregularly asymmetrical ovate, 2.0–2.2 × 1.3–1.4 cm, Apex obtuse, White with a yellow dot at the base, and a darker reddish spot inside	Rhomboid, 2.5–2.7 × 1.6–1.7 cm, Apex acute, White with a yellow patch along the center
Labellum	Obovate, 2.0–2.1 × 1.38–1.45 cm, White with a yellow band extending from the apex down to about half their length. At the base of the labellum, there are two yellow dots with a darker reddish spot inside, positioned on the side closer to the staminode. Adjacent to these dots are two pale purple patches measuring approximately 4–5 × 1.5–2 mm	Broadly obovate, 22–24 × 21–22 mm, White with embossed yellow median band extending from tip to base (diverging at base in a Y-shape), and two paler yellow crescent patches from the apex on each side to the half of length
Filament	c. 6 mm long, 4.5–5 mm wide, white	c. 5 mm long, 5–6 mm wide, pale yellowish white
Anther thecae	c. 4 mm long	c. 6 mm long
Anther crest	2.5–2.8 mm long, Apex slightly retuse	c. 0.8 mm long, Apex rounded
Anther spurs	c. 1 mm long, Folding or curving backward under the anther base	c. 0.5 mm long, Not folding, pointing downwards
Stigma	Not exerted from the anther lobe	Exerted from the anther lobe
Epigynous glands	4.2–4.5 mm long, Apex acute not sharp	c. 4 mm long, Apex rounded or blunt
Ovary	2.7–3.0 × 2–2.5 mm, White	c. 5 × 3 mm, Pale greenish yellow

Vernacular name: “*Sri Sunthon*”, this name is derived from the esteemed Mr. Sunthon Aiamwilai, who introduced this undescribed species of *Curcuma* to the third author in 2021. Subsequently, specimens of the plant were gathered in the years that followed. In honor of Mr. Sunthon Aiamwilai’s pivotal role in the discovery of this species, it was named after him, with the prefix “*Sri*” conveying respect and admiration in this context. Additionally, the word “*Sunthon*” in Thai means “*beautiful*”, which is fitting as it is associated with the beauty of this species.

Etymology: The specific epithet “*retrocalcaria*” derives from Latin roots. The “*retro*” denotes “backward”, indicating the characteristic of the spurs folding or curving backward; “*calcaria*” is the plural form of “*calcar*”, meaning “spurs”. Together, “*retrocalcaria*” describes the unique anatomical feature of this new *Curcuma* species, where the spurs fold backward under the base of the anther (Figures 6 and 7).

Distribution: The newly discovered species is currently endemic to Thailand, currently found exclusively within the forests of San Pa Tong District, Chiang Mai Province in Northern Thailand.

Ecology: This species thrives in deciduous forests, preferring sandy loam and pebbly soil compositions. It thrives in habitats with moderate-to-high moisture levels and is typically found at elevations ranging from 300 to 450 m above sea level. It grows under the shade of deciduous trees such as *Pentacme siamensis* (Miq.) Kurz, *Shorea obtusa* Wall. ex Blume, and *Tectona grandis* L.f.

Phenology: This species undergoes dormancy from late November to late April. With the arrival of the first rains, it initiates new shoot development. Upon reaching maturity, it produces terminal inflorescences between the innermost leaf sheaths. Flowering typically occurs from late June to August, occasionally extending into September, with most blooms opening early in the morning and lasting only one day.

Utilization: This newly identified species, known only to a limited group of collectors due to its rarity, is currently not widely cultivated as an auspicious ornamental plant and remains relatively unknown in the market.

Conservation Status: *Curcuma retrocalcaria* currently occupies an extent of occurrence (EOO) of less than 100 km² and an area of occupancy (AOO) of less than 10 km² across just two locations, facing significant conservation challenges. Classified as Critically Endangered (CR B1B2ab(iv,v); C2a(i)) according to the Guidelines for Using the IUCN Red List Categories and Criteria Version 16 (March 2024) [13], this designation underscores the species’ vulnerability to extinction primarily due to habitat loss and degradation exacerbated by climate change, alongside potential threats from human activities, particularly forest fires. Urgent measures are essential to protect its remaining habitats, mitigate threats, and ensure the long-term survival of *C. retrocalcaria*. Strategies such as designating this area as Other Effective Area-Based Conservation Measures (OECMs) and involving local communities will play crucial roles in safeguarding this species and preserving its ecological importance within its restricted range. Further exploration is crucial to assess the species’ entire range, as suitable habitats for *C. retrocalcaria* may remain unexplored. This exploration could potentially lead to adjustments in its conservation status, ensuring a more accurate assessment of its distribution and population dynamics.

Palynology: The pollen grains of *Curcuma borealis* are monads, inaperturate, prolate, with thick intine and thin exine, psilate with sparsely micro-granulate sculpture, $49.92 \pm 2.14 \times 37.12 \pm 2.31$ µm (Figure 8a). While the pollen grains of *C. retrocalcaria* are monads, inaperturate, subspherical, with thick intine and thin exine, with micro-granulate sculpture, $51.31 \pm 2.29 \times 40.65 \pm 1.98$ µm (Figure 8b).

The key to species similar to the two new species provides a comprehensive guide to accurately identifying and differentiating closely related taxa (Table 3).

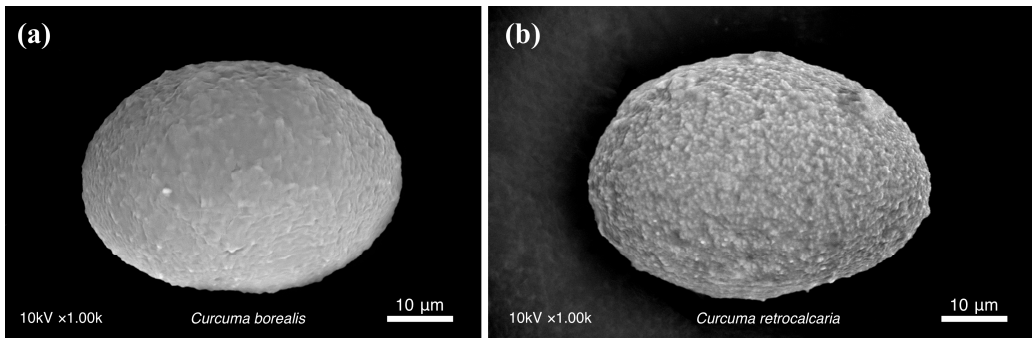


Figure 8. Scanning electron microscopy (SEM) photomicrographs of pollen morphology: (a) *Curcuma borealis* Saensouk, P.Saensouk, and Boonma sp. nov; (b) *C. retrocalcaria* Saensouk, P.Saensouk, and Boonma.

Table 3. Key to two new species and their allied species in subgenus *Ecomata*.

1a. Anther spurs less than 2 mm in length	2
1b. Anther spurs longer than 2 mm in length	3
2a. Labellum with two pale purple patches; spurs c. 1 mm in length and folding or curving backward under the anther base	<i>C. retrocalcaria</i>
2b. Labellum without purple patches; spurs c. 0.5 mm in length and pointing downwards	<i>C. chantaranothaii</i>
3a. Anther base without appendages or projections; anther spurs not producing mucilage	<i>C. borealis</i>
3b. Anther base with prominent appendages or projections; anther spurs producing mucilage	4
4b. Labellum with red dots at the basal of a yellow median band	<i>C. sabhasrii</i>
4a. Labellum with yellow median band to the base, without red spots	5
5a. Staminalodes white with yellow at the distal part, purple patch at the base	<i>C. glans</i>
5b. Staminalodes pale pink to dark purple without yellow at the distal part	<i>C. ecomata</i>

4. Discussion

The present article identifies two newly discovered species within the *Curcuma* genus: *Curcuma borealis* Saensouk, P.Saensouk, and Boonma, and *Curcuma retrocalcaria* Saensouk, P.Saensouk, and Boonma. Both species belong to the *Curcuma* subgenus *Ecomata* based on their morphological characteristics, including the presence of epigynous glands, inflorescences lacking coma bracts, and the production of open-form flowers [4]. However, upon examining the descriptions of these two taxa against existing species, particularly within the subgenus *Ecomata*, we found no matches, even the species reported on the *Curcuma* genus in the *Flora of Thailand*, volume sixteen part two, on the Zingiberaceae family [2].

This investigation clarifies the taxonomic designations of these species, which were previously misidentified as *C. ecomata* and *C. chantaranothaii* due to similarities in flower coloring and certain morphological traits. *Curcuma borealis* can be distinguished by its unique anthers, which lack appendages or projections at the base and do not produce mucilage, contrasting with the projections and mucilage-producing anther spurs in *C. ecomata* and *C. sabhasrii* [14]. *Curcuma retrocalcaria* can be differentiated from *C. chantaranothaii* by its anther spurs that fold or curve backward beneath the anther base, along with two purple patches located at the base of the labellum.

Moreover, *Curcuma retrocalcaria*, found near the distribution range of *C. ecomata*, exhibits distinct differences. *C. retrocalcaria* has calcarate anthers with short spurs around 1 mm long, which fold or curve backward under the anther base. In contrast, *C. ecomata* features longer spurs measuring approximately 3 mm, with anther spurs producing mucilage and prominent appendages or projections. Furthermore, the flower of *C. retrocalcaria* more closely resembles *C. chantaranothaii*, allowing for easy differentiation from *C. ecomata*.

The precise identification of species within the *Curcuma* genus is heavily reliant on the careful analysis of specific morphological features. These distinguishing traits play a crucial role in accurately classifying and categorizing the different species, thereby contributing considerably to the field of taxonomy.

The present article additionally provides the first investigation of the pollen structure of these two recently discovered species, providing more insights into their classification. The pollen grains of *C. borealis* and *C. retrocalcaria* are monads, inaperturate, prolate, with thick intine and thin exine, psilate with micro-granulate sculpture. These characteristics align with previous studies by Chen and Xia [15], Saensouk et al. [16], and Zou et al. [17], which reported that the pollen of *Curcuma* spp. are monads, inaperturate, and prolate, with thick intine and thin exine but differ in shape—which can be prolate, subspheroidal, or spheroidal—and size—ranging between approximately $40\text{--}120 \times 34\text{--}94 \mu\text{m}$ [15–17]. Specifically, *C. borealis* pollen measures $49.92 \pm 2.14 \times 37.12 \pm 2.31 \mu\text{m}$ and *C. retrocalcaria* pollen measures $51.31 \pm 2.29 \times 40.65 \pm 1.98 \mu\text{m}$. The findings highlight the significance of conducting a comprehensive taxonomic examination to clarify uncertainties and guarantee precise species identification. Precise accuracy is essential for the successful implementation of conservation strategies and the sustained exploitation of these species.

The recognition of these two novel taxa, *Curcuma borealis* and *C. retrocalcaria*, not only enriches our understanding of regional biodiversity but also underscores the need to protect their natural habitats. Accurate identification of these species is crucial for conservation efforts, highlighting the necessity of preserving biodiversity, especially in Northern Thailand where their natural habitat is located. This research contributes to the broader understanding of the *Curcuma* genus and its diversity.

5. Conclusions

This study identifies and distinguishes two new species within the *Curcuma* subgenus *Ecomata*: *Curcuma borealis* Saensouk, P.Saensouk, and Boonma, and *C. retrocalcaria* Saensouk, P.Saensouk, and Boonma. Detailed morphological analyses reveal unique characteristics that differentiate *C. borealis* and *C. retrocalcaria* from previously known species, specifically in their anther structures and flower morphology. Additionally, this research pioneers the examination of the pollen morphology of these new species. The findings underscore the importance of meticulous taxonomic investigation for accurate species identification, which is essential for conservation efforts. Protecting these newly identified species and their habitats is critical to preserving biodiversity in Northern Thailand.

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