Dulong People's Traditional Knowledge of *Caryota obtusa* (Arecaceae): a Potential Starch Plant with Emphasis on Its Starch Properties and Distribution Prediction

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Abstract: The greatest global challenge is to ensure that all people have access to adequate and nutritious food. Wild edible plants, particularly those that provide substitutes for staple foods, can play a key role in enhancing food security and maintaining a balanced diet in rural communities. We used ethnobotanical methods to investigate traditional knowledge on *Caryota obtusa*, a substitute staple food plant of the Dulong people in Northwest Yunnan, China. The chemical composition, morphological properties, functional, and pasting properties of *C. obtusa* starch were evaluated. We used MaxEnt modeling to predict the potential geographical distribution of *C. obtusa* in Asia. Results revealed that *C. obtusa* is a vital starch species with cultural significance in the Dulong community. There are large areas suitable for *C. obtusa* in southern China, northern Myanmar, southwestern India, eastern Vietnam, and other places. As a potential starch crop, *C. obtusa* could substantially contribute to local food security and bring economic benefit. In the future, it is necessary to study the breeding and cultivation of *C. obtusa*, as well as the processing and development of starch, to solve long-term and hidden hunger in rural areas.

Key Words: Dulong people, Traditional knowledge, *Caryota obtusa*, Ethnobotany

摘要：全球面临的最大挑战是如何确保获得充足且营养的食物。野生食用植物，特别是代粮植物，可在维持偏远地区的粮食安全和均衡饮食的营养方面发挥重要作用。本文采用民族植物学的方法，对滇西北独龙族利用董棕的传统知识进行了调 查，采用食品科学的方法对董棕淀粉的化学成分、形态、功能和糊化特性进行了评价，利用 MaxEnt 对董棕在亚洲的潜在地理分布进行了预测。董棕是独龙族重要的文化物种，一种很好的潜在淀粉植物，在中国南部、缅甸北部、印度西南部、 越南东部等地均有大片适宜生境区。董棕作为一种潜在的淀粉植物，不仅有助于保障当地的粮食安全，还可以带来经济利益。因此有必要对董棕的育种和栽培，以及淀粉的加工和开发利用进行研究，以应对未来偏远地区长期的隐性饥饿问题。

Received: 5 September 2022; accepted: 28 December 2022; published online 16 February 2023

Economic Botany, 77(1), 2023, pp. 63–81

Introduction

Food security is seriously threatened by both the current and potential pandemics and future climate change. For example, the COVID-19 pandemic has had a serious impact on global food supplies, and hence on hunger and malnutrition levels (FAO/IFAD/UNICEF/WFP/WHO 2021, 2022). Because of the continuing increase of the global population, many people are dependent on emergency food and livelihood support (Bishopp and Lynch 2015). According to estimates of the Global Network Against Food Crises, approximately 155 million people worldwide had serious food safety difficulties in 2020, with the number expected to increase by almost 40 million in 2021 (GNAFC 2021, 2022). In the future, many countries and regions, particularly in Africa, will face severe challenges in terms of food security and sustainability. Food security has long been a critical problem for developing countries. In Asia, some of the most affected countries include Myanmar, Laos, Vietnam, Pakistan, Nepal, and Afghanistan (Rosegrant and Cline 2003).

Although there are approximately 7000 cultivated species globally, most of the world's agriculture depends on about 100 crops. They provide nearly 90% of the per capita plant food supply, but only 20–30 crops constitute the main source of food for people (Garn and Leonard 1989; Khoshbakht and Hammer 2008; Von Wettberg et al. 2020). In fact, the three major crops, rice, maize, and wheat, alone provide 60% of the world's human food and energy supply (Siddique et al. 2021). For instance, in Cambodia and the Lao People's Democratic Republic (PDR), rice provides over 63% and 77% of the entire daily food energy needs, respectively (Siddique et al. 2021). The industrial revolution and the large-scale cultivation of a limited number of crops have led to the underutilization of many wild edible plants (Marrelli et al. 2020). Dependence on a limited number of staple food crops has had unexpected and harmful effects on human health. There is a lot of concern that wild edible plants are not being used to their maximum potential.

In addition to filling food gaps during periods of limited resources, wild edible plants, especially substitutes for staple food plants, serve an important role in preserving the food security of many people in developing countries, and contributing nutritional diversity to a balanced diet (Chen et al. 1999; Ju et al. 2013). These foods may serve as a major source for local inhabitants, or as a supplementally source for non-local residents (Sundriyal and Sundriyal 2001, 2004). Moreover, they may represent crop wild relatives and can provide valuable genetic resources for improvement of crop varieties (Ford-Lloyd et al. 2011; Ogle et al. 2003).

Caryota obtusa Griff., a tree-like palm belonging to the Arecaceae family, is a tropical rainforest, evergreen species native to Asia, with the majority of its distribution in China, India, Sri Lanka, and the Indochina Peninsula (Pei et al. 2010). *C. obtusa* has been used for decades as a food, medicinal, material, catalyst, fiber, and ornamental plant by diverse peoples in various countries. For example, in Sri Lanka, *C. obtusa* is used to make sweet syrup, sugar, and alcoholic beverages (Everett 1995). In India, the food industry has a lot of potential uses for the starch that is extracted from this palm (Wijesinghe et al. 2015). In the eastern Himalaya, the stems and buds of *C. obtusa* are used as vegetables, while the inside of the stalk is used to make soup in Lao PDR (Łuczaj et al. 2021; Uprety et al. 2016). *C. obtusa* is prescribed in Ayurvedic medicine, for weak semen and urinary system disorders. The juice is applied to the forehead as a treatment for hemicranias. The flowers are used to cure gastric ulcers, migraine headaches, snake bite poisoning, and rheumatic swellings. The tender flowers are claimed to help promote hair growth, and the roots to heal tooth ailments. The flour made from this palm is used to control diabetes (Charles et al. 2011; Devanesan et al. 2013; Ferreres et al. 2021; Smita et al. 2012). Furthermore, *C. obtusa* fiber can be utilized as a sustainable material for production of high performance polymer composites. The seed of *C. obtusa* is an agricultural product that can be applied as an inexpensive and eco-friendly adsorbent to remove metal ions (Anbalagan et al. 2016; Prakash et al. 2020; Ravulapalli and Kunta 2018; Saravanan et al. 2016).

Current research on *C. obtusa* is mostly concerned with the physicochemical characteristics of its starch, as well as phytochemical and pharmacological investigations of various *C. obtusa* plant parts (such as the inflorescence, fruit or leaves) (Azam et al. 2016; Gunaratne et al. 2016; Sudheesh et al. 2019a, 2020). Most of these studies take place in India and Sri Lanka (Sudheesh et al. 2019b). Although there are some previous reports on traditional knowledge, for example, that the flowers of *C. obtusa* are used to make snacks by Hani people in Honghe Prefecture, and the trunk-pith is used as supplementary food by Dai people in Xishuangbanna, China, extensive investigations of the ethnobotany of *C. obtusa* have not previously been published (Luo et al. 2019; Pei 1985).

The Dulong, also known as the Drung, are a small ethnic minority in China, with a population of just 6930 people, the majority of whom reside in the Dulongjiang Region, Gongshan Dulong and Nu Autonomous County, Nujiang Lisu Autonomous Prefecture, Yunnan Province (Geng et al. 2020). Due to high rainfall, many crops in the Dulongjiang area often fail to bear fruit, resulting in low yields. As a result, in the past the Dulong have experienced frequent food shortages (Cheng et al. 2020). The Dulong people have accumulated a wealth of traditional knowledge on the use of plants in the long-term mutual adaptation process to their living environment, and they depend on wild plants for their survival (Geng et al. 2017). The cultivation and utilization of *C. obtusa* is part of the adaptation process. As a key staple food replacement plant for Dulong people during times of resource shortage, *C. obtusa* has played an important role in sustaining the Dulong people's life and contributing to provision of a balanced diet (Long et al. 1999).

There may be an irreconcilable conflict between plant conservation and exploitation. Due to its limited natural distribution range, *C. obtusa* is an important protected species at the national level. However, *C. obtusa*, which has an attractive shape and plant architecture, is extensively cultivated as an ornamental tree species in many southern provinces of China, indicating the abundance of potentially suitable habitat areas for this species in China. The use of a model to predict the potential distribution range is important for plant exploitation and protection (Liu et al. 2016). Except for research on forest characteristics and population structure, there is not much information available on the distribution and the ecological suitability of *C. obtusa* as resource plant (Tang et al. 2022). Future development of this edible plant with high starch content will depend on studies of the climatic factors affecting its distribution. Identification of suitable distribution regions are required for the further scientific introduction, development, and refinement of planting management of *C. obtusa.* The main objectives of this research were to: (1) investigate the traditional use of *C. obtusa* by the Dulong people and evaluate the importance of these various uses by quantitative methods; (2) study the chemical composition, morphology, function, and pasting characteristics of *C. obtusa* starch traditionally processed by the Dulong people; and (3) use the MaxEnt model and GIS to select the main climatic factors affecting *C. obtusa* and predict the potentially suitable distribution areas for *C. obtusa* in Asia.

Materials and Methods

Study Site

Dulongjiang Township is located in the west of Gongshan Dulong and Nu Autonomous County, in the Nujiang Lisu Autonomous Prefecture of Yunnan Province, (Fig. 1). Dulongjiang Township (27°40′ to 28°50′ N, and 97°45′ to 98°30′ E) is adjacent to Bingzhongluo and Cikai townships in the east, Chayu County of Tibet Autonomous Region to the north, and Kachin State of Myanmar to the west and south. The Dulongjiang Region comprises high mountains and deep valleys. The elevation varies from 222 to 3,400 m (Cheng et al. 2020). It has long been historically isolated, with no road access to the outside world from each December to June of the following year due to excessive snowfall, and it remains China's most remote, poorest, and most closed region (Long et al. 1999). The region has abundant or extensive rainfall (average rainfall is 3,672 mm per annum), the highest in China (Cheng et al. 2022a). This region is one of the core zones of the protected areas of Gaoligongshan National Nature Reserve and the Three Rivers Parallel

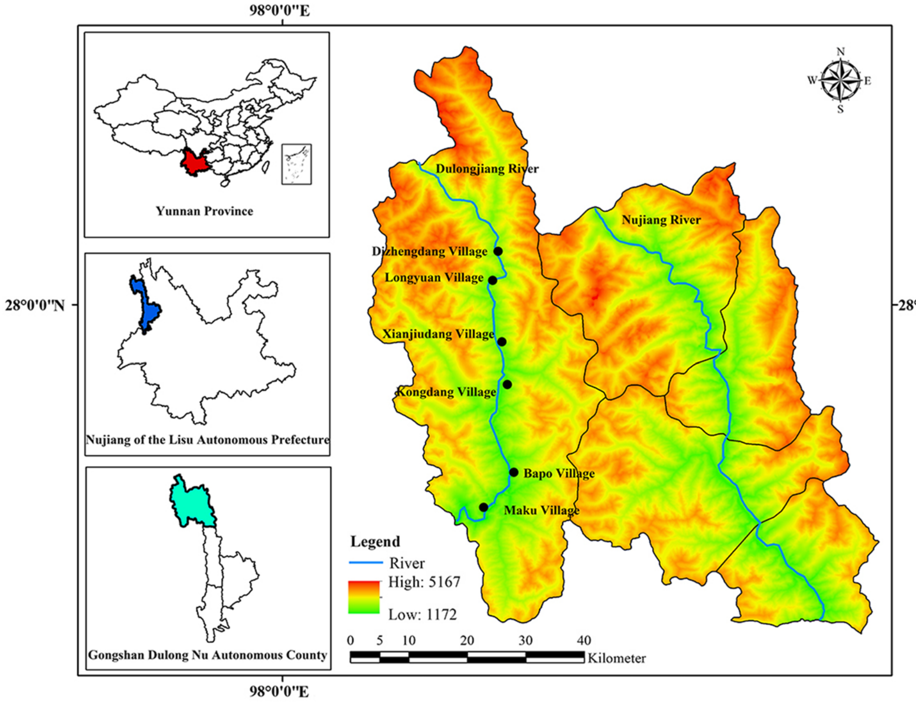

Fig. 1. Study site.

World Natural Heritage. It is one of the most biodiverse regions in China, with over 2,000 species of seed plants (Cheng et al. 2022b).

The Dulong people are one of China's 55 minority groups, and their population is the lowest among Yunnan's ethnic groups. In Dulongjiang Township, Dulong people account for 99% of the total population (with 6,930 people only). (Cheng et al. 2020). The majority of the people speak the Dulong language. Only young people can speak Mandarin Chinese. The main source of income for these indigenous peoples are the production, processing, and sale of spices and medicinal plants. (Cheng et al. 2022a).

Ethnobotanical Investigation and Quantitative Analysis

Field surveys were conducted from August 2019 to September 2021 through free listing, semi-structured interviews, and participatory observation, and 155 informants (including the elderly, village officials, and herbalists) were selected using snowballing. For interviewee informed consent and related aspects, the International Society of Ethnobiology Code of Ethics was followed (ISE 2006). The interview consisted of two parts. One was about the background of the informant (ethnicity, age, education, occupation). Then the questionnaire covered questions related to detailed information about *Caryota obtusa*, such as the local name, part used, processing method, and other uses.

The relative frequency of citation (RFC) is used to quantify the use frequency of each use of *C. obtusa*, and the utilization frequency was determined using the following formula:

$$RFC = FC/N$$

Where FC refers to the number of respondents who mention a particular purpose (use), and N represents the number of all respondents participating in the survey. The importance of each purpose was indicated by its FC value, which allowed all purposes mentioned in the survey to be listed in order of importance (Luo et al. 2021; Vitalini et al. 2013). The RFC values vary from 0 to 1, and the higher the RFC value, the more significant and valuable this use is in the area (Cheng et al. 2022a).

Chemical Composition and Morphological Properties

The flour extracted from the trunk of *C. obtusa* was collected in Gongshan Dulong and Nu Autonomous County in August 2019 and identified by Prof. Chunlin Long (Minzu University of China). The chemical composition of the flour was quantitatively determined by Symbol Materials Technology R&D Center (Qingdao City, Shandong Province, China) using the following methodology: moisture, protein, ash, and fat (GB/T 18868–2002), dietary fiber (GB 5009.88–2014), starch (GB/T 20378–2006), and amylose (GB/T 15683–2008).

The morphological characteristics of the flour were examined by scanning electron microscopy (Zeiss Supra 55, Oberkochen, Germany) at × 500, × 1000, × 2000 magnifications. Flour was investigated for the presence of birefringence of starch granules with polarized light microscopy (Olympus Bx51, Japan).

Functional and Pasting Properties

The solubility and swelling index of the starch were determined following Wang et al. (2015). Weigh 0.5 g sample into 50-mL water in a test tube, make 2% starch suspension, and stir them at 60 ℃, 70 ℃, 80 ℃, and 90 ℃, respectively. Heat for 30 min, cool quickly, and heat it at 4000 r/centrifuge at min speed for 15 min, put the supernatant in a watch glass, and heat in oven at 105 ℃ to a consistent weight to obtain the amount of dissolved starch. The swelling index and solubility were calculated using the following formulas (Kou et al. 2017).

$$\text{Solubility(S)} = \frac{A}{W} 100\%$$

$$\text{Swelling index(B)} = \frac{P}{W \times (100 - S)} \times 100\%$$

A is the weight of dried supernatant; *W* is sample weight; *P* is the weight of sediment.

The pasting properties of flour were determined using a Rapid Visco-Analyzer (RVA 4800, the USA) following the China standards method (GB/T 24853–2010). Weigh 3.0 g of flour and add deionized water to prepare a 6% mass suspension. During the stirring process, the following temperature profile was applied: hold at 50 °C for 1 min; heat up to 95 °C at a rate of 6 °C/min; hold at 95 °C for 5 min; lower the temperature to 50 °C at a rate of 6 °C/min and keep this temperature for 2 min. The puddle rotates at a speed of 960 r/min for the first 10 s and then maintains 160 r/min. Pasting temperature, peak viscosity, breakdown viscosity, trough viscosity, setback viscosity, and final viscosity were recorded (Zhao et al. 2018).

Construction and Evaluation of the MaxEnt Model

MaxEnt software (version 3.4.1) was downloaded from the Museum of Natural History website (https://www.amnh.org/). The 187 distribution data of *C. obtusa* were obtained by searching GBIF (Global Biodiversity Information Facility, https://www.gbif.org/), FOC (Flora of China, http://www.iplant.cn/foc), PPBC (Plant Photo Bank of China, http://ppbc.iplant.cn/), and CVH (Chinese Virtual Herbarium, https://www.cvh.ac.cn/) and 25 distribution points recorded by our laboratory from August 2019 to September 2021. The spatial analysis function of ArcGIS (10.4.1) was used to reduce the effect of spatial autocorrelation in SDM Toolbox (Brown 2014). Through the above procedure, a total of 156 distribution points were obtained.

Nineteen bioclimatic variables were downloaded from the WorldClim website (https://www.worldclim.org/) (30 s). These variables were the average values from 1970 to 2000. Based on the selected distribution data and environmental variables, the model was established and run 10 times (Boral and Moktan 2021). The impact of variables on the distribution of *C. obtusa* was analyzed using response curves, and other software parameters were left at their default level (Wang et al. 2021). The jackknife of regularized training gain is used to show the training gain of each variable if the model were run in isolation, compared to the training gain with all the variables, to identify the variables that contribute the most individually. The MaxEnt method was applied as described by different groups of scientists (Phillips et al. 2006; Young et al. 2011). The natural breaks classification method in ArcGIS software separates *C. obtusa* suitable habitat into four levels: highly suitable, moderately suitable, poorly suitable, and unsuitable habitat area.

Results

Ethnobotanical Investigation

The various parts (pith, trunk, leaves, shoots, and flower buds) of *Caryota obtusa* have different food, material, medicinal, and ornamental uses (Table 1). For example, the pith of *C. obtusa* is rich in starch and can be processed into food to prepare "baba," a native cake. The shoots of young trees and flower buds (young inflorescences) are cooked as vegetables. The hard and durable trunk of the tree has been used to make sinks, stone mills, and waterwheels. The leaves act as rainproof covers, and the fibers in the leaf sheath are used to make ropes, brooms, brushes, and straw rain caps. The starch processed from *C. obtusa* can be prescribed as medicine to treat indigestion, abdominal pain, diarrhea, and dysentery. The procedure is to take a small amount of starch, wash it with boiling water, and take it orally. In addition, *C. obtusa* plants are beautiful ornamental palm trees because of their tall, straight trunk, graceful structure, and large, neatly arranged leaves. The use of food was mentioned most frequently (0.52), followed by material use (0.27), ornamental use (0.22), and handicraft use (0.14). Table 1 shows that medicinal use was the least frequently mentioned (0.1).

The traditional method of preharvesting *C. obtusa* starch by the Dulong people is systematic and includes seven main steps (Table 2). The Dulong people use simple tools obtained from nature to process starch of *C. obtusa*, such as bamboo pedals, wood hammers, bamboo filter devices, and wood sinks. There are a number of religious beliefs or taboos associated with the extraction of *C. obtusa* starch. For example, after trial cutting of the tree, people are prohibited from drinking water and eating flour-like food. Otherwise, the trunk will be empty of flour. Such cultural phenomena indicate that *C. obtusa* was an important staple food substitute plant that had a key role in the prehistoric culture of the Dulong people. When cutting trees, they must be cut from top to bottom, not directly from the base. On

Table 1.. Traditional knowledge of *C. obtusa* in the Dulong community.

Purposes	Used part	Uses	FC	RFC
Food	Shoots and flower buds	Vegetables	81	0.52
	Pith	Starch extracted and processed, used to make a cake		
Material	Trunk	Hardy woody material used to make sinks, stone mills, and waterwheels	42	0.27
	Leaves	Rainproof cover or house shelter		
	Leaf-sheath	Ropes, brooms, brushes, clothes, etc.		
Medicine	Pith	Starch dissolved in boiling water and taken orally, with a dose of 9–15 g, to treat indigestion, abdominal pain, diarrhea, and dysentery	16	0.10
Handicraft	Leaf-sheath	Making packages and baskets	22	0.14
Ornamental	Whole plant	Cultivated in the front and back of houses for its beautiful appearance and huge leaves arranged neatly	35	0.22

FC is the number of respondents who mentioned a particular purpose, *RFC* is the ratio of the number of respondents who mention a particular purpose

Table 2.. Traditional method of making *C. obtusa* starch by the Dulong people.

Procedure	Specific operation	Tools used and taboos
Trial cut	On the night of the full moon, try to cut the tree before stars come out. If there is white powder on the knife, it means that the tree is ripe. Afterward, go home and wait for the next day, then ask others to help cut the tree together	The people cannot drink water or eat flour-like food; otherwise, the tree will have no flour
Cut	Use bamboo material to make pedals, and cover them with leaves of *Musa basjoo* Siebold and Zucc. ex Iinuma to prevent scratches. When cutting, firstly cut off the inflorescence of *C. obtusa*, then cut the tree into sections from top to bottom, with each section about 50 cm	Bamboo pedals; *C. obtusa* must be cut from its tip of stem to the base
Knock	Split each section, and then use a wooden hammer made of tree roots and stones to break the pith of *C. obtusa*	Wooden hammer
Filter	Put the broken pith on the bamboo frame, covered with leaves of *M. basjoo*, which is equivalent to a simple filtering device. The process uses a rotating bamboo tube to control the water flow while people step on the broken pulp. The starch flows down with the water and flows into the sink	Bamboo filter device
Starch separation	The sink is a simple sedimentation device made from the trunk of *C. obtusa*. Wait for a while, the starch will settle on the bottom of the sink; tilt the sink slightly to drain the water, and the rest is starch	*C. obtusa* sink
Pressing	Put the starch in a basin, press it down with a big stone, and squeeze to remove the remaining water	Big stone
Dry	Starch needs to be baked	The finished starch must be eaten by the elderly first

the one hand, this is due to the limitations of old processing tools. The collection of starch is time-consuming and will take 3–5 days. On the other hand, according to the Dulong's traditional knowledge, cutting starch from the top helps preserve its freshness.

Table 3.. Chemical composition of starch extracted from *Caryota obtusa* compared with starches from other two palm species.

Parameters	*Caryota obtusa*	*Metroxylon sagu*	*Arenga pinnata*
Moisture (%)	5.1	15.1	12.4
Protein (%)	0.3	0.2	4.7
Fat (%)	0.1	0.3	0.4
Ash (%)	0.2	0.1	0.7
Dietary fiber (%)	0.1	—	5.4
Starch (%)	89.2	80.4	62.3
Amylose (%)	22.7	24.1	—

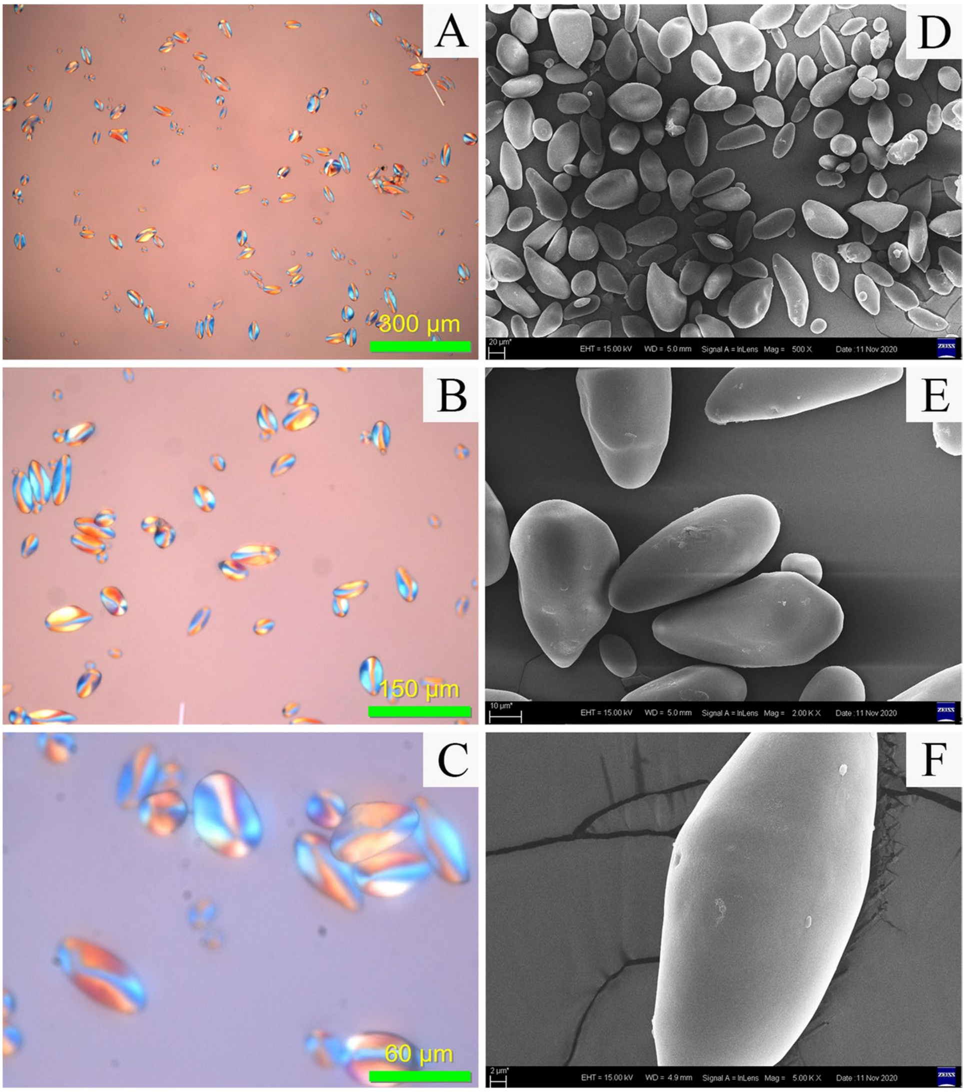

Fig. 2. Morphological characteristics of *C. obtusa* starch by scanning electron microscopy [500×(B), 1000×(D), 2000×(F)].

Physicochemical Properties of the Starch

Chemical Composition

The chemical composition of *C. obtusa* starch, and a comparison with two other palm starches, is shown in Table 3 (Du et al. 2020; Wu 2011). Moisture, protein, fat, ash, and dietary fiber content of *C. obtusa* starch were 5.1%, 0.3%, 0.1%, 0.2%, and 0.1%, respectively, similar to other starches (Table 3). The total starch content of *C. obtusa* (89.2%) was higher than that of *Metroxylon sagu* Rottb. We observed that *C. obtusa* and *Arenga pinnata* Merr. were suitable sources of starch (Du et al. 2020; Wu 2011). The amylose contents of *C. obtusa* starch (22.7%) and *M. sagu* starch (24.1%) were similar.

Morphological Properties

The morphological characteristics of *C. obtusa* starch are shown in Fig. 2. Under three levels of magnification, electron micrographs show that *C. obtusa* starch granules are elliptical, have smooth surfaces and are uneven in size. This is similar to the starches from sago (*M. sagu*), cassava (*Manihot esculenta* Crantz), and sugar palm (*A. pinnata*) starch granules. There were only small amounts of protein and fiber bodies and no granular clusters. This shows that the traditional way the Dulong people process *C. obtusa* is effective for high quality separation of the starch. The average length and width of *C. obtusa* starch granules were about 20–60 µm and 15–40 µm.

Polarized light micrography of *C. obtusa* starch is depicted in Fig. 2. When light passes through starch granules, a polarized cross is generated due to the birefringence characteristics of starch. There are differences in the position, shape, and apparent degree of the polarized cross in various starch granules. The birefringence is related to crystalline characteristics, and poor crystallinity of starch granules is indicated by low birefringence values. Figure 2 shows a distinct polarized cross for *C. obtusa* starch, suggesting that *C. obtusa* flour is highly crystalline.

Functional and Pasting Properties

The solubility and swelling power of *C. obtusa* starch increases with temperature (Fig. 3A). High temperatures destroy the crystalline structure of the starch. Moreover, and the number of hydrogen bonds disrupted in the crystallization zone increases. This makes it easier for free water to penetrate the starch granules, so the solubility and swelling degree of the starch get larger and larger. The solubility of *C. obtusa* increases from 12.3 to 17.6%, while the swelling rises from 7.2 to 9.6%. Pasting characteristics of *C. obtusa* starch are shown in Fig. 3B. The pasting temperature is the minimum temperature required for gelatinization of the starch. Pasting temperature of *C. obtusa* flour was 69 °C, peak viscosity was 549 cP, breakdown was 128 cP, and final consistency was 234 cP, respectively. The peak and final viscosities of *C. obtusa* flour are generally lower than those of pea, maize, and potato starches, indicating that the ability to form a gel is weak. The final viscosity values and insufficient setback show strong thermal stability. Lower breakdown viscosity indicates that starch molecules are more resistant to heat and shear forces during cooking.

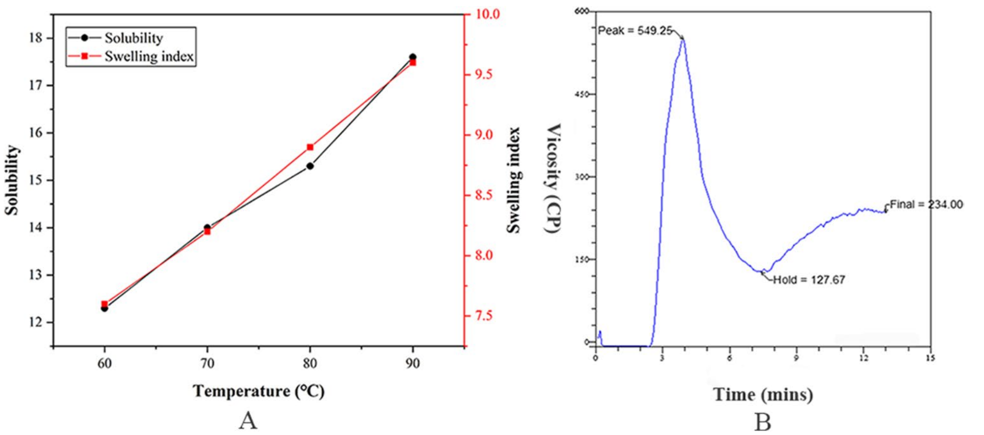

Fig. 3. **A.** Solubility and swelling index of *C. obtusa* starch. **B.** Pasting characteristics of *C. obtusa* starch

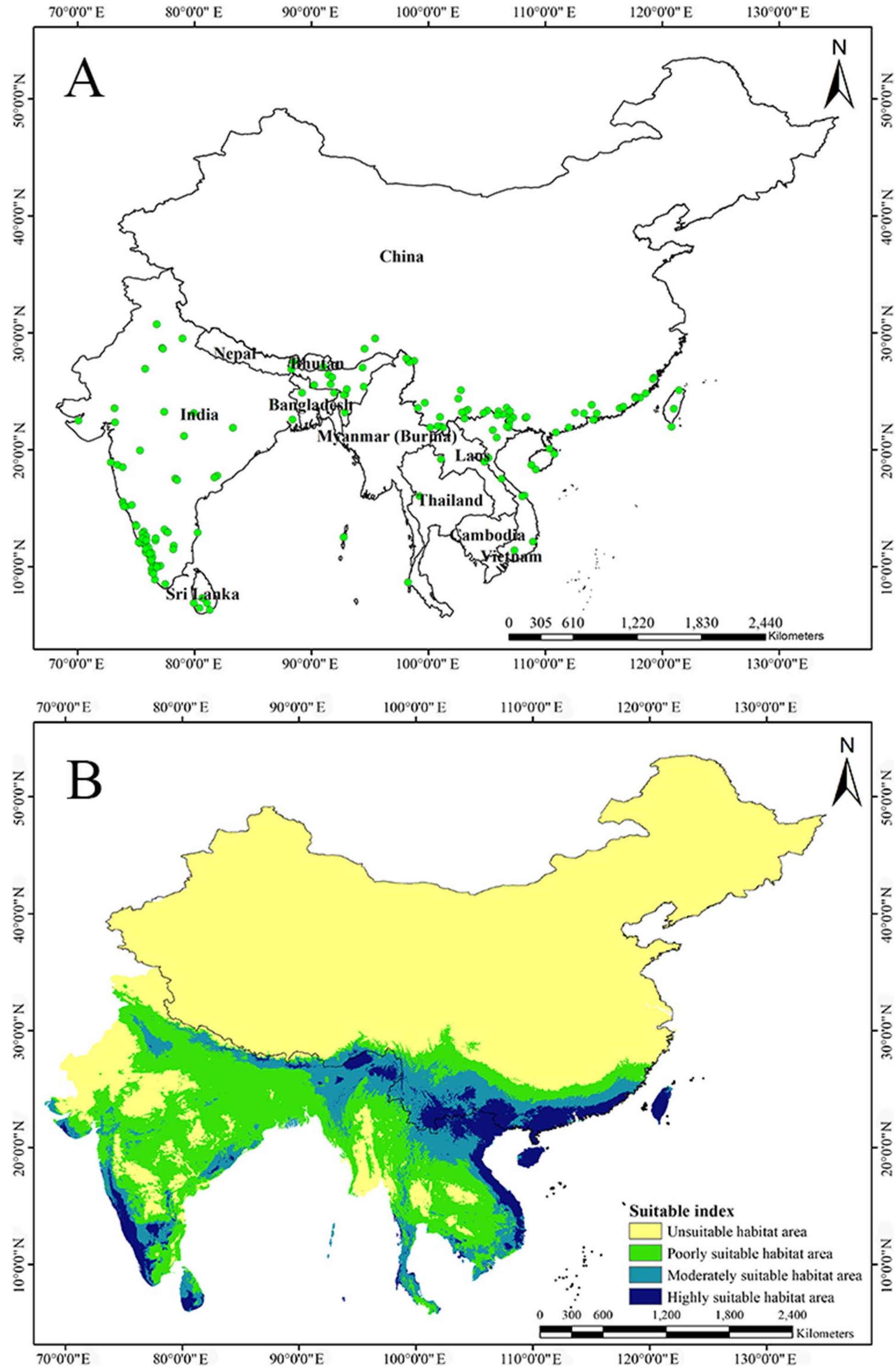

Fig. 4. **A.** Distribution of *C. obtusa* in Asia. **B.** Potential geographical distribution of *C. obtusa* under the current climate.

Predicting the Potential Geographical Distribution

Based on 156 distribution points, the MaxEnt model was used to simulate the potential geographical distribution of *C. obtusa* in Asia (Fig. 4A). The accuracy of the Maxent model was evaluated using a receiver operator characteristic (ROC) curve. The average training area under the curve (AUC) for the replicated runs was 0.950, and the standard deviation was 0.005 (Appendix, Fig. 5). According to the evaluation criteria, the predictive accuracy of the model reached an exceptionally high level. This indicates that the results of the model's predictions of the geographical distribution of *C. obtusa* are precise.

Among all variables, the annual temperature range (bio_7) showed the highest regularized training gain (1.08) (Appendix, Fig. 5), and it was the most important climate variable affecting the distribution of *C. obtusa*. The standard deviation regularized of temperature seasonality (bio_4) and annual precipitation (bio_12) were 0.94 and 0.92, respectively, which indicated that these variables play an important role in shaping its distribution. The regularized training gains of precipitation seasonality (bio_15) and maximum temperature of the warmest month (bio_5) were 0.08 and 0.22, respectively, indicating that the contribution of these variables to the predicted distribution was low. The annual temperature range (bio_7), standard deviation of temperature seasonality (bio_4), annual precipitation (bio_12), precipitation of the coldest quarter (bio_19), mean temperature of the coldest quarter (bio_11), and minimum temperature of the coldest month (bio_6) were the key climatic variables affecting the potential distribution of *C. obtusa*.

The MaxEnt model also predicts the geographical distribution of *C. obtusa* in Asia given the current climatic conditions (Fig. 4B). The highly suitable habitat area of *C. obtusa* is 97×10^4 km^2, mainly in southern China, northern Myanmar, southwestern India, eastern Vietnam, and other places. The moderately suitable area of *C. obtusa* is 185×10^4 km^2, mainly in southern Yunnan, southern and northeastern India, northern Myanmar, and northern Laos.

Discussion

A Potential Starch Plant

As a potential starch plant, *Caryota obtusa* is rich in traditional ethnobotanical knowledge and has favorable physical and chemical properties, including high starch content, amylose content, and digestibility.

C. obtusa has numerous traditional uses across China's various ethnic groups. For example, Hani people in Honghe Prefecture make snacks using the flowers of *C. obtusa*, while Dai people in Xishuangbanna use the trunk-pith as supplementary food (Luo et al. 2019; Pei 1985). In the daily life of the Dulong people, *C. obtusa* is a species with high cultural importance and many traditional uses, especially edible uses. The frequency of citations can reflect the importance of different usage in the community (Cheng et al. 2020). Several informants mentioned that the pith of *C. obtusa* can be processed into starch, indicating that among Dulong people's traditional knowledge of *C. obtusa*, starch intake is the most common and valuable.

The total starch content of *C. obtusa* flour was greater than that of other plants in the same genus, such as *M. sagu* and *A. pinnata*, and the amylose content of *C. obtusa* starch was comparable to that of *M. sagu* starch (Du et al. 2020; Wu 2011), which was lower than the previously reported range by Sudheesh et al. (2019a, b, 2020). Higher amylose content causes susceptibility to retrogradation and increased elasticity of starch pastes, which is conducive to producing hydrogel films and gelation. Furthermore, the high amylose content reduces digestibility. It affects the solubility, gelatinization, and thermal properties of starch; therefore, *C. obtusa* starch can be used to make snacks and puffed products (Chen et al. 2010).

The morphological characteristics of starch differ across species. The form and size of starch granules may reflect differences in their molecular structure, which can impact their physical and chemical characteristics and digestibility.

According to previous studies, the digestibility of starch is related to the size of starch granules (Zhou et al. 2014). Smaller diameter starch granules are more easily digested. Compared with other starches, *C. obtusa* starch has a medium granule size and higher digestibility (Sudheesh et al. 2019a, b).

Conservation of Traditional Knowledge

The Dulong are considered to be the last hunting group and seasonal foragers in China (Fortier 2014; Hitchcock 2021; Song 1999). In the past, collecting and hunting were essential for the Dulong people to maintain their way of life (Du and Chen 2019). Our previous ethnobotanical study documented 148 species of wild edible plants used by the Dulong people (Cheng et al. 2022a, b), especially food substitute plants, which played an essential role in the past for the Dulong people (Du and Chen 2016; Lu et al. 2021; Xu et al. 2021). The Dulong people mostly live in the Dulongjiang Region. Generally, crops and fruits are not pollinated in this area because of excessive rainfall. *C. obtusa* is a species with significant cultural significance and several traditional uses in the Dulong people's everyday lives. The various parts of *C. obtusa* are of substantial value in edible, material, medicinal, and ornamental aspects. The traditional knowledge of cultivation and utilization of *C. obtusa* by the Dulong people can help ensure food security in rainy areas, which is part of their adaptation to the harsh environment (Du and Chen 2019). The Dulong use simple tools derived from natural materials to process *C. obtusa* starch, which preserve rich pearls of ecological wisdom. Furthermore, during their farming activities, the Dulong people remove weeds from *C. obtusa* or transplant some seedlings from the mountains into their home gardens or next to the villages. Generally, for major events like building a house or getting married, *C. obtusa* is often planted in the home gardens in case of famine. The cultivation and management mode of *C. obtusa* was generated by the Dulong to adapt to their harsh environment. It is not only related to the local environmental conditions but also to the traditional culture, which is helpful in maintaining the population of *C. obtusa*. Thus, regional food security was guaranteed, and biodiversity was conserved. Therefore, it is critical to record and protect the traditional knowledge associated with the cultivation and utilization of *C. obtusa*, to provide a reference for the cultivation and conservation of *C. obtusa* resources.

Wild Edible Plants Relieve Hidden Hunger

The most recent estimate (2019) shows that prior to the COVID-19 pandemic, almost 690 million people, or 9% of the global population, were undernourished. The number of malnourished people will exceed 840 million by 2030, according to the State of Food Security and Nutrition in the World (SOFI) Report 2020. It will be a solution to find new resources to feed the world's population. Research suggests that neglected potential starch crops could help ease the global food crisis (Chen et al. 2021). The food security and health strategies of regional communities are based on ethnobotanical knowledge, especially traditional knowledge of wild edible and medicinal plants (Quave and Pieroni 2015). The collection and consumption of wild edible plants is not only an imperative part of global livelihood strategies but also plays an important role in maintaining livelihood security in developing countries and keeps their diets balanced (Cantwell-Jones et al. 2022).

Currently, ethnobotanical surveys of wild edible plants (WEP) have attracted many ethnobotanists and have become a research focus. Previous studies mainly focused on the recording of traditional knowledge of edible plants, while quantitative research methods, protection of traditional knowledge, management of local resources, and analysis of nutrition and chemical composition of edible plants would be key topics for future ethnobotanical research (Geng et al. 2015). There are many studies on WEPs in China, mainly focusing on the use of plants by ethnic minorities (Kang et al. 2014; Luo et al. 2019; Wang et al. 2020; Wujisguleng and Khasbagen 2010; Xu et al. 2004). These studies are crucial to the preservation of traditional knowledge. These ethnobotanical surveys identify the most widely consumed varieties and analyze their nutritional values (Lulekal et al. 2011; Termote et al. 2011). In this article, the total starch content of *C. obtusa* (89.2%) was higher than those of two other palm species, indicating that *C. obtusa* could be a good starch source.

Furthermore, WEP are one of the main sources of income for residents in poor communities and play an essential role in helping communities to eliminate poverty. In recent years, with people's attention to dietary balance, the market demand for *C. obtusa* starch has significantly increased. In the Dulongjiang Region, *C. obtusa* starch is a favorite food material of local people. It is also sold as a local product at a high price (30 to 60 CNY/kg; 1 USD = 6.95 CNY as of December 10, 2022), bringing income to locals.

According to the yield of 300 kg per tree, a *C. obtusa* tree can bring 18,000 CNY (2,590 USD) in revenue. The cultivation of *C. obtusa* has great potential to promote economic development in remote areas. However, utilization is still at a relatively primary level. In-depth scientific research on processing is lacking. In the future, modern technology can develop *C. obtusa* starch into puffed food, beverages, wine, and effervescent tablets. The composition and physicochemical properties of *C. obtusa* starch in this study can be used as a reference for processing technology and as a basis for quality evaluation.

Conclusion

In this study, ethnobotanical methods, food science methods, and MaxEnt modeling were employed to investigate *Caryota obtusa*, a unique species used by the Dulong community in Northwest Yunnan, China, including traditional knowledge, starch properties (chemical composition, morphological, functional, and pasting properties), and the potential geographical distribution in Asia. Results show that *C. obtusa* is a viable potential starch-producing species with high cultural importance in the Dulong community. It can make positive contributions to food security and bring income as well. In the future, it is necessary to study the breeding and cultivation of *C. obtusa*, as well as the processing and development of starch, to contribute to solving long-term hidden hunger in rural areas.

Authors' Contributions

LCL conceived and designed the study. CZ and LXP collected the data. LCL and CZ identified the plants. CZ interpreted and analyzed data, and wrote the manuscript. LXP, HX, ZQ, AM, and LCL modified the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by grants from the National Natural Science Foundation of China (31761143001 and 31870316), Minzu University of China (2020MDJC03, 2022GJAQ04 and 2022ZDPY10), Assessment of Edible and Medicinal Plant Diversity and Associated Traditional Knowledge in Gaoligong Mountains (GBP-2022–01), and Biodiversity Survey and Assessment Project of the Ministry of Ecology and Environment of China (2019HJ2096001006).

Data Availability

All data generated or analyzed during this study was included in this published article (along with the supplementary files).

Declarations

Ethics Approval and Consent to Participate

Before collecting indigenous knowledge of *C. obtusa*, all informants were informed about the purpose of the research and its benefits, clearly underlining the fact that the results will be used for academic purposes and that no commercial interest will be attached to it. A verbal agreement was obtained from the authorities of local communities to create informed decisions on whether or not to participate in the study, prior to administering the interview.

Competing Interests

The authors declare that they have no competing interests.

Appendix

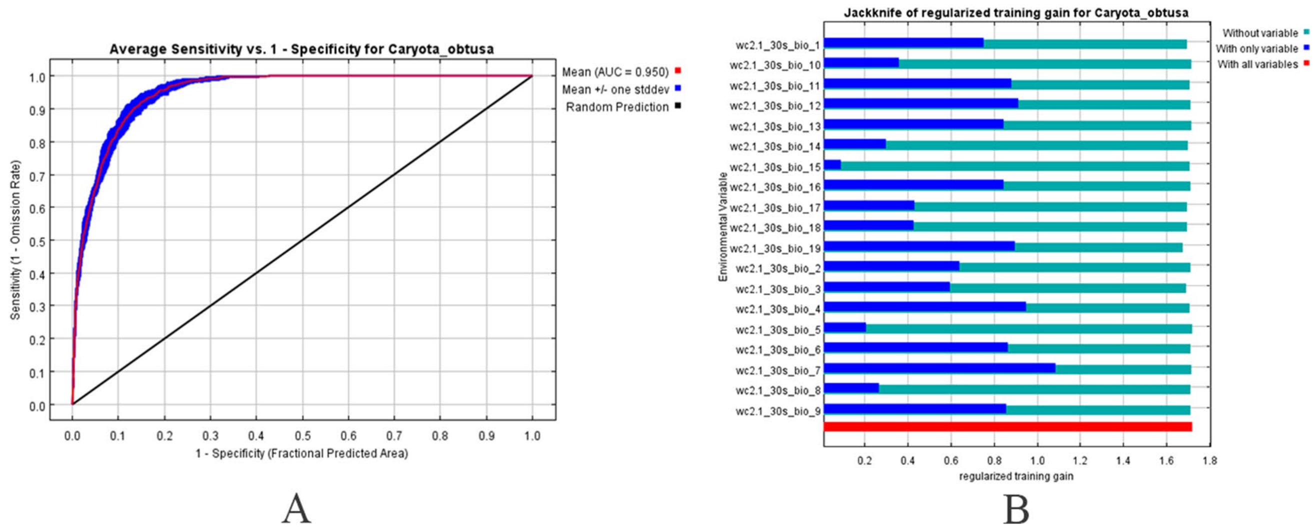

Fig. 5. A: ROC curve of *C. obtusa* by MaxEnt model; B: Jackknife test result of environmental factors for *C. obtusa*.

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