Edible Orchids from Forest to Plate: A Review on Nutritional, Functional, and Sustainable Perspectives

Soumi Naha Nag*
Ananda Mohan College, 102/1, Raja Rammohan Sarani, Kolkata – 700009, India
*E-mail: souminaha@gmail.com, Mob. 0091-9903762200

Abstract: The family Orchidaceae is one of the most diverse, species-rich, and ecologically specialized groups of flowering plants. While orchids are globally renowned for their ornamental and medicinal value, their role as sources of food and nutraceutical compounds remains under-recognized. This review synthesizes current understanding of wild and cultivated edible orchids, that occupy a distinctive position at the interface of biodiversity conservation, traditional food systems, and emerging nutraceutical markets. Used across Asia, Africa, and parts of the Americas, these species provide dietary energy through complex carbohydrates while also supplying bioactive metabolites with antioxidant, antimicrobial, immunomodulatory, and neuroprotective functions. However, many edible orchids are undergoing rapid population declines due to overexploitation, habitat loss, climate change, and expanding unregulated trade. This review synthesizes current knowledge on the diversity, functional properties, and ethnobotanical significance of edible orchids, and evaluates various strategies for their sustainable utilization, including cultivation, *in vitro* propagation, metabolic engineering, and community-based management. An integrative framework is proposed that links conservation biology, ethnobotany, and applied biotechnology to enable sustainable production while safeguarding wild populations.

Keywords:

Orchidaceae; Nutraceuticals; Traditional knowledge; *In vitro* Propagation; Sustainable utilization; Conservation.

1. Introduction

The family Orchidaceae comprises of over 28,000 species, and is among the most diverse and evolutionarily advanced family among angiosperms (Dressler, 1993**;** Chase *et al.*, 2015). Orchids demonstrate remarkable morphological diversity and ecological specialization, often relying on specific pollinators and mycorrhizal fungi for survival. While historically valued for their ornamental beauty, orchids have long been utilized as food and medicine in Asia, Africa, and various parts of Europe since ancient days.

Over recent decades, phytochemical and pharmacological studies have validated many traditional uses of orchids, identifying compounds with antioxidant, anti-inflammatory, anticancer, and neuroprotective activities (Teoh, 2016). At the same time, increasing commercial demand has led to unscrupulous harvesting from wild populations. As a result, orchid research needs to integrate biotechnology with conservation biology to ensure sustainable utilization of these precious resources.

2. Orchids as Food Resources

2.1 Vanilla: The Dominant Orchid in Food Industry

Vanilla planifolia and related species (*V. tahitensis*, *V. pompona*) represent the most economically significant food orchids. Although vanilla is now largely cultivated, expansion of plantations has historically involved forest conversion and genetic erosion, raising concerns regarding sustainability and resilience (Bory *et al.*, 2010).

Vanilla planifolia Andrews, a climbing orchid native to Mesoamerica, represents the most significant orchid which is extensively used commercially in food industries. Natural vanilla is derived from cured fruits (beans) and is widely used in the global food, beverage, cosmetic, and pharmaceutical industries. The primary flavour compound, vanillin, is accompanied by over 200 minor aromatic constituents that contribute to the complexity of natural vanilla flavor (Havkin-Frenkel and Belanger, 2018). The cured fruits contain vanillin, along with minor phenolic compounds contributing to flavour complexity (Havkin-Frenkel and Belanger, 2018). Beyond its sensory attributes, antimicrobial, antioxidant, and anti-inflammatory properties of vanilla extract are also well documented. The antimicrobial activity of *V. planifolia* is mainly attributed to vanillin (4-hydroxy-3-methoxybenzaldehyde) and related phenolic compounds such as vanillic acid and p-hydroxybenzaldehyde21 consistently demonstrated that vanillin exhibits broad-spectrum antibacterial activity against Gram-positive bacteria *Staphylococcus aureus*, *Listeria monocytogenes*, *Bacillus subtilis*) and Gram-negative bacteria e.g. *Escherichia coli*, *Salmonella enterica*, *Pseudomonas aeruginosa* (Delaquis *et al.*, 2002; Fitzgerald *et al.*, 2004; Walton *et al.*, 2010). In *Pseudomonas aeruginosa,* vanillin reduced biofilm formation and quorum sensing, thereby indicating its activity beyond simple bacteriostasis (Walton *et al.*, 2010). Antifungal effects of vanillin have also been reported against *Candida albicans* and *Aspergillus* spp. that involved suppression of spore germination (Kumar *et al*., 2007) observed strong inhibitory effects of vanillin against *Candida albicans* and *Aspergillus niger*. Vanillin is also reported to interfere with fungal cell wall synthesis and oxidative stress pathways, contributing to fungistatic effects (Priefert *et al*., 2001).

Mechanistic investigations indicate that vanillin exerts antimicrobial activity through multiple complementary pathways, including disruption of microbial cell membrane integrity, interference with cellular energy metabolism, and inhibits quorum sensing and biofilm formation, collectively leading to reduced microbial growth and virulence (Fitzgerald *et al*., 2004; Walton *et al*., 2010). Such multi-target modes of action are particularly relevant in the context of rising antimicrobial resistance, as they decrease the likelihood of rapid resistance development compared with single-target antimicrobial agents. In addition, synergistic interactions between vanillin and other phenolic compounds or conventional antibiotics have been documented, resulting in enhanced antimicrobial efficacy at lower concentrations and highlighting its potential as an adjuvant in antimicrobial formulations (Delaquis *et al*., 2002; Friedman *et al*., 2003).

In addition to its antimicrobial properties, multiple studies have also demonstrated that *Vanilla planifolia*–derived vanillin exhibits antioxidant activity, predominantly through inhibition of lipid peroxidation. This dual antioxidant–antimicrobial functionality supports the positioning of vanilla as a promising natural preservative for food and pharmaceutical applications, particularly in systems seeking to reduce reliance on synthetic additives (Rao and Ravishankar, 2000; Friedman *et al.*, 2003; Fitzgerald *et al.*, 2004).

From a biotechnological perspective, vanilla cultivation faces challenges including low genetic diversity, susceptibility to fungal diseases, and labour-intensive hand pollination. Research on in vitro propagation, somatic embryogenesis, and molecular marker-assisted selection has significantly improved planting material quality and yield stability (Divakaran *et al.*, 2006). Additionally, studies on metabolic engineering and biotechnological production systems aim to enhance vanillin biosynthesis using plant cell cultures and engineered microbial platforms, thereby reducing dependence on conventional cultivation and alleviating pressure on cultivated and wild *Vanilla* populations (Priefert *et al.*, 2001; Walton *et al.*, 2003; Hansen *et al.*, 2009).

From a comparative standpoint, it is evident that the orchids with the strongest antimicrobial compounds are often those under greatest conservation threat, due to destructive harvesting of whole plants or underground organs. In contrast, *Vanilla planifolia* demonstrates how cultivation and biotechnology can decouple antimicrobial utilization from biodiversity loss. Although the antimicrobial potency of vanilla is generally moderate relative to some phenanthrene-rich orchids, but its exceptional advantage lies in sustainability and scalability. The ability to produce vanillin through domestication, micropropagation, and metabolite-focused production using biotechnological approaches significantly reduces pressure on wild orchid populations, aligning pharmaceutical utilization with conservation goals. Therefore, such conservation strategies can stand as a model for other medicinal orchids as a promising pathway toward sustainable use.

2.2 Salep-Producing Orchids

Salep is a traditional food and medicinal concoction, prepared from the powdered, dried tubers of terrestrial orchids, mainly species of *Orchis*, *Anacamptis*, *Dactylorhiza*, and *Ophrys*. It has long been consumed across the Mediterranean region, the Middle East, and parts of Central and South Asia and is known to confer soothing and nutritive properties (Sezik, 2002; Teoh, 2016). It is prescribed for gastrointestinal disorders, respiratory ailments, and general debility due to its high content of glucomannan-rich polysaccharides, which exhibits prebiotic and antidiabetic effects (Hacıbekiroğlu and Kolak, 2011). In addition, salep tubers are rich in starch, and proteins, which account for their high nutritional value and characteristic thickening properties, as well as their traditional use as demulcent and digestive agents (Sezik, 2002; Teoh, 2016). However, salep production relies on the destructive harvesting of whole plants, often before reproduction, resulting in drastic population declines of wild orchids. Harvesting tubers results in plant death, making salep production a major driver of orchid population decline in Turkey and surrounding regions (Sezik, 2002).

Ethnobotanical surveys and trade assessments indicate that millions of orchid tubers are collected annually, contributing to the threatened or endangered status of many terrestrial orchid species and prompting legal restrictions in various countries (Kasparek and Grimm, 1999; Ghorbani *et al*., 2014; Kreziou *et al*., 2016). Consequently, salep-producing orchids represent one of the most severe cases of use-driven extinction risk within the family

Orchidaceae, making them a priority group for conservation biotechnology research, including *in vitro* propagation, tuber induction, and the development of sustainable alternatives to overcome the ever-increasing collection pressure from the wild.

2.3 Subsistence and Traditional Food Uses

In several regions of sub-Saharan Africa and Southeast Asia, orchids have historically functioned as subsistence and traditional food resources, particularly during periods of famine, seasonal hunger, or agricultural failure. Terrestrial orchid genera such as *Eulophia* and *Disa* are widely reported to be harvested for their underground tubers, which are processed and consumed as emergency or supplementary foods, supplying carbohydrates and limited proteins when conventional food crops are scarce (Hinsley *et al*., 2018). Ethnobotanical studies indicate that these practices are deeply entrenched in local knowledge systems, reflecting long-standing adaptive strategies developed by indigenous and rural communities to cope with environmental uncertainty and fluctuating food availability (Ghorbani *et al*., 2014; Teoh, 2016). Similarly, in the Himalayas, *Dactylorhiza hatagirea* is used as food, tonic, and medicine. High market value and cross-border trade have resulted in overharvesting, placing the species in the Endangered category and prompting cultivation trials and legal protection (Ghorbani *et al*., 2014).

Despite their cultural and nutritional significance, the subsistence use of orchid tubers carries substantial ecological consequences, as harvesting typically involves the complete removal of the plant, thereby eliminating its capacity for vegetative regeneration and seed production. Repeated extraction has been linked to localized population declines and long-term depletion of wild orchid populations, particularly in habitats already under pressure from land-use change and climate variability (Hinsley *et al*., 2018; Kreziou *et al*., 2016). Such impacts underscore the vulnerability of food-used orchids to use-driven population collapse, even when exploitation occurs at a local or subsistence scale. While largely subsistence-based, increasing commercialization around urban centres has intensified harvesting pressure, leading to localized depletion (Hinsley *et al*., 2018).

While these food practices remain culturally important, continued reliance on wild-harvested orchid tubers highlights the urgent need for cultivation-based alternatives, including community-managed propagation systems, in vitro micropropagation, and other conservation-oriented biotechnology approaches that can provide sustainable biomass without further depleting natural populations (Ghorbani *et al*., 2014). Integrating traditional ecological knowledge with modern cultivation, micropropagation, and *ex situ* conservation strategies offers a promising pathway to balance food security needs with the long-term conservation of orchid biodiversity, ensuring that orchids can continue to serve as traditional food resources without compromising their survival.

3. Orchids as Nutraceuticals:

Edible orchids predominantly contribute to dietary energy through complex carbohydrates, yet their nutritional relevance extends well beyond caloric provision. They also provide bio-functional components that blur the boundary between food and medicine. These orchids are gradually being recognized as a potent **nutraceutical resource**, that occupies a functional space between food and medicine due to their rich repertoire of bioactive metabolites and long history of dietary use in traditional health systems across diverse cultures. Several orchid species consumed as foods, beverages, or health tonics—such as *Vanilla planifolia*, *Dendrobium officinale*, *Gastrodia elata*, and *Anoectochilus roxburghii*—contain compounds with scientifically validated antioxidant, anti-inflammatory, immunomodulatory, neuroprotective, and metabolic regulatory activities (Bulpitt *et al*., 2007; Teoh, 2016). These bioactivities support their classification as functional foods and highlight their potential for incorporation into evidence-based nutraceutical formulations aimed at promoting health and reducing disease risk beyond basic nutrition.

3.1 Macronutrients and Polysaccharides

The underground tubers of terrestrial orchids such as *Orchis*, *Dactylorhiza*, *Eulophia*, and *Habenaria* are rich in starch and glucomannan-type polysaccharides. In salep-producing orchids, glucomannan may constitute up to 40–50% of dry weight, conferring high viscosity, slow digestibility, and demulcent properties (Sezik, 2002; Teoh, 2016). Glucomannan and related complex carbohydrates contribute to satiety and have long been associated with gastrointestinal health, glycemic regulation, and immune modulation (Xie *et al*., 2013) in traditional diets.

3.2 Micronutrients and Proteins

Although orchids are not major protein sources, tubers contain low to moderate levels of amino acids, minerals (calcium, potassium, magnesium), and trace elements that supplement nutritionally marginal diets during famine periods (Teoh, 2016). In subsistence contexts, this nutritional buffering function is often more important than caloric contribution alone.

3.3 Functional and Bioactive Compounds

Several edible orchids are outstanding sources of phenolic compounds, flavonoids, and minor alkaloids that confer distinct antioxidant and antimicrobial activities, reinforcing their value as functional food ingredients. Among these, *Vanilla planifolia*—the most popular, extensively cultivated and globally traded edible orchid—is particularly rich in vanillin and structurally related phenolics. These compounds display strong free-radical scavenging capacity, broad-spectrum antimicrobial effects, and natural preservative properties, thereby supporting the widespread use of vanilla-derived extracts in both food preservation and pharmaceutical formulations (Rao and Ravishankar, 2000; Friedman *et al*., 2003). Beyond vanilla, other edible orchids accumulate bioactive phenolics such as bibenzyls and phenanthrenes, which demonstrate comparable antioxidant and antimicrobial efficacy and further substantiate the traditional and contemporary use of orchid-derived products in functional foods and natural preservative systems (Rao and Ravishankar, 2000; Friedman *et al.,* 2003). In addition to these protective bioactivities, certain orchids produce neuroactive compounds of high nutraceutical relevance. Notably, gastrodin, a phenolic glucoside isolated from *Gastrodia elata*, has been incorporated into nutraceutical and functional formulations targeting cognitive performance and neurological health, with experimental evidence supporting its neuroprotective, anti-neuroinflammatory, and neuromodulatory effects (Huang *et al*., 2015). Collectively, these bioactive profiles underscore the growing translational potential of edible orchids as

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multifunctional nutraceutical resources bridging antioxidant defence, microbial control, and neurological health support.

Despite this growing interest, the nutraceutical development of orchids faces significant challenges related to raw material sustainability, as many nutraceutically valuable orchids are still sourced from wild populations. This reliance exacerbates conservation pressures, particularly for slow-growing terrestrial species harvested for tubers or rhizomes. Consequently, the future of orchids as nutraceuticals depends heavily on biotechnology-driven production systems, including controlled cultivation, in vitro propagation, cell and suspension cultures, and metabolic engineering, which can ensure consistent bioactive compound supply while minimizing impacts on natural populations. Integrating nutraceutical innovation with conservation biotechnology is therefore essential to realizing the full potential of orchids as sustainable health-promoting resources.

4. Reasons for Population Decline in Edible Orchids

4.1 Overexploitation and Unsustainable Harvesting

Overexploitation is the principal driver of decline in edible orchids. Harvesting of underground organs eliminates individual plants and prevents regeneration, leading to rapid population depletion (Bulpitt *et al.*, 2007). Orchid life histories—characterized by slow growth, delayed reproduction, and dependence on specific mycorrhizal fungi—further reduce their resilience to intensive extraction (Rasmussen *et al.*, 2015).

4.2 Fragmentation and Habitat Loss

Habitat loss resulting from agriculture, deforestation, urban expansion, and infrastructure development poses a severe threat to orchid diversity (Swarts and Dixon, 2009). Fragmentation disrupts pollinator networks, soil microbial communities, and hydrological regimes, all of which are critical for orchid survival and recruitment (Fay, 2018).

4.3 Climate Change

Climate change exacerbates existing threats by altering temperature and precipitation patterns, shifting suitable habitats, and disrupting phenological synchrony between orchids and their pollinators (Dearnaley *et al.*, 2012). High-altitude and range-restricted edible orchids are particularly vulnerable to these changes.

4.4 Unregulated and Illegal Trade

Rising global demand for natural foods and traditional medicines has expanded both domestic and international trade in orchids, often beyond regulatory oversight (Hinsley *et al.*, 2018). In many source regions, enforcement capacity is explicitly inadequate, which enable illegal harvesting and laundering of wild-collected material into legal markets without much difficulty.

5. Traditional Knowledge Systems in Edible Orchids

Traditional knowledge systems are integral to the utilization and management of edible orchids, particularly within Indigenous and rural communities across Asia, Africa, and parts of the Americas (Bulpitt *et al.*, 2007; Pant and Raskoti, 2013). These systems incorporate detailed knowledge of species identification, habitat specificity, seasonal availability, harvesting techniques, processing methods, and dietary or therapeutic applications (Kala, 2005; Teoh, 2016). Historically, customary norms regulated harvesting intensity, timing, and access, thereby reducing ecological impacts and enabling natural regeneration of orchid populations (Swarts and Dixon, 2009). Edible orchids were often harvested selectively, through partial removal of tubers or rotational collection across sites, reflecting an implicit conservation ethic embedded within cultural practice (Kala, 2005; Veldman *et al*., 2014). However, the erosion of traditional governance structures, together with market-driven commercialization and disrupted intergenerational knowledge transmission, has weakened these management systems and contributed to unsustainable extraction and population declines (Phelps and Webb, 2015; Hinsley *et al*., 2018). Therefore, integrating traditional ecological knowledge with contemporary conservation and management strategies remains essential for developing culturally appropriate and ecologically sustainable frameworks for the conservation and utilization of edible orchids (Swarts and Dixon, 2009; Fay, 2018).

6. Conservation Status and Regulatory Frameworks

6.1. IUCN Red List Assessments

Many of the edible orchid species are recognized as threatened under the IUCN Red List, although many taxa remain unassessed or are classified as Data Deficient due to limited field data and taxonomic ambiguities (Swarts and Dixon, 2009; Fay, 2018). This underrepresentation is more prevalent in tropical regions, where orchid diversity is highest but systematic population monitoring is comparatively inadequate. The cryptic growth habits of many orchids, combined with their dependence on specific mycorrhizal fungi and pollinators, further complicate accurate assessments of population trends and extinction risk (Rasmussen *et al.*, 2015). As a result, the conservation status of numerous edible orchids may be more perilous than currently reflected in global threat assessments.

6.2. CITES and International Trade Regulation

All orchid species are listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), with the majority included in Appendix II and a smaller number afforded stricter protection under Appendix I (CITES, 2019). This listing reflects age-old concerns over the impacts of international trade on wild orchid populations. While CITES has contributed to improved awareness, documentation, and regulation of cross-border trade, its effectiveness in conserving edible orchids remains limited. Persistent challenges include species misidentification in trade, exemptions for artificially propagated material that can be exploited to launder wild-collected specimens, and weak enforcement at national and local levels (Phelps and Webb, 2015; *Hinsley et al*., 2018). Moreover, CITES primarily regulates international trade and its proposition to control the domestic markets remains largely relaxed, where much of the consumption of edible orchids takes place.

7. Regional Case Studies: Use-Driven Extinction Risk

7.1. Himalayan and South Asian Region

In the Himalayan range and extended South Asian region, several terrestrial orchid species such as *Dactylorhiza*, *Habenaria*, and *Eulophia* are extensively harvested for food, traditional

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medicine, and tonic preparations (Pant and Raskoti, 2013). Historically, harvesting was regulated through habitual practices that restricted collection intensity and timing. However, increasing commercialization and integration into regional and international markets have eroded these traditional controls, resulting in unsustainable extraction and localized population declines (Kala, 2005; Subedi *et al*., 2013). The usual slow growth rates and poor natural regeneration of these species further intensify their vulnerability to overharvesting.

7.2. Sub-Saharan Africa

The chikanda trade in southern and central Africa represents a well-documented example of use-driven extinction risk. Chikanda is a starch-based food traditionally prepared from orchid tubers which was once harvested primarily for local consumption. Through last few decades, rising urban demand for chikanda has transformed it into a commercial commodity. Its transboundary trading combined with limited regulatory oversight, has led to large-scale depletion of multiple *Disa* species (Veldman *et al.*, 2014). It has raised serious concerns regarding the long-term survival of the affected species.

7.3. East and Southeast Asia

In East and Southeast Asia, *Gastrodia elata* and some other orchids are heavily exploited for medicinal use. Despite the development and expansion of cultivation practices, wild-harvested material is often preferred as these are believed to be more effective and have higher market value which in turn, lays continued pressure on natural populations (Teoh, 2016; Chen *et al*., 2011). This preference underscores the complex interplay between superstitions, cultural beliefs, market dynamics, and conservation outcomes, and highlights the limitations of cultivation alone as a conservation strategy in the absence of effective regulatory framework and consumer awareness.

8. Strategies for Sustainable Utilization

8.1. Cultivation and Agro-Technological Approaches

Cultivation stands as the key strategy for reducing pressure on wild orchid populations. Recent advances in substrate formulation, symbiotic germination, and controlled-environment cultivation have improved production success for several edible species (Rasmussen *et al*., 2015).

8.2. Micropropagation and *Ex Situ* Cultivation

In vitro propagation methods, including asymbiotic seed germination, protocorm culture, and somatic embryogenesis, have been successfully applied to edible orchids such as *Dactylorhiza* and *Eulophia*, providing scalable alternatives to wild harvesting (Pant, 2013). These rapid multiplication techniques can simultaneously support commercial production and conservation objectives by supplying planting material for cultivation as well as conservation by population reinforcement and reintroduction programs (Fay, 2018).

8.3. Metabolic Engineering and Synthetic Production

Metabolic engineering and in vitro callus/cell culture approaches offer effective alternatives for producing valuable orchid-derived compounds without harvesting whole plants, as plant cell and tissue cultures have been demonstrated to function as renewable "bio-factories" for high-value secondary metabolites (Sharma *et al.*, 2020), plant cell cultures as heterologous bio-factories (Wu *et al.*, 2021) and plant tissue culture as a perpetual source for bioactive compounds (Chandran e*t al.*, 2020). These technologies may act as a powerful device for decoupling demand from wild populations.

8.4. Community-Based Management

Community-based management integrates local traditional ecological knowledge with conservation incentives and legal frameworks. Participatory governance, benefit-sharing, and support for small-scale cultivation practice can enhance compliance and foster sustainable utilization (Swarts and Dixon, 2009; Kala, 2005).

9. Synthesis and Future Directions

The decline of edible orchids stems from intertwined biological vulnerabilities and escalating socio-economic pressures. Addressing this challenge requires interdisciplinary approaches that combine conservation biology, ethnobotany, biotechnology, and robust policy frameworks. Future research priorities should include: (i) nutritional profiling of under-utilized edible orchid species, (ii) development of large-scale cultivation and propagation systems, (iii) socio-economic assessments of orchid-based food value chains, and (iv) the integration of traditional knowledge with biotechnology-driven conservation strategies. Additionally, sustained efforts are needed to support long-term population monitoring, metabolomics-driven domestication, improved Red List coverage, and the incorporation of community-based conservation models embedded in global frameworks.

10. Conclusions

Orchids used as food occupy a distinctive yet vulnerable position at the nexus of cultural practice, nutrition, and biodiversity conservation. In the absence of effective intervention, continued reliance on wild harvesting poses a substantial risk of irreversible population declines. Approaches to sustainable utilization— anchored in biotechnological innovation, domestication and cultivation, and supportive policy frameworks—offer a viable pathway to reconcile traditional food uses with the long-term conservation of Orchidaceae.

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