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## EDITED BY

Matteo Balderacchi,  
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## REVIEWED BY

Endang Semiarti,  
Gadjah Mada University, Indonesia  
Brandon Eduardo Gutiérrez Rodríguez,  
Instituto de Ecología (INECOL), Mexico

## \*CORRESPONDENCE

Susanne Masters  
✉ [susanne.masters@naturalis.nl](mailto:susanne.masters@naturalis.nl)

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# Horticultural hybrid development of edible terrestrial orchids for verifiable sustainable trade

Susanne Masters<sup>1,2\*</sup>, Diego Bogarín<sup>1,3</sup>, Juan Viruel<sup>4</sup>,  
Rogier van Vugt<sup>5</sup>, Tinde van Andel<sup>1,2,6</sup>, Hugo J. de Boer<sup>1,7</sup> and  
Barbara Gravendeel<sup>1,8</sup>

<sup>1</sup>Naturalis Biodiversity Center, Leiden, Netherlands, <sup>2</sup>Institute of Biology, Leiden University, Leiden, Netherlands, <sup>3</sup>Lankester Botanical Garden, University of Costa Rica, Cartago, Costa Rica, <sup>4</sup>Royal Botanic Gardens, Kew, United Kingdom, <sup>5</sup>Hortus Botanicus, Leiden University, Leiden, Netherlands, <sup>6</sup>Biosystematics Group, Wageningen University, Wageningen, Netherlands, <sup>7</sup>Natural History Museum, University of Oslo, Oslo, Norway, <sup>8</sup>Radboud Institute for Biological and Environmental Sciences, Nijmegen, Netherlands

**Introduction:** Edible terrestrial orchids are endangered worldwide due to overharvesting and illegal trade. One method to distinguish illegally traded wild-collected orchids from sustainably harvested and legally traded cultivated ones is to artificially create hybrids that do not occur naturally and can be morphologically recognized. Creating artificial orchid hybrids is relatively simple. As a result, thousands of artificial orchid hybrids have already been registered with the Royal Horticultural Society, but predominantly for ornamental purposes. We identified a potential hybrid parental pool for edible orchids from terrestrial species that possess desirable traits from both the grower and consumer perspective.

**Method:** From the pool of candidate species, we evaluated the possibility of crosses producing viable seed based on phylogenetic distance metrics, based on *matK* and *nrITS* sequences of 435 species. Subsequently, we checked the accuracy of our prediction of hybrid compatibility against registered records of hybrids on the International Orchid Register and by experimental production of hybrids.

**Results:** Our results show that phylogenetic distance can indeed be used as a proxy for predicting hybrid compatibility in orchids.

**Discussion:** Potential of creating edible orchid hybrids for sustainable trade has not yet been fully exploited.

## KEYWORDS

CITES, *chikanda*, *salep*, wildlife trade, orchids (Orchidaceae)

## Introduction

Containing approximately 8% of the world's vascular plants, Orchidaceae, the Orchid family, is a notable assemblage of biodiversity (Willis, 2017). Orchids are a natural resource extensively used by humans, and wild harvesting poses the greatest threat to their survival (Nic Lughadha et al., 2020; Wraith and Pickering, 2018). Regional surveys report uses of orchids, including as foods, ornamentals, and medicines, in all continents where they grow (Fonge et al., 2019; Lawler and Slaytor, 1970; Moerman, 2021; Nurfadilah, 2020; Pieroni et al., 2017; Rahamtulla et al., 2020; Schultes, 1990).

Orchids uses are not confined to the regions in which they grow. They are commercially traded across international boundaries (Hinsley et al., 2018). The scale of annual trade for many species of orchid used in traditional medicine, food, and cosmetics is measured in tonnes. For example, in 2013, importer reports recorded by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) of orchids used in Traditional Chinese Medicine included 715 tonnes of *Dendrobium nobile*, 908 tonnes of *Gastrodia elata*,

40 *Bletilla striata*, and 24 *D. eriiflorum* (UNEP-WCMC, 2013). Wild orchids attract higher prices on international markets than they do in domestic markets. While collectors of wild orchids in Nepal for medicinal trade reported being paid up to \$2.5 per kilo, the international trade price for *D. eriiflorum* was \$1300 in 2008–2009 (Subedi et al., 2013). At least 35 non-native orchid species, most likely sourced through import, are traded in Europe for cosmetics, food, and medicinal products (Brinckmann, 2014). Tubers of terrestrial orchids consumed as *chikanda* in Zambia are wild-collected, not only within Zambia but also from Angola, the Democratic Republic of the Congo, Malawi, Mozambique, and significant volumes from Tanzania (Veldman et al., 2017).

A total of 84% of the plant species listed by CITES are orchids (Willis, 2017). Global orchid trade is mostly in cultivated plants, however harvesting wild orchids for international trade is a significant conservation concern. Moreover, some species traded as cultivated may, in fact, be wild-collected, as suspected in the export of *Dendrobium chrysotoxum* from Laos (IUCN, 2017). Traceability is a suggested means of limiting illegal wild-collected orchid trade via authenticating legal trade, in which cultivated or sustainably harvested CITES-listed species are tracked on entry, progress, and exit through a regulated system (Lehr and Jaramillo, 2017).

Wild-collected orchids can be identified by looking at physical features such as presence of algae and lichens on leaves or bark held by roots, or damage caused by removing the plant from its growing location (CITES Secretariat, 2002). However, these indicators of wild origins can be removed by growing wild collected plants under cultivation for some time and are not present in dried or otherwise processed orchids traded for food, medicine, and cosmetics. CITES provides guides using morphological features to identify groups of plants in trade for Traditional Asian Medicine (Arcery and Briggs, 2006; Pendry et al., 2004; Variawa et al., 2023). There is no guide for orchid species in trade, for reasons that include the difficulty of identifying non-flowering orchids and the immense number of species in trade.

Forensic science methods, deployed in criminal justice systems to identify people who are perpetrators or victims of crime, have been considered for application in detecting wildlife trade. Stable isotope analysis is a means by which living conditions and geographical origin can be distinguished. In conjunction with other approaches to identification, such as wood anatomy and genetics, stable isotope analysis is being used to identify illegally harvested timber (Dormontt et al., 2015) and salep orchids (Bilgin et al., 2023). However, stable isotope analysis alone has not been adopted for use as a sole identification tool. DNA metabarcoding can be used to detect traces of orchids in processed products (de Boer et al., 2017), but this method alone cannot distinguish whether a plant is wild-collected or cultivated. Creating hybrids to meet market demand has the advantage that these are ultimately intended for commercial purposes rather than for reintroduction of endangered species into natural habitats.

In the case of *salep*, a product sold as tubers or powder used in the preparation of a drink and ice cream, at least 35 species of orchids from different genera that grow in the Mediterranean region, of which *Anacamptis*, *Dactylorhiza* and *Orchis* are most well-known, may be included in the mixture (Ghorbani et al., 2016; Kasperek and Grimm, 1999; Kreziou et al., 2016). *Salep* is currently illegally traded in contravention of CITES requirements for permits and for international orchid trade to comply with national legislation (Masters et al., 2022).

As *salep* is already traded as a blended product, not as a single species of orchid, an artificial hybrid may both satisfy consumer requirements and be identifiable as having cultivated origins at CITES control points. Creating artificial hybrids is relatively simple as many orchids are prone to spontaneous hybridization in the wild (Cozzolino et al., 2006). As a result, 192,749 artificial orchid hybrids have already been registered with the Royal Horticultural Society but these were predominantly recorded for ornamental purposes (Royal Horticultural Society, 2024).

Alternative orchid species to supply the trade in edible terrestrial orchids for *chikanda* and *salep* have previously been sought. The German botanist Georg Rumphius, who was active in Indonesia during the 17th century, evaluated the tropical orchids he found, considering the properties of orchids used for *salep* in the Mediterranean region and Europe. He described eating the root of *Habenaria rumphii*, which he called *Orchis Amboinica major*, *radice Raphanoide*: “The taste comes close to that of Satyrium, not bitter, but cloying, and a little sharp,” and “...crumbles when chewed, almost melting in one’s mouth, and is considered to have the same effects as our European Satyria” (Beekman, 2003). Despite surveys for taste and texture as described above, actual *salep* cultivars have not yet been developed. In contrast to *Erycina pusilla*, an emerging orchid model organism because it is fast-growing (Dirks-Mulder et al., 2017), edible orchids take several years to progress from pollination to mature plants producing harvestable tubers (Pan et al., 2012). For expediency and economical use of resources, it is worth focusing hybridisation of orchids for sustainable production of edible products on genera and species that are most likely to have edible parts. Lack of cultivar development is likely caused by the relatively long developmental time of most *salep* orchids.

In this study, we sought to identify a potential hybrid parent pool for orchids that can be cultivated for *salep* from orchids that have edible tubers and possess desirable traits from both the grower and the consumer perspective to satisfy the demand for trade. Such traits include a high glucomannan content in tubers and individual plants that produce more than one new tuber annually. From the pool of candidates found we evaluated the possibility of crosses producing viable seed based on phylogenetic distance metrics. Using DNA sequence data, the distance between species can be represented and used to predict viability of interspecific and intergeneric crosses (Viruel et al., 2021). Subsequently, we checked the accuracy of this prediction of hybrid compatibility against registered records of hybrids on the International Orchid Register (Royal Horticultural Society, 2024), and results from hybrid crosses that we attempted to produce ourselves. We focused on crosses between species that do not naturally flower in close proximity in the wild due to geographic, pollinator, or temporal separation barriers, following the concept of reproductive isolation (Bateman, 2012; Scopece et al., 2007). Conservation action is propelled by legislation, economy, and technology. Here, we address the technical feasibility of a proposed solution to unsustainable collection of wild orchids for *salep*.

## Materials and methods

### Selection of edible terrestrial orchids

We inventoried ‘Medicinal Orchids of Asia and Orchids as Aphrodisiac, Medicine, or Food’ (Teoh, 2019; Teoh, 2016), and

selected orchids of which the tubers, or other parts such as pseudobulbs, were described as edible and having uses or properties that were similar to *salep*, for example, to soothe coughs. This was supplemented by references focused on smaller regions or specific countries (Challe and Price, 2009; Fuchs, 1542; Ghorbani et al., 2014; Gras et al., 2017; Hamisy, 2010; Kasperek and Grimm, 1999; Kasulo et al., 2009; Kreziou et al., 2016; Lee et al., 2008; Low, 1987; Moerman, 2021; Tekinşen and Güner, 2010; Upretry et al., 2016; Veldman et al., 2017, 2018). Reference source, name in reference, and use were recorded alongside currently accepted name and, when documented, chromosome number (Cozzolino et al., 2006; Leitch et al., 2019; POWO, 2024; Rice et al., 2015). This resulted in a list of 203 taxa (See Supplementary Data Appendix I).

### Hybridisation records

For each orchid selected, we checked records of cross-compatibility by searching parentage records, as pollen parent and seed parent, against all other orchids within our selection in The International Orchid Register (Royal Horticultural Society, 2024). This was used to generate a matrix of known hybrids (Supplementary Data Appendix II).

### Phylogenetic framework and heatmap analyses

Multispecies sequence alignments were made with DNA sequences of nrITS and matK markers generated by Jin et al. (2017) downloaded from NCBI GenBank, and aligned using MAFFT (Katoh and Standley, 2013). We followed the methods described in Viruel et al. (2021) to reconstruct an ultrametric phylogenetic tree and calculate pairwise phylogenetic distances. Phylogenetic trees were reconstructed using IQ-TREE applying the GTR + G model of nucleotide evolution and 1,000 replicates of bootstrapping searches (Nguyen et al., 2015). An ultrametric tree was produced using treePL by assigning the value of ‘1.0’ to the root of the tree (Smith and O’Meara, 2012). The ultrametric tree was used to calculate pairwise phylogenetic distances using the patristic method as implemented in the function `distRoot` from the R package `adephylo` (Jombart et al., 2010; Pavoine et al., 2008). Species from Cranichideae and Diurideae were used as outgroups. Both Cranichideae and Diurideae are predominantly terrestrial tribes of orchids, of which no species are used as *salep* (Salazar et al., 2003; Zhang et al., 2023). Phylogenetic trees were visualized with iTOL v6 (Letunic and Bork, 2024). For the heat map analyses, a total of 17 intergeneric hybrids registered with the Royal Horticultural Society (Table 1), were scored for whether both, or one of the two parental species were present in the alignments. If no parental species was present in the dataset, a score of 0 was assigned, if one of the parents was sequenced a score of 1 was given, and if both parental species were sequenced a 2 was assigned. The consensus tree was visualized using the *ape* package (Paradis and Schliep, 2019) and the *ggtree* package (Yu et al., 2017), with the heatmap generated by the *gheatmap* function in R (R Core Team, 2023) within RStudio (RStudio Team, 2022). This approach included an integrated heatmap representing the relationships between nothogenera and

TABLE 1 Intergeneric hybrids for which the potential of creating sustainable *salep* was assessed.

Intergeneric hybrid	Mother plant genus	Father plant genus
<i>Anamantoglossum</i>	<i>Anacamptis</i>	<i>Himantoglossum</i>
<i>Cynorkaria</i>	<i>Cynorkis</i>	<i>Habenaria</i>
<i>Dactylocamptis</i>	<i>Dactylorhiza</i>	<i>Anacamptis</i>
<i>Dactylodenia</i>	<i>Dactylorhiza</i>	<i>Gymnadenia</i>
<i>Gymnaplatanthera</i>	<i>Gymnadenia</i>	<i>Platanthera</i>
<i>Neotinacamptis</i>	<i>Neotinea</i>	<i>Anacamptis</i>
<i>Ophramptis</i>	<i>Ophrys</i>	<i>Anacamptis</i>
<i>Orchimantoglossum</i>	<i>Orchis</i>	<i>Himantoglossum</i>
<i>Orchinea</i>	<i>Orchis</i>	<i>Neotinea</i>
<i>Orchiserapias</i>	<i>Orchis</i>	<i>Serapias</i>
<i>Pectabenaria</i>	<i>Pecteilis</i>	<i>Habenaria</i>
<i>Pseudadenia</i>	<i>Pseudorchis</i>	<i>Gymnadenia</i>
<i>Pseudanthera</i>	<i>Pseudorchis</i>	<i>Platanthera</i>
<i>Seraphrys</i>	<i>Serapias</i>	<i>Ophrys</i>
<i>Serapicamptis</i>	<i>Serapias</i>	<i>Anacamptis</i>
<i>Serapirhiza</i>	<i>Serapias</i>	<i>Dactylorhiza</i>
<i>Spilorhiza</i>	<i>Spiranthes</i>	<i>Dactylorhiza</i>

their parental species as tree tip labels. The same method was employed to visualize a heatmap of patristic distances derived from the phylogenetic analyses.

### Experimental hybrid crossing

Hybrid crossing attempts were conducted in the Netherlands in collaboration with horticultural hobbyist growers from the Vereniging Orchideeën Vermeerdering (VOV) Working Group on *salep*. Pollinia were removed from the paternal parent using tweezers and placed on the stigma of the maternal parent, whose pollinia had also been removed and discarded. Pollinia packages from 1 to 4 fresh flowers from 6 father plants of a total of 4 species were hand-collected and transferred to the stigma of flowers on 6 mother plants in 2020 and 2023 (Table 2). This resulted in the formation of 6 sets of fruits in 2020, and 2 sets of fruits in 2023 (see Table 2).

Choice of parentage of the hybrid was based on having both parent plants verifiably cultivated and legally available for use, and having desirable tuber characteristics such as fragrant tubers (*Dactylorhiza maculata* subsp. *fuchsii*).

In 2020, for two crosses, we used *Dactylorhiza* × *foliorella*, a hybrid that is readily available in cultivation, as the maternal and paternal parent, respectively. This hybrid cannot occur spontaneously in the wild due to geographical separation of its parental species: *Dactylorhiza foliosa* is endemic to Madeira, and *D. purpurella* is native to Denmark, Great Britain, the Netherlands, and Norway (POWO, 2024). We crossed *D. × foliorella* with *Dactylorhiza fuchsii* as the maternal and paternal parent, respectively, one of the orchids used in *salep* that has particularly fragrant tubers and the characteristic palmate tubers of *Dactylorhiza*.

TABLE 2 Hybrid crosses attempted and their success rate.

	Year of cross	Maternal parent	Paternal parent	Hybrid reached maturity?
Plant 1	2020	<i>Serapias cordigera</i>	<i>Dactylorhiza maculata</i> subsp. <i>fuchsii</i>	no
Plant 2	2020	<i>Dactylorhiza maculata</i> subsp. <i>fuchsii</i>	<i>Dactylorhiza</i> × <i>foliorella</i>	yes
Plant 3	2020	<i>Dactylorhiza maculata</i> subsp. <i>fuchsii</i>	<i>Serapias cordigera</i>	no
Plant 4	2020	<i>Dactylorhiza foliorella</i>	<i>Dactylorhiza maculata</i> subsp. <i>fuchsii</i>	yes
Plant 5	2023	<i>Serapias lingua</i>	<i>Anacamptis morio</i>	not yet mature
Plant 6	2023	<i>Serapias strictiflora</i>	<i>Anacamptis morio</i>	not yet mature

*Serapias* is a genus of orchids with known capacity to produce more than one new tuber per year, individual plants have 2 to 5 tubers (Delforge, 2005). Additional crosses were attempted between *Serapias cordigera* and *Dactylorhiza fuchsii*. Tuber production by *Anacamptis morio* has been documented in horticulture (Cribb and Bailes, 1989). In 2023, we crossed *A. morio* with two species of *Serapias*: *S. strictiflora* and *S. lingua*. *A. morio* tolerates a range of growth conditions from dry to damp and acidic to alkaline soils, and is found from North Africa to the boreal (Plant Atlas 2020, 2024; POWO, 2024). *S. strictiflora* and *S. lingua* form more than one new tuber, and have not been reported as being traded for *salep* although other species of this genus are traded for *salep* (Masters et al., 2022; Veltman et al., 2023).

### Hybrid cultivation and validation

Pod ripening was assessed visually. Nearly ripe (still closed) pods were sent to Phytisia SA, an orchid growing company, in 2020 and members of the Vereniging Orchideeën Vermeerdering in 2023. Seeds were sown on nutrient medium. DNA was extracted from fresh leaves of both parental plants and hybrids following the CTAB protocol of Doyle and Doyle (1990) with overnight incubation in CTAB buffer for 1–3 days. PCR on a Westburg T3 Biometra thermocycler was used to amplify plastid trnL-trnF with a and b, c and d, e and f primers (Taberlet et al., 1991) and nrITS1 and nrITS2 DNA barcoding markers using 17SE and 26SE primers (Sun et al., 1994). NucleoSpin Gel and PCR clean-up kits (Sigma-Aldrich) were used to purify all resulting amplicons. A total of 5 microliter of PCR product was loaded on an 1.5% agarose gel, visualized by staining with Ethidium bromide, and sized by visual comparison with a standard size ladder. PCR products of the correct size were sent to be Sanger sequenced on an ABI 3730 XL (ThermoFisher) at Radboudumc Technology Center Genomics in Nijmegen. (See Supplementary Data Appendix III gel electrophoresis images of hybrid amplicons). The DNA sequences generated for hybrid validation were not included in the phylogenetic framework.

## Results

### Phylogenetic analysis and heatmap

Pairwise phylogenetic distances were calculated (see Supplementary Data Appendix IV) and a consensus phylogenetic tree of orchids with known or potential use as edible was generated (see Supplementary Data Appendix V). Inter-generic hybrids registered on the International Orchid Register were combined with the phylogenetic tree to generate a heatmap of crosses between species, and crosses

between genera for registered inter-generic crosses. The combined phylogenetic tree and heatmap generated is depicted in Figure 1.

The combined phylogenetic tree and heat map show that phylogenetic distance can be used as a proxy for predicting hybrid compatibility. Aggregation is visible and already registered, or potential hybrids are not spread all over the phylogeny but clearly confined to specific clades of closely related species with low phylogenetic distances. Intergeneric compatibility seems to be restricted to the genera *Anacamptis*, *Cynorkis*, *Dactylorhiza*, *Gymnadenia*, *Habenaria*, *Himantoglossum*, *Neotinea*, *Orchis*, *Ophrys*, *Pecteilis*, *Platanthera*, *Pseudorchis*, and *Serapias*. There are several intergeneric hybrids with underexploited potential. *Amantoglossum* (*Anacamptis* × *Himantoglossum*) and *Orchimantoglossum* (*Himantoglossum* × *Orchis*) may be particularly desirable for cultivation because *Himantoglossum* is a genus known for large tubers offering the possibility of high yield. There was no *Serapirhiza* (*Serapias* × *Dactylorhiza*) hybrid registered for the species within our phylogenetic tree, however the two genera are compatible. So, attempting to hybridize species of *Dactylorhiza* and *Serapias* known to be traded as *salep* is likely to succeed.

### New experimental hybrid

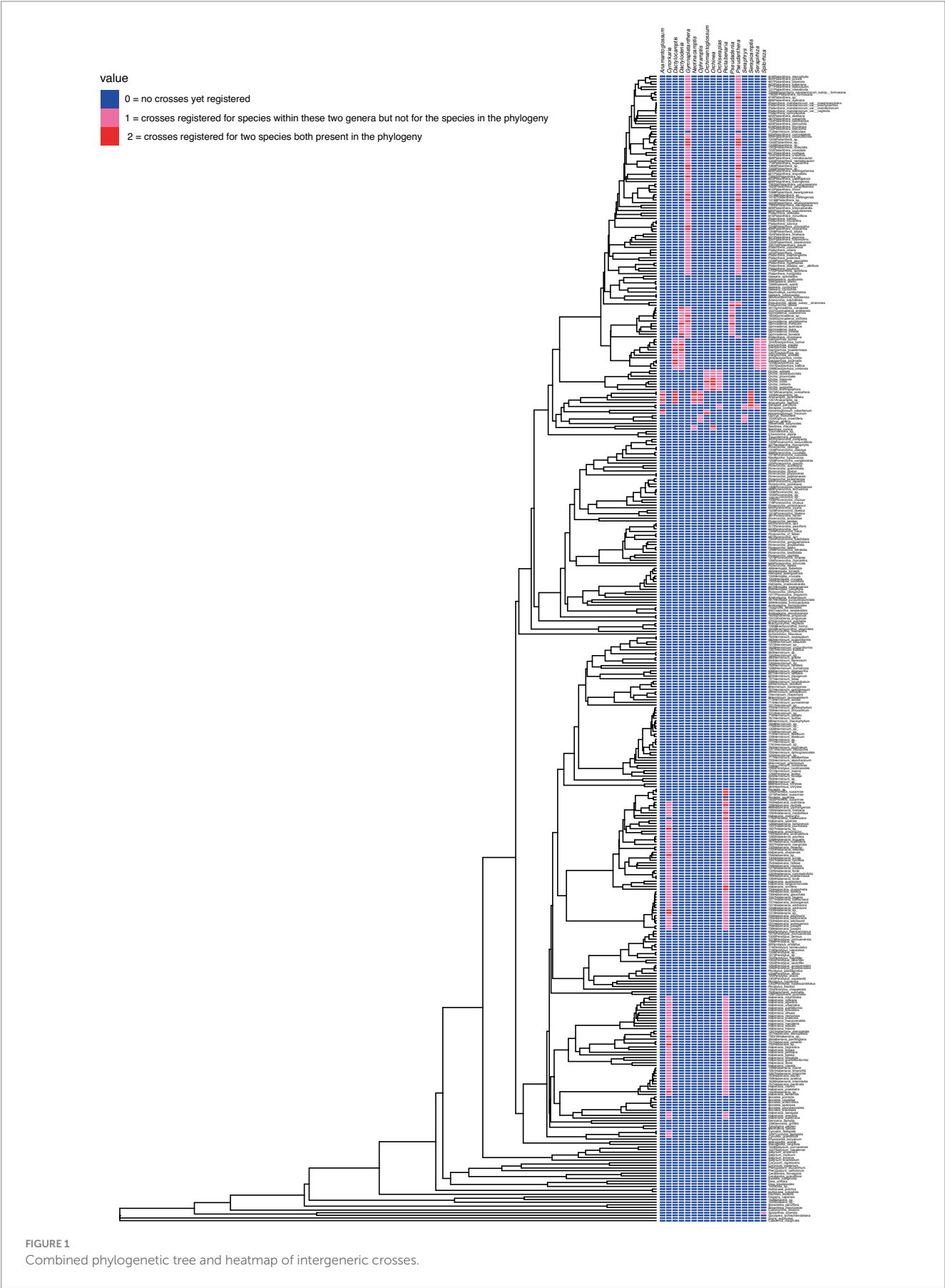
Validation via DNA barcoding rejected successful hybridisation for 5 out of the 6 crosses attempted but confirmed that a hybrid was successfully created between *Dactylorhiza* × *foliorella* and *D. maculata* subsp. *fuchsia*, i.e., the seeds harvested from the pods were not the result of self-pollination. This newly created hybrid was registered with the International Orchid Register (Royal Horticultural Society, 2024) under P.34144. It is also documented via botanical illustrations and photographs (see Figure 2). Botanical illustration of hybrid ‘Sarah’ and Figure 3 photograph of flowers of hybrid ‘Sarah’. A description of this newly created hybrid and the three species of its parentage, highlighting morphological differences between the hybrid and its parents, was created (Supplementary Data Appendix VI).

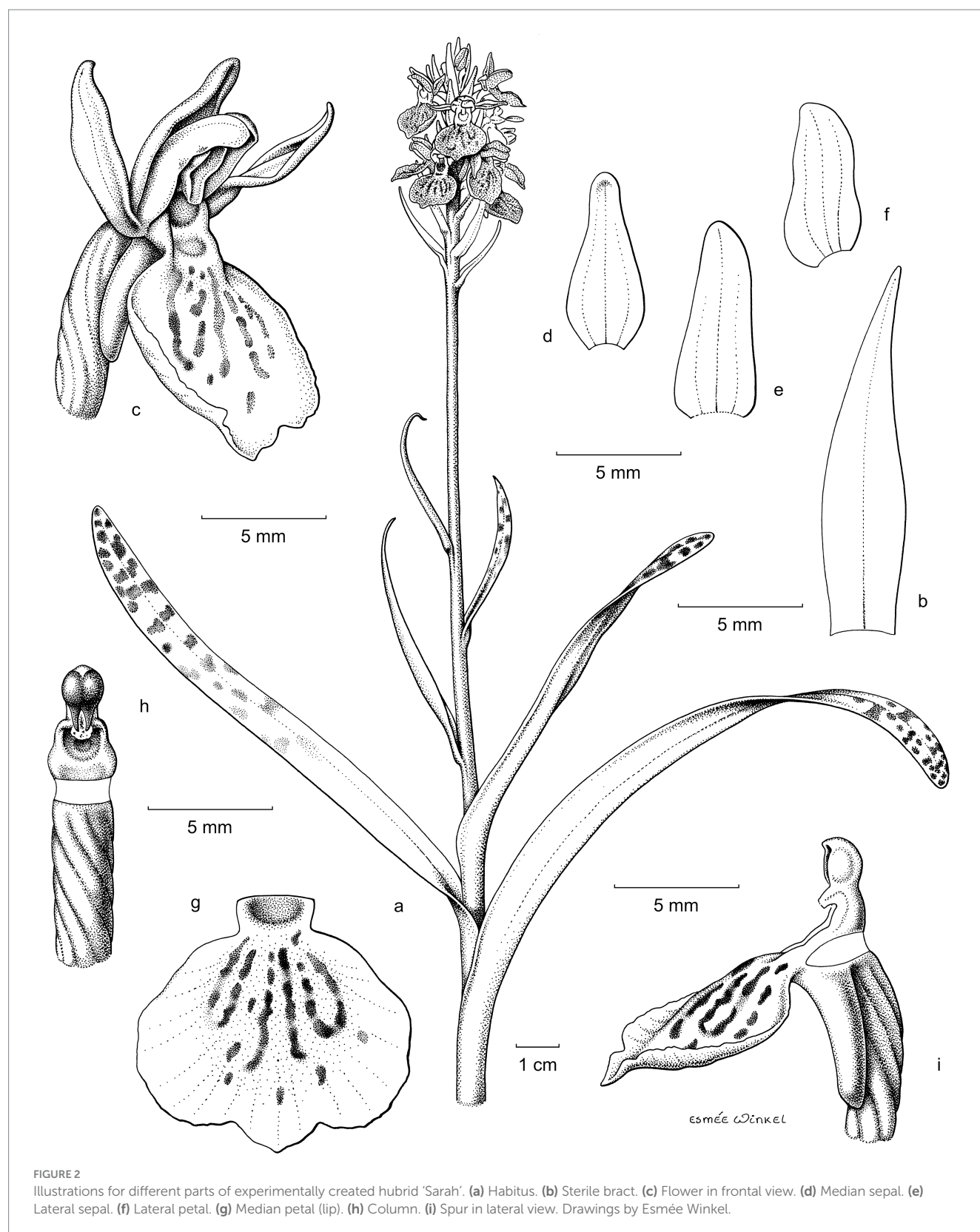
## Discussion

### Phylogenetic distance metrics help predict viable crosses

Known and likely intergeneric hybrids clustered within close proximity on the phylogenetic tree. This confirms that intergeneric hybrids can occur but are more likely between closely related genera. Our integrated heatmap and phylogenetic tree show the territory of known hybrids and highlight species with edible tubers that are likely







to successfully hybridize. This predictive power is useful for focusing hybridisation efforts where they are most likely to succeed. This is particularly important when the time scale for hybridisation is both constrained by seasonal flower production, and long due to the length of time from flowering to seed capsule formation, and then germination, followed by growth to maturity.

## Novel hybrid

Our successful hybridisation of *D. x foliorella* crossed with *Dactylorhiza maculata* subsp. *fuchsii*, combined a species known to have particularly fragrant tubers with a hybrid containing the germplasm of an endemic species not currently in *salep* trade. This



FIGURE 3  
Inflorescence of experimentally created hybrid 'Sarah'. Photograph by Rogier van Vugt.



FIGURE 4  
Peloric form of *Anacamptis morio* subspecies *syriaca*. Photograph by Rogier van Vugt.

created a hybrid with distinct morphology, that cannot occur as a wild plant and is also predisposed to meeting requirements for use as *salep*.

To prevent the risk that our hybrid, or others, out-compete or back cross with wild species, additional steps need to be taken, such as developing infertile plants with peloric flowers, in which the inner two floral whorls with stamen and stigma are replaced by tepals, so-called non-perianth transitions (Bateman and Rudall, 2006). Such sterile 'double flowers' have been developed for many horticultural varieties, for instance, rose, peony, and carnation (Meyerowitz et al., 1989), and are sporadically found in wild orchids (Figure 4). A potential additional benefit from sterile flowers is that resources may be directed to tuber growth instead of seed production.

Our hybridisation experiment was restricted to using orchids that were already in cultivation with known provenance, i.e., they were not wild-collected. The next step is to expand hybridisation to a wider range of parents by collecting pollinia from wild orchids. This would provide greater scope for integrating more desirable traits, such as selecting parents on the basis of their volatile chemical profile, vigorous above ground growth, or proliferation of their underground tubers (Şavşatlı, 2023).

## Hybrids as tools of conservation and items for trade

Both wild and artificial plant hybrids have demonstrated utility in conservation and sustainable trade. For example, in conservation of genetic diversity, Butternut (*Juglans cinerea*) has declined across its

native range in eastern North America due to butternut canker (*Ophiognomonia clavignenti-juglandacaerum*), a fungal pathogen. Buartnut (*J. x bixbyi*) is a naturally occurring hybrid with introduced Japanese walnut (*J. ailantifolia*), which tolerates this infection. A framework for conserving butternut proposes backcrossing buartnut with butternut to enhance butternut canker-resistance while retaining native germplasm (Pike et al., 2021). An example of sustainable trade is Tahitian vanilla (*Vanilla x tahitensis*), an edible orchid hybrid with high value, noted for its floral aroma, due to the anisyl alcohol content of its seeds. Its parents are *V. planifolia* and *V. odorata* (Lubinsky et al., 2008; Nielsen-Massey, 2024; Pérez-Silva et al., 2021).

Previously, attempts were undertaken to make *salep* trade more sustainable by creating synthetic products packaged in sachets made with corn starch and artificial sweeteners to thicken milk and give it a smooth, creamy texture just like real *salep*. Such artificial *salep* products are much cheaper to produce than collecting, drying, and grinding real orchid tubers into powder and, therefore, also much more affordable. It was hoped that artificial *salep* would reduce the pressure on wild-collected orchids because of its low costs for both producers and consumers. This did not happen, however, because of rising global demand for authentic food products. We developed a method to make *salep* trade more sustainable by using real orchids. Although rather than collecting them from the wild, we propose to create and grow artificially made sterile hybrids.

As previously noted, the higher cost of orchid tubers from cultivated plants compared to wild collected plants is a barrier (Masters et al., 2022). Analysis of economic viability is a stage for

subsequent investigation. Using tissue cultivation for propagation could reduce the cost of purchasing juvenile plants for cultivation. Similarly hybrids producing 2 or more new tubers would sustain replanting from cultivated stock and having tubers to sell. To outcompete harvesting of wild orchids, additional costs of growing such hybrids and harvesting the tubers should be kept at a minimum as well. This could, for instance, be done by combining outdoor cultivation with other crops in mixed farming where local wild orchid populations have already gone extinct.

Focusing on technical feasibility of an identifiably cultivated orchid, in this case via hybridisation, was the purpose of this research. However, we recognize that collecting tubers from wild orchids for *salep* trade is a component of rural income (Ertuğ, 2000). Cultivation schemes can ensure that income received benefits community members and is not only accessible to landowners. An example of returning benefits to the community from formerly wild collected orchids is the cultivation of *Cymbidium* orchids supported by the government of Bhutan (Masters, 2015). One of the resolutions passed at the International Orchid Conservation Congress 2016 was that propagation of threatened orchids by small and local enterprises should be supported for sustainable production (Gale et al., 2018).

## Conclusion

There is viable opportunity to develop hybrid orchids that can meet consumer demand for *salep* from verifiably cultivated supply. On a global scale, there is value in supporting wildlife trade to be legitimate as legal wildlife trade has an average worth of \$220 billion per annum. In contrast, from 1997 to 2016, illegal wildlife trade was estimated to be worth \$7–23 billion per annum (Andersson et al., 2021). An identifiable hybrid orchid suitable for *salep* offers a pathway from illegal trade in wild-harvested orchids to verifiably cultivated tubers.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

SM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review

& editing. DB: Formal analysis, Software, Visualization, Writing – review & editing. JV: Conceptualization, Software, Visualization, Writing – review & editing. RV: Methodology, Validation, Writing – review & editing. TA: Conceptualization, Formal analysis, Supervision, Writing – original draft, Writing – review & editing. HB: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. BG: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

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## Conflict of interest

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## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2025.1526533/full#supplementary-material>

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