Notes on *Allium* section *Rhizirideum* (Amaryllidaceae) in South Korea and northeastern China: with a new species from Ulleungdo Island

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Abstract

*Allium* section *Rhizirideum* is reviewed for South Korea and neighboring northeastern China based on critical observation of wild populations and herbarium materials. Species delimitations are re-evaluated on the basis of morphological and somatic chromosome numbers, resulting in the recognition of five species. *Allium dumebuchum* from Ulleungdo Island, South Korea, is described as a new species. This species is most similar to *A. senescens* due to its habits, but is clearly distinguished particularly by its rhomboid scapes in cross-section, light purple perianth color, entire and narrowly triangular inner filaments, and flowering season from late September. One previously recognized species is placed into synonymy: *A. pseudosenescens* (under *A. senescens*). Photographs and a key to species of *Allium* section *Rhizirideum* in South Korea and northeastern China are provided in addition to information on nomenclatural types, synonymies, chromosome numbers, distribution, and specimens examined.

Keywords

Chromosome number, DNA barcode, distribution, morphology, new species, synonym, taxonomy
Introduction

With over 900 species (Seregin et al. 2015), *Allium* L. is one of the largest genera in the Amaryllidaceae (Friesen et al. 2006; Fritsch et al. 2010; Li et al. 2010). It is characterized by bulbs enclosed in membranous to fibrous tunics, free or almost free tepals, and often a subgynobasic style (Friesen et al. 2006). Most taxa produce remarkable amounts of cysteine sulfoxides causing the well-known characteristic odor and taste (Friesen et al. 2006). *Allium* is distributed naturally in the northern hemisphere and in South Africa, mostly in regions with dry seasons (De Sarker et al. 1997; Friesen et al. 2006; Nguyen et al. 2008; Neshati and Fritsch 2009). The classification of *Allium* by Friesen et al. (2006) based on molecular phylogenetic analyses includes 15 subgenera and 56 sections. About 23 taxa, excluding cultivated species, are known from the Korean peninsula and neighboring northeastern China (Choi and Oh 2011; Shukherdorj et al. 2018; Choi et al. 2019).

*Allium* section *Rhizirideum* G.Don ex W.D.J.Koch is the typical section of subgenus *Rhizirideum* (G.Don ex W.D.J.Koch) Wendelbo and characterized by having bulbs enclosed in membranous tunics and attached to horizontal rhizomes, a leaf shape ranging from hemicylindrical to plain, and a flower color from white to purple (Sinitsyna et al. 2016). Section *Rhizirideum* consists of 24 species and is part of the third of three main evolutionary lines of *Allium* (Fritsch 2001; Fritsch and Friesen 2002; Friesen et al. 2006; Li et al. 2010; Choi et al. 2012b). The distribution area of section *Rhizirideum* reaches from Europe to East Asia (Sinitsyna et al. 2016). There is a distinct narrowing of the distribution area east of the Ural Mountains approximately along 70° eastern longitude, and most species of section *Rhizirideum* are distributed in temperate Asia (Sinitsyna et al. 2016). The center of species diversity is situated in the mountain steppes of South Siberia and Mongolia (Sinitsyna et al. 2016). The species of section *Rhizirideum* share a basic chromosome number of $x = 8$, and four ploidy levels were found: di-, tetra-, penta-, and hexaploids (Sinitsyna et al. 2016).

The taxonomy of the section is complicated because of morphological diversity and hybridization involving polyploidy (Friesen 1988, 1992; Kamelin 2004). Additionally, the nomenclature is confusing, which may be explained by similar morphology of some species and disappearance of many morphological characters in the voucher specimens in herbaria (Sinitsyna et al. 2016; Sinitsyna and Friesen 2018). Recently, Sinitsyna et al. (2016) and Sinitsyna and Friesen (2018) investigated the phylogenetic relationships in the section *Rhizirideum* based on molecular markers, and organized nomenclature, distribution maps, and identification key for all known species of the section. Although there is general agreement regarding the *Allium* species of section *Rhizirideum* in South Korea and its neighboring northeastern China (Choi and Oh 2011) studies on materials from these regions are still limited.

Here, we have combined morphological, cytological, and molecular characters to address the taxonomy of *Allium* section *Rhizirideum*, and organized nomenclature, distribution maps, and identification key for species in South Korea and north-eastern China. The goals of this study are: 1) to review and expand the current knowledge on
Allium section Rhizirideum in South Korea and northeastern China

Materials and methods

Morphological characters

This revision is based on the use of living and herbarium material, including photographs of type specimens, from the following herbaria: B, CBU, KB, KH, KWNNU, LE, LINN, PE (abbreviations are according to Thiers 2020+), and the herbarium of Changwon National University (CWNNU). Field surveys were carried out mainly in South Korea and north-eastern China from July 2014 to October 2020. We also observed populations from Far Eastern Russia and Mongolia especially for Allium spirale Willd. and A. senescens L. Materials preserved in 70% ethanol were used especially for observation and measurement of floral parts, cross-sections of leaf and scape. Segments from the middle third of the leaf blade and scape were stained with 2% aceto carmin for observation of the cross-section. Measurements were based on at least 30 samples for quantitative characters.

Principal component analysis

To analyze floral morphology known as a key character to distinguish Allium species (Choi and Oh 2010; Choi and Oh 2011), principal components analysis (PCA) was performed based on 14 characters: flower number per inflorescence, inflorescence length, inflorescence width, pedicel length, inner tepal length, inner tepal width, outer tepal length, outer tepal width, inner filament length, inner filament width, outer filament length, anther length, anther width, and pistil length. The principal components analysis used the {ggfortify} and {ggplot2} packages of the R-project (Tang et al. 2016; Wickham 2016; R Core Team 2020). The specimens used for principal components analysis were indicated with an asterisk (*) in specimens examined for each species.

Somatic chromosome numbers

Root tips were pre-treated in distilled water on ice for 24 h in total darkness at 4 °C and then fixed in Carnoy’s fluid (3 parts absolute ethanol: 1 part glacial acetic acid, v/v) overnight at 4 °C. The root tips were macerated in 1M hydrochloric acid at 60 °C for 3–5 min. After washing 3–5 times to eliminate residual hydrochloric acid and staining
with feulgen for 5 min, the material was squashed for observation in 2% aceto carmin. Observations and photographing of chromosome micrographs were made using an Olympus BX43 (Tokyo, Japan).

DNA barcoding

In this study, we investigated the application of concatenated cpDNA regions of *ndhF-trnF*, *trnH-psbA*, *psbD-trnT*, and *psbJ-petA* in barcoding analyses of *Allium* section *Rhizirideum* and related taxa (Table 1). In order to analyze the relationship among the species using these four cpDNA regions, we extracted each cpDNA region from complete chloroplast genome sequences stored in NCBI GenBank (https://www.ncbi.nlm.nih.gov/; Fig. 6). The species in subgen. *Butomissa* were selected as outgroup referred from wide phylogenetic study of *Allium* (Li et al. 2010). Detailed information on sample collection, voucher specimens and Genbank accession numbers of each sample is provided in Table 2.

Total genomic DNA was extracted from silica gel-dried leaf materials using the DNeasy Plant Mini Kit (Qiagen, Seoul, South Korea). We conducted PCR with a ProFlex 96-Well PCR System (Applied Biosystems, Foster City, CA, USA). Each reaction mixture contained AccuPower PCR PreMix (Bioneer, Daejeon, South Korea), ca. 10 ng (1μL) of genomic DNA, and 100 pM of primers in a total volume of 20 μL. Conditions included an initial denaturation at 94 °C for 5 min, followed by 30 amplification cycles comprising 94 °C for 1 min, 54 °C for 1 min, and 72 °C for 1 min, with a final extension at 72 °C for 7 min. After the PCR products were visualized on 2% agarose gels, they were treated with a MG PCR Purification kit (MGmed), and sequenced with the ABI 3730xl Analyzer, using the ABI BigDye Terminator v3.1 Cycle Sequencing Kits (Applied Biosystems, Foster City, CA, USA). The obtained sequences were manually determined and aligned by using MAFFT with Geneious Prime 2019.2.3 (Biomatters Ltd., Auckland, NZ). The DNA sequences generated in this study have been deposited in GenBank (Table 2).

The phylogenetic analyses were conducted using Maximum Likelihood (ML) by using W-IQ-TREE (Trifinopoulos et al. 2016), based on user-friendly web servers for IQ-TREE (Nguyen et al. 2015). The concatenated sequence dataset was tested to find the best-fit model by using W-IQ-TREE with the Akaike criterion and new model selection procedures. TIM+R3+F were confirmed as best-fit models for the sequences. Maximum likelihood analysis was performed with default settings in W-IQ-TREE (Fig. 6).

| Fragment | Marker  | Sequence 5' → 3' | Reference               |
|----------|--------|------------------|-------------------------|
| ndhF-trnF | ndhF   | ATGCCYGAAAGTGGATAGG | Shaw et al. (2007)      |
|          | TabE   | GGTTCAGGTCCTCTATCCC | Taberlet et al. (1991)  |
| trnH-psbA | trnH    | CGGCATGTTGGAATTCAATCC | Tate and Simpson (2003) |
|          | psbA   | GTTATGCAATGATAGTCATGC | Sang et al. (1997)      |
| psbD-trnT | psbD   | CTTCTGATTTAAGTTGCAATC | Shaw et al. (2007)      |
|          | trnT    | GCTCTTTTTAATGCTTGGTAG | Shaw et al. (2007)      |
| psbJ-petA | psbJ   | ATAGGACTGTARCYGTTATT | Shaw et al. (2007)      |
|          | petA   | AACARTYYGARAAGTGGTCAATT |                       |
Table 2. List of *Allium* species sequenced in this study.

| Taxon       | Locality                             | Voucher information           | GenBank number           |
|-------------|--------------------------------------|-------------------------------|--------------------------|
|             |                                      |                               |                          |
| *A. angulosum* | Kazakhstan: Burlinsky, Zharsuat      | H.J.Choi 200923               | MW478175 MW478211 MW478247 MW478283 |
| *A. austrosibiricum* | Mongolia: khovd, Munkhdairkhan, Khuren khesuu | H.J.Choi 160730-001           | MW478174 MW478210 MW478246 MW478282 |
| *A. danubium* | South Korea: Gyeongbuk, Uleungdo, Nari | H.J.Choi 190917-01           | MW478172 MW478208 MW478244 MW478280 |
| *A. minus*   | South Korea: Gyeonggi, Yangju, Jangheung | H.J.Choi 151006-01           | MW478170 MW478206 MW478242 MW478278 |
| *A. prostratum* | Mongolia: Ulanbaatar, Uvor Gunt davaa | H.J.Choi 140708              | MW478168 MW478204 MW478240 MW478276 |
| *A. senescens* | Mongolia: Govi-Altai                 | H.J.Choi 160811               | MW478167 MW478203 MW478239 MW478275 |
| *A. spirale*  | South Korea: Gyeongbuk, Uleungdo, Nari | H.J.Choi 190917-02           | MW478171 MW478207 MW478243 MW478279 |
|             | Russia: Primorskiy kray, Terneysky   | H.J.Choi et al. 140826-01     | MW478157 MW478193 MW478229 MW478265 |
| *A. tuberosum* | China: Jilin, Erdaobaihe             | H.J.Choi 190908-001-01-01     | MW478141 MW478177 MW478213 MW478249 |
| *A. thunbergii* | South Korea: Gangwon, Gangneung      | H.J.Choi 190919-001-01-02     | MW478150 MW478176 MW478212 MW478248 |
Results

Morphological characters

Our data indicate that several morphological characters are of taxonomic utility in *Allium* section *Rhizirideum*. Among these, the shape and size of leaf, scape and various floral parts are useful diagnostic traits at the specific level (Table 3; Fig. 1; Choi and Oh 2010; Choi and Oh 2011). According to the PCA results, first combined five principal components accounted for 83.65% of the total variation among taxa in the studied taxa. The PC1 accounted for 52.94% of variance, while PC2 accounted for 15.54% of total variability. The first two principal components were strongly associated with the inflorescence length, outer tepal length and inner filament width. The anther length and inner tepal width were mostly contributed to PC1, while the pedicel length and

Table 3. Comparison of major characters of *Allium* section *Rhizirideum* in South Korea and northeastern China.

| Character          | A. dumebuchum | A. spirale | A. spurium | A. minus | A. senescens |
|--------------------|---------------|------------|------------|----------|--------------|
| Rhizome            | oblique to horizontal | horizontal | horizontal | oblique | horizontal |
| Leaf sheath        | exposed       | buried     | buried     | exposed  | exposed      |
| Leaf blade         | fleshy, glaucous | leathery, lustrous | leathery, lustrous | fleshy, glaucous | fleshy, glaucous |
| length (cm)        | 19.5–38.0     | 20.0–45.0  | 15–30.0    | 11.4–24.5 | 23.0–45.0    |
| width (mm)         | 3.8–13.0      | 4.0–10.0   | 1.5–4.0    | 2.8–4.5  | 5.0–15.0     |
| Scape              | rhomboid      | flattened-winged | rhomboid to subterete | subterete | subterete |
| length (cm)        | 23.4–49.0     | 33.0–65.0  | 10.0–40.0  | 11.7–20.5 | 25.8–70.0    |
| diameter (mm)      | 2.5–5.6       | 4.0–5.1    | 1.5–2.5    | 1.5–1.6  | 3.0–5.5      |
| Pedicel            | 9.8–11.2      | 6.0–12.4   | 7.6–11.1   | 8.7–11.1 | 8.0–13.0     |
| Perianth           | semi-radially spreading | campanulate | campanulate | radially spreading | radially spreading |
| shape              | light purple  | reddish purple | strong purple or pale purple | pale purple | pale purple |
| color              | light purple  | ovately-elliptical | ovately-elliptical | elliptical | elliptical |
| length (mm)        | 5.2–7.2       | 4.0–6.8    | 3.9–6.3    | 4.0–4.8  | 4.3–6.4      |
| width (mm)         | 3.4–4.5       | 2.0–4.2    | 2.2–3.4    | 1.2–1.9  | 1.8–2.9      |
| Outer tepal        | ovately-elliptical | ovately-elliptical | ovately-elliptical | ovate-oblong | ovate-elliptical |
| length (mm)        | 4.8–6.1       | 3.1–5.0    | 2.9–5.2    | 3.7–4.6  | 3.1–5.2      |
| width (mm)         | 2.1–3.7       | 1.3–3.0    | 1.1–2.3    | 1.1–1.7  | 1.1–2.5      |
| Filament           | exerted       | exerted    | exerted    | non-exserted | exerted |
| exertion           | 6.2–8.4       | 5.3–8.8    | 5.0–7.0    | 3.2–4.4  | 4.6–6.9      |
| Inner filament     | entire        | entire     | entire     | entire or 2-toothed broadened for ca. 1/2 in length |
| margin             | narrowly triangular | entire subulate | entire subulate | entire broadened for ca. 1/2 in length in length |
| Anther             | 2.2–2.5       | 1.7–2.2    | 1.7–2.0    | 1.3–1.4  | 1.5–2.0      |
| length (mm)        | 0.9–1.1       | 0.7–1.0    | 0.6–0.8    | 0.6–0.8  | 0.7–0.9      |
| width (mm)         | 3.2–3.8       | 2.0–3.4    | 1.8–2.8    | 2.1–2.4  | 2.4–3.1      |
| Ovary              | 3.2–3.7       | 1.8–3.1    | 1.5–2.7    | 1.8–2.0  | 2.6–2.8      |
| length (mm)        | 5.4–5.6       | 5.0–5.3    | 4.8–5.1    | 3.5–3.7  | 4.5–5.5      |
| Capsule            | 5.6–5.8       | 4.5–5.0    | 4.5–5.0    | 3.6–4.0  | 4.5–5.6      |
| Seed               | 3.7–3.8       | 3.0–3.3    | 2.8–3.2    | 2.0–2.2  | 3.0–3.5      |
| length (mm)        | 2.4–2.6       | 2.0–2.2    | 2.0–2.3    | 1.3–1.5  | 2.2–2.4      |
| Flowering season   | late Sep. to Oct. | Aug. to Sep. | Jul. to Aug. | May to Jul. | Jul. to Aug. |
| Chromosome number (2n) | 2n = 32       | 2n = 16, 32 | 2n = 16, 32 | 2n = 16 | 2n = 32      |
flower number were contributed only to PC2. PC1 versus PC2 in scatter plot showed that *A. dumebuchum* and *A. minus* were distinctly separated from *A. senescens*, *A. spirale*, and *A. spurium* (Fig. 2).

**Somatic chromosome numbers**

The somatic chromosome numbers of *Allium* species investigated were counted as diploid (2*n* = 2x = 16; Fig. 3C, D) or tetraploid (2*n* = 4x = 32; Fig. 3A, B, E, F). Among studied species, *A. spirale* and *A. spurium* showed polyploidy (Table 3).

**Phylogenetic relationships**

Total combined dataset of four chloroplast regions was comprised of 93 samples, including 58 from chloroplast genome. The aligned dataset was 6,046 bp long (4,086 bp in newly sequenced samples) with 556 parsimony-informative site and 4,881 constant site. The dataset consists of *ndhF-trnF*, *trnH-psbA*, *psbD-trnT*, and *psbJ-petA* with 923 bp, 609 bp, 1,121 bp, and 1,095 bp, respectively.

Our phylogenetic tree revealed a similar topology, not showing distinct monophyly, to the previous study (Li et al. 2010; Hauenschild et al. 2017). Nevertheless, subgen. *Rhizirideum* is monophyletic, despite subgen. *Cepa* and *Allium* being polyphyletic (Fig. 6). Section *Rhizirideum* especially constructed a clade supported high bootstrap value (Fig. 6). *Allium* species in section *Rhizirideum*, excluding *A. dumebuchum*, dispersed to several clades, showing a confusing phylogenetic relationship. Especially, *A. dumebuchum* revealed monophyly in the tree with high support value and specific morphological characters (Figs 1, 2 and 4), even though it does not show a distinct phylogenetic relationship among the species in section *Rhizirideum*.

**Taxonomic treatment**

**Key to the species of Allium section Rhizirideum in South Korea and northeastern China**

1a Leaf sheaths buried under ground; leaf blades leathery, lustrous; perianths campanulate; inner tepals ovate-elliptical; inner filaments entire at margin .......... 2  
1b Leaf sheaths exposed above ground; leaf blades fleshy, glaucous; perianths radially spreading; inner tepals elliptical; inner filaments entire or toothed at margin .... 3  
2a Leaf blades 4–10 mm wide; scapes clearly flattened-winged in cross-section........ ................................................................. *A. spirale*  
2b Leaf blades 1.5–4 mm wide; scapes rhomboid in cross-section ........ *A. spurium*  
3a Leaf blades 2.8–4.5 mm wide; scapes subterete in cross-section, 11.7–20.5 mm long; inner tepals 4.0–4.8 mm long, 1.2–1.9 mm wide; outer tepals 3.7–4.6 mm long, 1.1–1.7 mm wide; filaments non-exserted, 3.2–4.4 mm long; capsules
3.5–3.7 mm long, 3.6–4 mm wide; seeds 2.0–2.2 mm long, 1.3–1.5 mm wide; flowering from May to July \((2n = 2x = 16)\)..........................\textit{A. minus}

3b Leaf blades 3.8–15 mm wide; scapes subterete to rhomboid in cross-section, 23.4–70 mm long; inner tepals 4.3–7.2 mm long, 1.8–4.5 mm wide; outer tepals 3.1–6.1 mm long, 1.1–3.7 mm wide; filaments exserted, 4.6–8.4 mm long; capsules 4.5–5.6 mm long, 4.5–5.8 mm wide; seeds 3.0–3.8 mm long, 2.2–2.6 mm wide; flowering from July to October \((2n = 4x = 32)\)...........................................4

4a Scapes rhomboid in cross-section; perianths light purple; inner filaments narrowly triangular, entire at margin; inner tepals 3.4–4.5 mm wide; ovaries 3.2–3.7 mm wide; flowering from late September to October.............\textit{A. dumebuchum}

4b Scapes subterete in cross-section; perianths pale purple; inner filaments broadened for ca. 1/2 in length, entire or 2-toothed at margin; inner tepals 1.8–2.9 mm wide; ovaries 2.6–2.8 mm wide; flowering from July to August........\textit{A. senescens}

\textit{Allium dumebuchum} H.J.Choi, sp. nov.

urn:lsid:ipni.org:names:77216563-1

Figs 1A–E, 4

\textbf{Diagnosis.} This new species is morphologically similar to \textit{A. senescens} due to its habits. However, it is clearly distinguished from \textit{A. senescens}, particularly by its rhomboid scapes in cross-section (vs. subterete), light purple perianth color (vs. pale purple), entire and narrowly triangular inner filaments (vs. sometimes toothed and broadened for ca. 1/2 in length), and flowering season from late September (vs. from July).

\textbf{Type.} South Korea. Gyeongbuk: Ulleung-gun, Namyang, 37.46702N 130.83665E, elev. 11m, 8 Oct 2020 [fl], H.J.Choi 201008-001* (Holotype: KH; Isotypes: CWNU, KB, KIOM).

\textbf{Description.} Herbs hermaphroditic. Rhizomes clearly elongated, thick and branched, oblique to horizontal, 14.8–55.4 mm long. Bulbs clustered, cylindrically conical, 9.6–15 mm in diam.; tunics membranous, smooth, white. Leaves 4–9; sheaths slightly exposed above ground, 4–7.8 cm long; blades ascending, slightly tortuous, linear, flat and solid in cross-section, flesh, 19.5–38 cm × 3.8–13 mm, apex obtuse to rounded. Scapes rhomboid and solid in cross-section, drooping before flowering, 23.4–49 cm × 2.5–5.6 mm. Inflorescences umbellate, subglobose, 23–41.5 × 37–53 mm, 48–113 flowered; pedicels terete, subequal in length, 9.8–11.2 mm long; bracts 3.2–5 mm long. Flowers bisexual; perianth semi-radially spreading, light purple; inner tepals longer than outer ones, elliptical, apex obtuse, 5.2–7.2 × 3.4–4.5 mm; outer tepals ovately elliptical, apex obtuse, 4.8–6.1 × 2.1–3.7 mm; filaments exserted, 6.2–8.4 mm long, margin entire; inner filaments narrowly triangular; anthers elliptical, reddish, 2.2–2.5 × 0.9–1.1 mm long; ovary obovoid, reddish, 3.2–3.8 × 3.2–3.7 mm, ovules 2 per locule; style terete, exserted; stigma smooth. Capsules cordiform, trigonous, 5.4–5.6 × 5.6–5.8 mm. Seeds oval, semi-circular in cross-section, 3.7–3.8 × 2.4–2.6 mm.

\textbf{Phenology.} Flowering from late September to October; fruiting from late October to November.
Allium section *Rhizirideum* in South Korea and northeastern China

**Figure 1.** Comparative photographs of the inflorescence, cross-section of leaf and scape, flower, and tepal and filament arrangement of *Allium section Rhizirideum* in South Korea and northeastern China. A–E *A. dumebuchum* (H.J.Choi 201008-001) F–J *A. spirale* (H.J.Choi 191010-01) K–O *A. spuriurn* (H.J.Choi 200831-01) P–T *A. minus* (H.J.Choi 080063) U–Y *A. senescens* (H.J.Choi 080119).

**Distribution and habitat.** Endemic to South Korea (Ulleung-do Island; Fig. 5). Open slope of rocky area.

**Etymology.** The specific epithet, “*dumebuchum*” is based on the name of traditional vegetable for this species in South Korea.
Vernacular name. The Korean name of the new species is “Du-me-bu-chu (두메부추)”.

Conservation status. The new species is endemic to Ulleungdo Island, and usually grows along the coast at altitudes of -23–171 m a.s.l. From the present study, the extent of occurrence (EOO) and the area of occupancy (AOO) of this species have been calculated to be 47,683 km² and 48 km², respectively. Currently, there is no information on population size and trend data. However, this new species is only known from a single location of Ulleungdo Island, and mainly occurs on the coast which is critically threatened by extensive construction and repair of coastal roads (Choi et al. 2012a). Therefore, decline in habitat area, habitat extent, and quality of habitat for this species have been continuously observed. Thus, *Allium dumebuchum* should be considered as Critically Endangered [CR B1ab(iii)] according to the IUCN Red List categories and criteria (IUCN 2021).

Notes. *Allium dumebuchum*, occurring in Ulleungdo Island of South Korea, has usually been misidentified as *A. senescens* (Choi and Oh 2010; Choi and Oh 2011). However, this new species remarkably distinguished itself from its related species of section *Rhizirideum* (e.g., *A. spirale*, *A. spurium*, *A. minus*, and *A. senescens*) in having clearly bigger floral parts that bloom from late September (Table 3; Fig. 1). The PCA results based on quantitative floral characters of five related species in section *Rhizirideum* clearly identified *A. dumebuchum* from others (Fig. 2). This new species is a tetraploid (2n = 4x = 32) taxon along with *A. senescens*, and *A. minus* is a diploid (2n = 2x = 16), whereas *A. spirale* and *A. spurium* showed polyploidy (Table 3; Fig. 3). Moreover, molecular phylogenetic analyses using chloroplast markers (*ndhJ-trnF, trnH-psbA, psbD-trnT*, and *psbJ-petA*) also clearly indicate that *A. dumebuchum* is genetically distinct from other species of section *Rhizirideum* (Fig. 6).

Additional specimens examined (Paratypes). South Korea. Gyeongbuk: Ulleungdo Isl., Namyang valley, 11 Sep. 2006, *ParkSH 61820* (KH); Ulleungdo Isl., Tonggumi, 26 Sep. 1995, *S-4255* (KH); Ulleungdo Isl., Namyang, 15 Aug. 2009, *Ulleung68-090815-002* (KH); Ulleungdo Isl., Namyang, 22 Aug. 2011, *JMC12750* (KH); Ulleungdo Isl., Namyang, 29 Oct. 2013, *2013KBV091* (KH); Ulleungdo Isl., Namyang, 5 Sep. 2003, *SCHONG2003100* (KH); Ulleungdo Isl., Chusan, 2 Sep. 2009, *JMC11306* (KH); Ulleungdo Isl., Dodong, 18 Sep. 2007, *H.J.Choi 070001* (KH); Ulleungdo Isl., Sadong, 23 Aug. 2005, *1073* (KB); Ulleungdo Isl., Sadong, 23 Aug. 2005, *KH1283* (KB); Ulleungdo Isl., Namyang, 25 Sep. 2001, *J.S.Kim s.n.* (KB); Ulleungdo Isl., Hyeonpo, 4 Oct. 2011, *19-1* (KB); Ulleungdo Isl., Namyang, 17 Sep. 2019, *H.J.Choi 190917-01* (CWNU); Ulleungdo Isl., Namyang, 8 Oct. 2020, *H.J.Choi 201008-002* (CWNU); Ulleungdo Isl., Namyang, 8 Oct. 2020, *H.J.Choi 201008-003* (CWNU); Ulleungdo Isl., Sadong, 12 Oct. 2005, *NAPI-20101161* (KB); Ulleungdo Isl., Namyang, 11 Jul. 2013, *H.J.Choi s.n.* (KB); Ulleungdo Isl., 23 Aug. 2005, *1406* (KB); Ulleungdo Isl., 3 Sep. 2008, *SK2008-019-096* (KB); Ulleungdo Isl., 15 Oct. 2009, *ksh84* (KB).
Allium section Rhizirideum in South Korea and northeastern China

Figure 2. Principal components analysis plot of five Allium species of section Rhizirideum in South Korea and northeastern China. dum = A. dumebuchum; min = A. minus; sen = A. senescens; spi = A. spirale; spu = A. spurium.

Allium spirale Willd., Enum. Pl. Suppl. 17 (1814)

Fig. 1F–J

Type. Russia (Far East), specimen without collection date and number (Holotype: B photo!).

Notes. Allium spirale is occasionally confused with A. senescens because of its more or less similar growth habit (Choi and Oh 2011), but the most distinctive characters include clearly flattened-winged scapes (Fig. 1H), campanulate perianth (Fig. 1I) and ovate tepals (Fig. 1J).

Specimens examined. China. Jilin: Gyoha, Ipbeopsan, 2 Sep. 2006, Jilin23-060902-007 (KH); hunchun, 17 Aug. ?, S.J.Lee et al. s.n. (KH); baisan, changbisan, 22 Aug. 2010, An-C1273 (KH); Yongjeong, Nampyeong, 8 Sep. 2007, H.J.Choi & J.W.Han 070014 (KH); Dandong, Aprokgang, 6 Sep. 2007, H.J.Choi & J.W.Han 070012 (KH); Tungwi, 26 Aug. 1960, Jilin Teaching Uni. 399 (PE); Tungwi, 14 Jul.
Figure 3. Mitotic metaphase chromosomes and their voucher plants of Allium species A A. dunebuchum (H.J. Choi 190917-01) B A. spirale (H.J. Choi 191010-01) C A. spirale (H.J. Choi 190910) D A. spurium (H.J. Choi 080390) E A. spurium (H.J. Choi s.n.) F A. senescens (H.J. Choi 080119, voucher plant: Fig. 2 of Choi and Oh 2010).

1960, Yeop 183 (PE); Near O-mu Hsien, 28 Aug. 1931, H.W.Kung 2195 (PE); Shuyi Valley, Ching-po Lake, Ning-gu-ta, 5 Sep. 1931, F.H.Chen 541 (PE); Erdaobaihe, 10 Sep. 2019, H.J.Choi 190910* (CWNU); Wharyoung, 8 Sep. 1959, 700828 (PE). Heilongjiang: Mudanjiangshi, Jingbo lake, 21 Aug. 2001, ChoiHJ-065 (KH); Harbin, 22 Aug. 2001, G.W.Park s.n. (KH); Qinggang, Aug. 1953, North-eastern group 571 (PE); Saertu, ?, s.n. (PE). Liaonong: Xiaodonggou, Benxi, 26 Aug. 1965, Liu et al. 1319 (PE); Daeryeon, 14 Sep. 1951, Wang et al. 965 (PE); Héngsan, Daeryeon, 11 Aug. 2008, B.U.Ob et al. s.n. (CBU). Russia. Primorsky: Mrs. Sikhote-Alin, 26 Aug. 2014, 2014CNU001 (KH); Khasan, Lotos lake, 17 Aug. 2015, 2015RUSV017-01 (KH); Bukhta Eksleditsii, 17 Aug. 2015, H.J.Choi et al. 150817-01 (KB); Bukhta Eksleditsii, 19 Aug. 2015, H.J.Choi et al. 150819-01* (KB); Bukhta Eksleditsii, 26 Aug. 2014, H.J.Choi et al. 140826-01 (KB); Khasansky, Perevoznaya, 10 Sep. 2013, 5-14 (KB); Khasansky, Shakhterskiy, 11 Sep. 2013, 8-13 (KB); ?, 4 Aug. 2014, RUS14-3-4
Figure 4. *Allium dumebuchum* A habit B inflorescence C underground structure (r = rhizome) D tepal and filament arrangement E Flower F pistil G capsule H seed. Photos by H.J. Choi: H.J. Choi 201008-001 (A, B, D–F) and H.J. Choi 070001 (C, G, H).

(KB). South Korea. Gangwon: Goseong, Ganseong, 12 Oct. 2010, NAPI-10-139-01 (KH); Goseong, Ganseong, 10 Oct. 2019, H.J. Choi 191010-01 (CWNU); Gangneung, Gangmun, 19 Sep. 2019, H.J. Choi 190919-001-01* (CWNU); Gangneung, Gangmun, 19 Sep. 2019, H.J. Choi 190919-002 (CWNU); Gangneung, Yeongok, 02
Oct. 2011, KYC1965 (KH); Yangyang, Sonnyang, 04 Sep. 2011, NAPI 2012-0020 (KH); Goseong, Hyeonmae, 15 Sep. 1965, T.B.Lee et al. s.n. (KH); Goseong, Gangseoong, 10 Sep. 2008, NAPI2008013 (KB); Goseong, Geojin, 10 Sep. 2008, J.O.Hyun s.n. (KB); Gangneung, Sacheon, 15 Nov. 2013, 2013-282 (KB); Goseong, Jugwang, 22 Sep. 2014, KYC2014-207(KB); Gangneung, Gangmun, 8 Aug. 2015, H.J.Choi s.n. (KB).

**Allium spurium** G.Don, Mem. Wern. Nat. Hist. Soc. vi. 59 (1827)
Fig. 1K–O

Allium dauricum N.Friesen, Fl. Sibir. (Arac.-Orchidac.) 58 (1987). Type: Russia. Transbaicalia Orientalis, pagum Kyra, in valle fuvii Bukukum, in prato substepposo, 31 Aug. 1964, G.Peschkova & L.Ovczinnicova s.n. (Holotype: LE!; Isotypes: NSK).

**Type.** Russia (Siberia, location in doubt). Type specimen not designated (protologue).

**Notes.** Allium spurium is occasionally confused with *A. spirale* because of its more or less similar growth habit, but the most distinctive characters include narrower leaf blades and scapes and smaller floral parts (Table 3; Fig. 1L–N). This species is newly recorded for South Korea, and the new vernacular name ‘Gak-si-du-me-bu-chu’ is given. Besides, Cheongnyangsan of South Korea is the disjunct southernmost limit for geographical distribution of *A. spurium* (Fig. 5).

**Specimens examined.** China. Jilin: Helong, 8 Sep. 2007, H.J.Choi s.n. (KH); Helong, 9 Sep. 2007, H.J.Choi s.n. (KH); Baishan, Linjiang, 29 Apr. 2019, H.J.Choi 190429-01 (CWNU); Erdaoba, 08 Sep. 2019, H.J.Choi 190908-001-01* (CWNU). North Korea. Hambuk: Yonsa, 25 Aug. 1958, C.K.Gen s.n. (LE). Hamnam: Sinpoo, 3 Oct. 2002, B.U.Ob 020062 (CBU); Hungnam, 21 Aug. 1956, C.K.Gen s.n. (LE). Phyonbuk: Huchang, 22 Aug. 1897, Komarov s.n. (LE); Jasong, 27 Aug. 1897, Komarov s.n. (LE). South Korea. Gyeongbuk: Bonghwa, Cheongnyangsan, 31 Aug. 2020, H.J.Choi 200831-01* (CWNU).

**Allium minus** (S.O.Yu, S.Lee & W.Lee) H.J.Choi & B.U.Ob, Brittonia 62(3): 200 (2010)
Fig. 1P–T

*A. senescens* L. var. minus S.OYu, S.Lee & W.Lee, J. Korean Pl. Taxon. 11: 32 (1981) ['minor']. **Basionym.**

**Type.** South Korea. Gangwon: Inje, Wolhaksam-ri, 26 May 1979, B.S.Gil s.n. (Neotype: KHI; Oh et al. 2018).

**Notes.** This species was originally published as a variety of *Allium senescens*, *A. senescens* var. minus ‘minor’. However, this Korean endemic taxon has been revealed as
a biologically distinct species. It is remarkably well distinguished from its relatives of the section *Rhiziridum* by having much narrower and shorter leaf blades and scapes, smaller floral organs, non-exerted filaments and earlier flowering season from May to late July (Table 3; Fig. 1; Choi and Oh 2010; Choi and Oh 2011). Considering these

**Figure 5.** Distribution map of *Allium dumebuchum* and its related species section *Rhizirideum* in Korea and northeastern China (revised from Sinitsyna et al. 2016).
major differences, Choi and Oh (2010) proposed the rank of species for this taxon as more appropriate than that of variety. Although it is cultivated as a vegetable in South Korea, its natural populations are only known from the type locality so far (Fig. 5). However, this species proved to have been extinct in the natural habitat in this study.

**Specimens examined.** SOUTH KOREA. Gangwon: Inje, 26 May 1979, B.S.Gil 0022887 (KWNU); Inje, W.T.Lee 0022892 (KWNU); Inje, Wolhaksam-ri, 18 May 2008, H.J.Choi 080063* (KH). Gyeonggi: Yangju, Jangheung, 6 Oct. 2015, H.J.Choi 151006-01 (CWNU).

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**Figure 6.** Phylogenetic tree of *Allium* section *Rhizirideum* and related taxa based on concatenated alignments of four cpDNA regions (*ndhJ-trnF, trnH-psbA, psbD-trnT, and psbJ-petA*). The numbers above branches are bootstrap values (BS > 50%) by maximum likelihood method. The samples of section *Rhizirideum* and the new species are in blue and red blods, respectively. The accession numbers from Genbank were indicated after the scientific names.
**Allium senescens** L., Sp. Pl. 1: 299 (1753)

Fig. 1U–Y

**Allium pseudosenescens** H.J.Choi & B.U.Oh, Brittonia 62(3): 200 (2010). Type: China. Heilongjiang, Tahe, Talin Linchang, *H.J.Choi 080119* (Holotype: KH!; Isotypes: KH!).

**Type.** Russia. From Siberia (foreshaical region), *LINN 419.25* (Lectotype: LINN photo!).

**Notes.** *Allium senescens*, originally described from the Baikal area of Russia, is certainly one of the most popular ornamental *Allium* species of the world, and is naturally distributed in southern Russia, Mongolia and north-eastern China (Sinitsyna et al. 2016; Sinitsyna and Friesen 2018). The existing records of this species in South Korea (Choi and Oh 2010; Choi and Oh 2011) are all the result of misidentification of herbarium materials, the identity of which we have verified to be *A. dumebuchum*. *Allium pseudosenescens* is newly proposed as an additional synonym of *A. senescens* in this study.

**Specimens examined.** China. Heilongjiang: ?, 1959, *Wang 163* (PE); Tahe, Talin Linchang, 31 Jul. 2008, *H.J.Choi 080119* (KH); Xifeng Linchang, Tahe, 1 Aug. 2008, *H.J.Choi 080278* (KH); Dashinganryeong, Aug. 1954, *Linxingzu 07577* (PE).

Mongolia. Bulgan, Khogno Khaan Mountain Nature Reserve, 29 Jul. 2000, *Sun Byung-Yun 32008* (KH); Sukhbaatar, Tumentsogt, 17 Jul. 2011, *Mongolia_V2012007* (KH); Ulaanbaatar, Sanzai, 09 Jul. 2014, *2014-MON-010* (KB); Tuv, Mungunmorit, 06 Jul. 2016, *H.J.Choi 160706* (CWNU); sanzai, 8 Jul. 2014, *2014-MON-010* (KB).

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**References**

Choi HJ, Oh BU (2010) A new species and a new combination of *Allium* sect. *Rhizirideum* (Alliaceae) from northeastern China and Korea. Brittonia 62(3): 199–205. https://doi.org/10.1007/s12228-009-9124-6

Choi HJ, Oh BU (2011) A partial revision of *Allium* (Amaryllidaceae) in Korea and north-eastern China. Botanical Journal of the Linnean Society 167(2): 153–211. https://doi.org/10.1111/j.1095-8339.2011.01166.x

Choi HJ, Jang HD, Isagy Y, Oh BU (2012a) Distribution and conservation status of the Critically Endangered *Scrophularia takesimensis*, a plant endemic to Ulleung Island, Republic of Korea. Oryx 46(3): 399–402. https://doi.org/10.1017/S0030605312000117
Choi HJ, Giussani LM, Jang CG, Oh BU, Kota-Sanchez JH (2012b) Systematics of disjunct northeastern Asian and northern North American Allium (Amaryllidaceae). Botany 90(6): 491–508. https://doi.org/10.1139/b2012-031
Choi HJ, Yang S, Yang JC, Friesen N (2019) Allium ulleungense (Amaryllidaceae), a new species endemic to Ulleungdo Island, Korea. Korean Journal of Plant Taxonomy 49(4): 294–299. https://doi.org/10.11110/kjpt.2019.49.4.294
De Sarker D, Johnson MAT, Reynolds A, Brandham PE (1997) Cytology of the highly polyploid disjunct species, Allium dregeanum (Alliaceae), and of some Eurasian relatives. Botanical Journal of the Linnean Society 124: 361–373. https://doi.org/10.1111/j.1095-8339.1997.tb02002.x
Friesen N (1988) Lukovye Sibiri: sistematika, kariologiia, khorologiiia. Nauka–Sibirskoe otd., Novosibirsk.
Friesen N (1992) Systematics of the Siberian polyploid complex in subgenus Rbizirideum (Allium). In: Hanelt P, Hammer K, Knupffer H (Eds) The genus Allium: taxonomic problems and genetic resources, proceedings of an international symposium held at Gatersleben. Institut fur Pflanzengenetik und Kulturpflanzenforschung, Gatersleben, 55–66.
Friesen N, Fritsch RM, Blattner FR (2006) Phylogeny and new intrageneric classification of Allium (Alliaceae) based on nuclear ribosomal DNA its sequences. Aliso 22(1): 372–395. https://doi.org/10.5642/aliso.20062201.31
Fritsch RM (2001) Taxonomy of the genus Allium L.: Contributions from IPK Gatersleben. Herbetia 56: 19–50.
Fritsch RM, Friesen N (2002) Evolution, domestication, and taxonomy. In: Rabinovich HD, Currah L (Eds) Allium crop science: recent advances. CABI Publishing, Wallingford, 5–30. https://doi.org/10.1079/9780851995106.0005
Fritsch RM, Blattner FR, Gurushidze M (2010) New classification of Allium L. subg. Melano-crommyum (Webb &Berthel.) Rouy (Alliaceae) based on molecular and morphological characters. Phyton 49: 145–320.
Hauenschild F, Favre A, Schnitzler J, Michalik I, Freiberg M, Muellner–Riehl AN (2017) Spatio-temporal evolution of Allium L. in the Qinghai–Tibet-Plateau region: Immigration and in situ radiation. Plant diversity 39: 167–179. https://doi.org/10.1016/j.pld.2017.05.010
IUCN (2021) The IUCN Red List of Threatened Species. Version 2020-3. https://www.iucn-redlist.org [accessed 6 January 2021]
Kamelin RV (2004) Lektsii po sistematike rastenii. Glavy teoreticheskoi sistematiki rastenii, Izdatel’stvo “AzBuka”, Barnaul.
Li QQ, Zhou SD, He XJ, Yu Y, Zhang YC, Wei XQ (2010) Phylogeny and biogeography of Allium (Amaryllidaceae: Allieae) based on nuclear ribosomal internal transcribed spacer and chloroplast rps16 sequences, focusing on the inclusion of species endemic to China. Annals of Botany 106(5): 709–773. https://doi.org/10.1093/aob/mcq177
Neshati F, Fritsch RM (2009) Seed characters and testa sculptures of some Iranian Allium L. species (Alliaceae). Feddes Repertorium 120(5-6): 322–332. https://doi.org/10.1002/fedr.200911112
Nguyen NH, Driscoll HE, Specht CD (2008) A molecular phylogeny of the wild onions (Allium; Alliaceae) with a focus on the western North American center of diversity.
Molecular Phylogenetics and Evolution 47(3): 1157–1172. https://doi.org/10.1016/j.ympev.2007.12.006

Nguyen LT, Schmidt HA, Von Haeseler A, Minh BQ (2015) IQ-TREE: A fast and effective stochastic algorithm for estimating maximum-likelihood phylogenies. Molecular Biology and Evolution 32(1): 268–274. https://doi.org/10.1093/molbev/msu300

Oh SH, Ji SJ, Choi HJ (2018) Neotypification of *Allium senescens* var. minus (Amaryllidaceae). Phytotaxa 382(1): 148–150. https://doi.org/10.11646/phytotaxa.382.1.9

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Sang T, Crawford DJ, Stuessy TF (1997) Chloroplast DNA phylogeny, reticulate evolution, and biogeography of Paeonia (Paeoniaceae). American Journal of Botany 84(8): 1120–1136. https://doi.org/10.2307/2446155

Seregin AP, Anaćkov G, Friesen N (2015) Molecular and morphological revision of the *Allium saxatile* group (Amaryllidaceae): Geographical isolation as the driving force of underestimated speciation. Botanical Journal of the Linnean Society 178(1): 67–101. https://doi.org/10.1111/bot.12269

Shaw J, Lickey EB, Schilling EE, Small RL (2007) Comparison of whole chloroplast genome sequences to choose noncoding regions for phylogenetic studies in angiosperms: The tortoise and the hare III. American Journal of Botany 94(3): 275–288. https://doi.org/10.3732/ajb.94.3.275

Shukherdorj B, Jang JE, Duchoslav M, Choi HJ (2018) Cytotype distribution and ecology of *Allium thunbergii* (= *A. sacculiferum*) with a special reference to South Korean populations. Korean Journal of Plant Taxonomy 48(4): 278–288. https://doi.org/10.11110/kjpt.2018.48.4.278

Sinitsyna TA, Friesen N (2018) Taxonomic review of *Allium senescens* subsp. *glaucum* (Amaryllidaceae). Feddes Repertorium 129(1): 9–12. https://doi.org/10.1002/fedr.201700008

Sinitsyna TA, Herden T, Friesen N (2016) Dated phylogeny and biogeography of the Eurasian *Allium section Rhizirideum* (Amaryllidaceae). Plant Systematics and Evolution 302(9): 1311–1328. https://doi.org/10.1007/s00606-016-1333-3

Taberlet P, Gielly L, Pautou G, Bouvet J (1991) Universal primers for amplification of three non-coding regions of chloroplast DNA. Plant Molecular Biology 17(5): 1105–1109. https://doi.org/10.1007/BF00037152

Tang Y, Horikoshi M, Li W (2016) ggfortify: Unified interface to visualize statistical result of popular R packages. The R Journal 8(2): 474–485. https://doi.org/10.32614/RJ-2016-060

Tate JA, Simpson BB (2003) Paraphyly of *Tarsa* (Malvaceae) and diverse origins of the polyploid species. Systematic Botany 28(4): 723–737.

Thiers B (2020+) [continuously updated] Index Herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden’s Virtual Herbarium. http://sweetgum.nybg.org/ih/ [accessed 5.11.2020]

Trifinopoulos J, Nguyen LT, Von Haeseler A, Minh BQ (2016) W-IQ-TREE: A fast online phylogenetic tool for maximum likelihood analysis. Nucleic Acids Research 44(W1): W232–W235. https://doi.org/10.1093/nar/gkw256

Wickham H (2016) ggplot2: Elegant graphics for data analysis. Springer-Verlag, New York, 216 pp. https://doi.org/10.1007/978-3-319-24277-4_9