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Morphometric and colour characteristics of garlic accessions (*Allium sativum* L.) in the Agricultural Institute of Slovenia

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Abstract

Garlic from the *Alliaceae* family is a vegetatively propagated bulbous crop with great morphological diversity. It is used worldwide as an important spice in cooking and in traditional medicine. Garlic accessions managed in the Slovenian Plant Gene Bank at the Agricultural Institute of Slovenia were studied on the basis of various morphometric and colour characteristics of the bulbs and cloves. A total of 49 garlic accessions were grown and evaluated in the experimental fields of Infrastructure Centre Jablje in 2023. Numerical descriptors included the bulb weight, height and diameter, the height/diameter ratio, the number of cloves, and clove size. Qualitative descriptors included ten UPOV descriptors related to the pseudostem (flowering stem), the bulb (size, ground colour of dry external scales, anthocyanin stripes on dry external scales, number of cloves), and the clove (size, colour of scales, intensity of colour of scales, anthocyanin stripes on scales, colour of flesh). Results have shown significant differences between the accessions in terms of the bulb size and colour parameters. The bulb weight ranged from 8.6–54.1 g, the bulb height from 26.5–45.8 mm, and the bulb diameter from 31.4–58.9 mm. The average number of cloves was 10 ± 3 and the weight of the cloves was 3.0 ± 1.2 g. The predominant bulb ground colours of dry external scales were white and yellowish white, 31 and 18 accessions, respectively. The clove colours of the scales were predominantly pink/purple, pink/purple/brown, brown, cream/pink, or cream, with anthocyanin stripes on the scales present in nearly 75% of the accessions. The highest coefficients of variation were observed for the bulb size (49.6%) and the clove size (39.6%) and the lowest for the height/diameter ratio (6.2%). The data obtained and the variability of the traits studied indicate that garlic accessions require further in-

depth agromorphological, nutritional, and genetic analyses to identify the best candidates for future breeding proposals.

***Key words**:* Accession, *Allium sativum*, Garlic, Morphometric descriptor, Colour parameter.

Introduction

Garlic belongs to the *Alliaceae* family and the *Allium* genus and is one of the most important edible bulbous crops, highly valued for its flavour-enhancing and medicinal properties (Kıraç et al., 2022; Kaushik et al., 2016). It is mainly cultivated for its bulbs, which consist of a varying number of cloves and are consumed fresh or cooked (Leišová-Svobodová et al., 2024). Classification of the different garlic genotypes based on the development of the 'scape' or 'flower stalk' usually includes two subspecies, *Allium sativum* var. *sativum*, known as softneck (or non-bolting) garlic, and *Allium sativum* var. *ophioscorodon*, known as hardneck (or bolting) garlic (Vavilov, 1951; Kazakova, 1971; Kamenetsky, 2007). Typically, hardneck garlic varieties have 4–12 cloves surrounding the flower stalk, while the softneck garlic generally contains between 10–40 cloves arranged in multiple layers. The latter usually has a longer shelf life than hardneck garlic and can be stored for 6-8 months, without deteriorating significantly (Block, 2010).

Garlic cultivation has a long tradition in Slovenia, both in small family gardens and for market production. Annual production in 2022 reached 736 tonnes of garlic on 163 ha, of which 52% was intended for the market (Republic of Slovenia Statistical Office [SI-STAT], 2023). The average garlic yield depends mainly on weather conditions and cultivation technology and ranges between 4.5 and 6 tonnes/ha. The quantities of garlic produced are far from meeting market demand, as over 1,000 tonnes of garlic are imported annually, mainly from Italy, Egypt, Austria, and China (SI-STAT, 2023).

Plant genetic resources can be defined as any type of reproductive or vegetative propagating material of a plant species. Their diversity in gene banks around the world forms the basis for plant breeding (Salgotra and Chauhan, 2023). The main challenges of gene banks are tracing the identity of accessions, avoiding unnecessary duplication within and between gene banks, and maintaining the genetic integrity of accessions (Mascher et al., 2019). Methods and guidelines for the characterization of plant genetic resources are defined by several organisations, including The International Union for the Protection of New Varieties of Plants (UPOV)–. The purpose of these guidelines is coordinated observation and evaluation of morphophenological parameters according to the plant descriptors used for the DUS testing (distinctness,

uniformity, and stability). By evaluating morphometric descriptors such as the length, width, height, shape, or colour, it is possible to distinguish within or between plant species and such descriptors serve as basic databases for breeders and researchers. Each descriptor used for *Allium sativum* has a prescribed method of description represented by a sketch, number, or description (UPOV, 2022). In Slovenia, native populations, ecotypes, and local varieties of important agricultural crops, including garlic, have been collected for a long time. At the Agricultural Institute of Slovenia, genetic resources of garlic are collected as part of the Slovenian Plant Gene Bank (SRGB), which have not yet been evaluated using the morphometric descriptors prescribed for *Allium sativum*.

The aim of the present study is to describe the garlic accessions using selected descriptors related to morphometric traits and colour parameters of bulbs and cloves.

Material and Methods

The 49 garlic accessions (*Allium sativum* L.) were acquired from the SRGB at the Agricultural Institute of Slovenia and vegetative propagation was carried out in the experimental fields of the Infrastructure Centre Jablje (304 m a.s.l.; 46.151° N 14.562° E) during the 2022/2023 growing season. An unheated tunnel field trial was established with twelve plants of each garlic accession in three-row strips with a spacing of 30 cm × 10 cm and a drip irrigation system was installed. The cloves were planted in early November 2022 and the mature bulbs were harvested in late June 2023. The garlic plants were fertilized once during growth in the early spring of 2023 with 96 kg/ha N, 64 kg/ha P_2O5, 128 kg/ha K_2O, 24 kg/ha MgO, and 80 kg/ha SO_3 and irrigated when needed. The garlic bulbs were harvested at the stage of technological maturity and dried in a dark place for several weeks. Morphometric characteristics and colour parameters were examined in October 2023 on six cleaned, fully developed representative bulbs of each garlic accession.

A set of ten qualitative descriptors prescribed by the UPOV (2022) for garlic bulbs and cloves was used to describe the garlic accessions (Table 1). Numerical descriptors were determined on six individual bulbs and/or cloves of each garlic accession and included the following parameters: bulb weight (g), bulb height (mm), bulb diameter (mm), height/diameter ratio, number of cloves per bulb, and clove weight (g). The bulb height and diameter (mm) were measured using a digital calliper (Mitutoyo 500-181-30) with an accuracy of 0.1 mm, while the dry weight of the bulbs and cloves (g) was measured using a laboratory scale (PB1502, Mettler Toledo) with an accuracy of 0.01 g. All numerical descriptors were also evaluated according to the corresponding classes, which were labelled with a number, as in Table 1.

Tab. 1 Qualitative UPOV descriptors for *Allium sativum* with associated classes, evaluated on 49 garlic accessions

UPOV code	Plant tissue	Descriptor	Class
10.	Pseudostem	Flowering stem	1 absent, 9 present
14. (g)	Bulb	Size (weight)	3 small (< 20 g), 5 medium (20 - 40 g), 7 large (> 40 g)
21.		Ground colour of dry external scales	1 white, 2 yellowish white, 3 reddish white
22.		Anthocyanin stripes on dry external scales	1 absent, 9 present
25.		Number of cloves	3 few (< 8), 5 medium (8 -12), 7 many (> 12)
28. (g)	Clove	Size (weight)	3 small (< 2 g), 5 medium (2 - 4 g), 7 large (> 4 g)
29.		Colour of scale	1 white, 2 cream, 3 pink, 4 purple, 5 brown
30.		Intensity of colour of scale	3 weak, 5 medium, 7 strong
31.		Anthocyanin stripes on scale	1 absent, 9 present
32.		Colour of flesh	1 white, 2 yellowish

Results and Discussion

The use of numerical and qualitative plant descriptors for the evaluation of garlic accessions has been the subject of many studies worldwide (Thapa et al., 2021; Kıraç et al., 2022; Popa et al., 2023; Khokhar, 2023; Leišová-Svobodová et al., 2024). Garlic breeders focus primarily on the bulb yield and quality, as well as variations such as the bulb size, morphology and colour, the number of cloves, and the number of days from sowing to harvest (Parreño-Montoro et al., 2023). Table 2 summarizes the results of statistical evaluation of the numerical parameters for 49 garlic accessions studied. The average weight of the garlic bulbs was 26.91 g, while the height and diameter of the bulbs were 34.42 mm and 44.12 mm, respectively. The average height-to-diameter ratio was 0.79 with ten cloves per bulb and the clove weight of 2.97 g. The range between the minimum and the maximum weight of the garlic bulbs varied considerably from 8.60 to 54.09 g, the bulb height from 26.52 to 45.78 mm, and the bulb diameter from 31.35 to 58.9 mm. The highest coefficients of variation were found for the

bulb (49.55%) and clove weight (39.62%), and the lowest for the height-to-diameter ratio (6.18%). Siddappa et al. (2020) reported lower bulb and clove size parameters and a higher number of cloves per bulb for 52 garlic genotypes from India. Similarly, Polyzos et al. (2019) reported a slightly higher number of cloves per bulb (11–15) and similar weight of cloves (< 4 g) for 34 Greek garlic genotypes grown at two locations. Characterization of 39 garlic cloves collected around Turkey revealed higher dry weight of bulbs (28.1–84.4 g) and similar bulb height and diameter compared to our data (Kıraç et al., 2022). Frequency distribution graphs of 49 garlic accessions for numerical parameters, i.e., the bulb weight, diameter and height, and the clove weight are shown in Figure1.

Tab. 2 Numerical parameters for 49 analyzed garlic accessions

Parameter	Unit	Min – Max	Mean ± SD	CV (%)
Bulb weight	g	8.60 – 54.09	26.91 ± 13.33	49.55
Bulb height	mm	26.52 – 45.78	34.42 ± 5.06	14.70
Bulb diameter	mm	31.35 – 58.90	44.12 ± 7.84	17.77
Height-to-diameter ratio		0.69 – 0.88	0.79 ± 0.05	6.18
Number of cloves	g	5.50 – 15.67	9.74 ± 2.69	27.64
Clove weight	g	1.13 – 6.07	2.97 ± 1.18	39.62

Data are means (n=49); SD, standard deviation; CV, coefficient of variation.

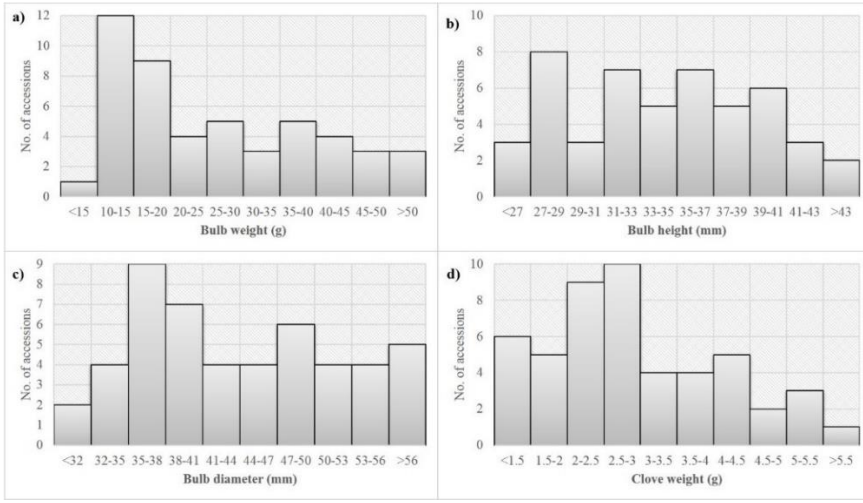

Fig. 1. Frequency distribution (n=49) of garlic accessions based on the numerical parameters: a) bulb weight, b) bulb height, c) bulb diameter, and d) clove weight

Figure 1 shows the distribution of garlic accessions based on four descriptive characteristics, namely the presence of a flowering stem, the bulb weight, the number of cloves per bulb, and the clove weight. The presence of flowering stems was found in 31 accessions, indicating that they belong to the hardneck garlic type, while 18 accessions belong to the softneck garlic type (Figure 1a). Based on the bulb size as a qualitative descriptor, the garlic accessions were divided into three groups (Figure 1b). The first group comprised accessions with small bulbs weighing <20 g (35% of the collection), the second group comprised garlic accessions with medium bulbs weighing 20 g to 40 g (35% of the collection), and the third group comprised garlic accessions with large bulbs weighing >40 g (20% of the collection). Similarly, three groups were formed for the qualitative descriptor referring to the number of cloves per bulb (Figure 1c). In addition, many (>12) cloves were developed in 12 accessions, medium (8–12) cloves in 20 accessions, and few (<8) cloves in 17 accessions. Based on the clove size, the garlic accessions can also be divided into three groups (Figure 1d). The first group included 10 accessions with large cloves >4 g, the second group included 29 accessions with cloves weighing from 2 g to 4 g, and the third group included 10 accessions with small cloves <2 g.

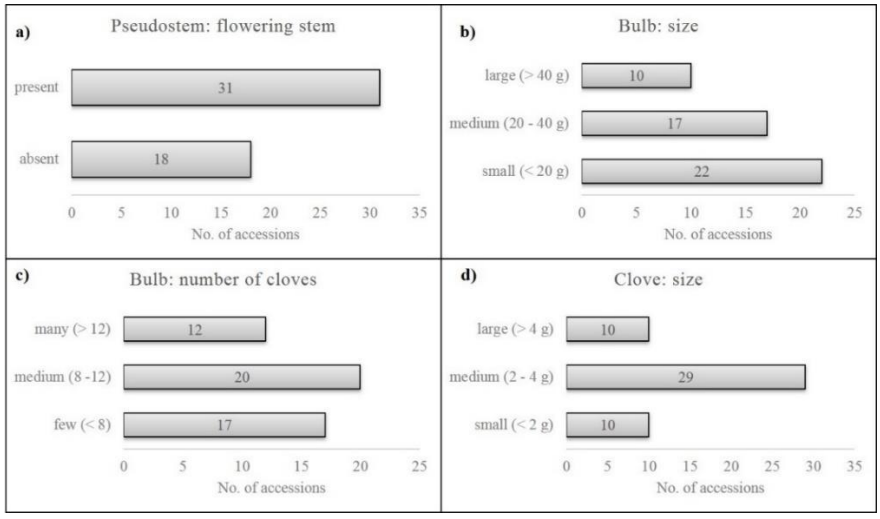

Fig. 2 Frequency distribution (n=49) of garlic accessions based on the qualitative descriptors a) presence of a flowering stem, b) bulb size, c) number of cloves per bulb, and d) clove size

Figure 2 shows the distribution of garlic accessions according to the bulb and clove colour parameters. The garlic accessions studied had bulbs with white (63% of the accessions) and yellowish white (37% of the accessions) ground

colour of the dry external scales (Figure 2a). As can be seen in Figure 2b, the cloves had different numbers of scale colours: 18 garlic accessions had one colour (cream or brown), 20 accessions had two colours (cream/pink or pink/purple), and 11 accessions had three colours (pink/purple/brown). The intensity of the colour of the scales on the cloves was strong in 19 garlic accessions, medium in 16 accessions, and weak in 14 accessions (Figure 2c). The anthocyanin stripes on the scale of the cloves were present in 71% of the accessions. The colour of the clove flesh was yellowish in all 49 garlic accessions examined (data not shown).

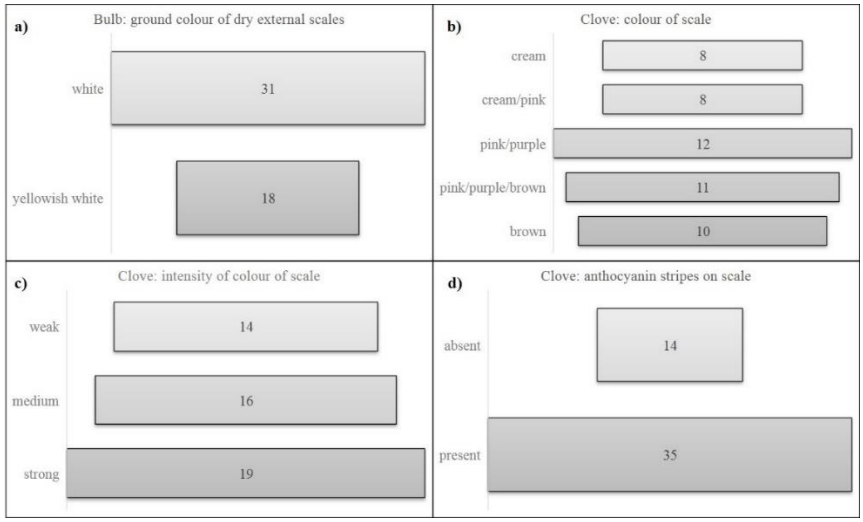

Fig. 3 Frequency distribution (n=49) of garlic accessions based on the colour parameters of bulbs (a) and cloves (b, c, d)

Conclusion

Based on the results obtained, the following conclusions can be drawn: (i) the garlic accessions from the SRGB at the Agricultural Institute of Slovenia have shown relatively high morphological diversity, based on the UPOV descriptors examined; (ii) the majority of the garlic accessions had a white ground colour of the dry external scales; (iii) 45% of the accessions developed small (<20 g), 35% medium (20–40 g), and 20% large garlic bulbs (>40 g); and (iv) the predominant colours of the clove scales were cream, pink, purple, and/or brown. These genetic resources represent diverse heritage that can play a key role in breeding new varieties and preventing genetic erosion in the future. Therefore, further agromorphological, molecular, and nutritional analyses are proposed to obtain an in-depth characterization of these garlic accessions.

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Морфометријске карактеристике и боја принова бијелог лука (*Allium sativum* L.) у Пољопривредном институту Словеније

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Сажетак

Бијели лук је врста из породице Alliaceae која се размножава вегетативно и испољава велику морфолошку разноликост. У свијету се користи као важан зачин у кулинарству и традиционалној медицини. На основу различитих морфометријских карактеристика, боје луковица и ченова проучаване су принове бијелог лука из Словеначћке банке биљних гена на Пољопривредном институту Словеније. На огледним пољима Инфраструктурног центра Јабље произведено је и описано укупно 49 принова бијелог лука у току 2023. године. Од морфометријских особина рађене су тежина, висина и пречник луковице, однос висине и пречника, број ченова и величину ченова. Квалитативни дескриптори укључивали су десет особине према УПОВ дескриптору који се односе на присуство цвјетног стабла, луковицу (величина, основна боја сувих овојних листова, присуство антоцијана на сувим спољашњим листовима, број ченова) и ченове (величина, боја сувих листова чена, интензитет боје сувог листа, присуство антоцијана, боја чена). Резултати су показали значајне разлике између принова у погледу величине луковице и параметара боје. Тежина луковице кретала се од 8,6–54,1 г, висина луковице од 26,5–45,8 мм и пречник луковице од 31,4–58,9 мм. Просјечан број ченова био је 10 ± 3, а тежина ченова 3,0 ± 1,2 г. Преовлађујуће основне боје сувих овојних листова луковице биле су бијела и жућкасто бијела, 31 и 18 принова. Боје сувих листова чена била је претежно розе/љубичасте, розе/љубичасте/смеђе, смеђе, крем/ружичасте или крем боје, са присуством антоцијана у скоро 75% принова. Највећи коефицијенти варијације примјећени су за величину луковице (49,6%) и величину ченова (39,6%), а најмањи за однос висине и пречника (6,2%). Добијени подаци и варијабилност проучаваних особина указују на то да принове бијелог лука захтијевају даље детаљније агроморфолошке, нутритивне и генетичке анализе како би се идентификовали најбоље принове за будуће оплемењивање.

Кључне ријечи: принова, *Allium sativum*, бијели лук, морфометријски дескриптор, параметар боје

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