

Morpho-numeric characterisation of Slovenian garlic varieties (*Allium sativum* L.)

Lovro Sinkovič , Mojca Škof , Barbara Pipan 

¹ *Agricultural Institute of Slovenia, Ljubljana, Slovenia*

Abstract

Garlic is a widely consumed bulbous crop primarily used as a culinary spice and in pharmaceutical applications. Slovenia has a long tradition of garlic cultivation, as evidenced by traditional varieties originating from the north-eastern region. Over the past four decades, seven garlic varieties have been developed and registered on the Slovenian National List of Varieties: Ptujski jesenski, Ptujski spomladanski, Jesenski Anka, Štrigon, Haloški, Primorski, and Markovski. These varieties were characterised and evaluated using prescribed *Allium sativum* descriptors, morphometric, and photographic documentation. Field trials were conducted using vegetative propagation in an unheated tunnel at the Agricultural Institute of Slovenia during the 2023/2024 growing season. Plant and leaf traits were assessed at defined developmental stages. Garlic was harvested at technological bulb maturity, dried, and morphologically characterised after three months of storage using six bulbs or ten representative cloves per variety. Eight quantitative and 27 qualitative traits were evaluated for each variety, covering plant, leaf, bulb, and clove characteristics. Significant varietal differences were observed for both quantitative and qualitative traits. Leaf length ranged from 36 to 64 cm and leaf width from 21 to 31 mm. The number of cloves per bulb ranged from 6 to 18, bulb weight from 23 to 57 g, and clove weight from 2.3 to 4.6 g. The varieties differed in foliage density and attitude, leaf colour, waxiness, and cross-sectional shape. Ptujski jesenski and Ptujski spomladanski did not develop a flowering stem and were classified as softneck types. Bulb ground colour of dry outer scales and clove scale colour were variety-dependent. The data provide a comprehensive morpho-numeric characterisation and detailed description of Slovenian garlic varieties developed over the last four decades.

Key words: Descriptors, Garlic variety, Plant genetic resources, Morpho-numeric traits, UPOV

Introduction

Garlic (*Allium sativum* L.) is an important vegetable crop cultivated worldwide, valued both as a culinary spice and for pharmaceutical and functional food applications (Yan et al., 2023; Chaudhari et al., 2022). Because garlic is predominantly vegetatively propagated, varieties are maintained as clonal lineages, which supports the preservation of stable morphological phenotypes and locally adapted types. In this context, morphological characterisation remains a cornerstone for variety identification, documentation, and the management of plant genetic resources (Kıraç et al., 2022).

Garlic genotypes are commonly classified according to the development of the flowering stem (scape) into two botanical varieties. *Allium sativum* var. *sativum*, known as softneck (or non-bolting) garlic, does not develop a flowering stem, whereas *Allium sativum* var. *ophioscorodon*, known as hardneck (or bolting) garlic, produces a scape (Alsup-Egbers et al., 2020; Sultan and Raina, 2020). Typically, hardneck garlic varieties have 4–12 cloves arranged around the flowering stem, while softneck garlic often contains 10–40 cloves arranged in multiple layers. Softneck garlic usually has a longer shelf life than hardneck garlic and can be stored for 6–8 months without significant deterioration (Selen et al., 2022).

Slovenia has a long tradition of garlic cultivation, particularly in north-eastern regions, where older cultivation practices have contributed to the persistence of local material. In 2024, annual garlic production reached 783 tonnes on 147 ha, of which approximately 55% was intended for the market (Si-Stat, 2026). Average garlic yield depends primarily on weather conditions and cultivation technology and is approximately 5 t ha⁻¹. Domestic production does not meet market demand; consequently, about 2.557 tonnes of garlic are imported annually, mainly from China, the Netherlands, Italy, Egypt, and Spain (Si-Stat, 2026).

Over the last four decades, seven garlic varieties have been bred and entered into the Slovenian National List of Varieties: Ptujski jesenski (1989), Ptujski spomladanski (1989), Jesenski Anka (2011), Štrigon (2014), Haloški (2018), Primorski (2018) and Markovski (2023) (National List of Varieties [...], 2025). Comprehensive and standardised descriptions of these varieties are essential for variety identification and differentiation, conservation and documentation of genetic resources, targeted use by growers and processors, and as a foundation for future breeding and quality-related research.

Standardised descriptor systems, such as the UPOV Test Guidelines for garlic, provide harmonised characteristics and scoring scales for describing foliage, leaf, pseudostem, bulb and clove traits and enable comparison across studies and environments. Such standardised descriptions are particularly

important for the long-term conservation and rational use of national plant genetic resources. Therefore, the aim of the present study was to generate a morpho-numeric characterisation of the seven Slovenian registered garlic varieties under uniform cultivation and storage conditions using UPOV TG/162/4 Rev. (2022) descriptors in combination with quantitative morphometric measurements of plants, bulbs, and cloves.

Material and Methods

Seven garlic (*Allium sativum* L.) varieties registered in the Slovenian National List of Varieties (2025), i.e., Ptujski jesenski, Ptujski spomladanski, Jesenski Anka, Štrigon, Haloški, Primorski, and Markovski, were evaluated during the 2023/2024 growing season (Fig. 1). The experiment was conducted in an unheated tunnel at the Agricultural Institute of Slovenia in Jablje (304 m a.s.l.; 46.151° N, 14.562° E). Garlic was grown from cloves under uniform agronomic conditions following standard production practices.

The field trial included twelve plants per variety, arranged in three-row strips at a spacing of 30 cm × 10 cm. A drip irrigation system was installed. Cloves were planted in early November 2023, and mature bulbs were harvested in late June 2024. Garlic was fertilised once during growth in early spring 2024 with 96 kg ha⁻¹ N, 64 kg ha⁻¹ P₂O₅, 128 kg ha⁻¹ K₂O, 24 kg ha⁻¹ MgO, and 80 kg ha⁻¹ SO₃, and irrigated as required. Plant and leaf traits were recorded at defined developmental stages during the growing period. Bulbs were harvested at technological maturity, dried, and stored under uniform conditions (room temperature and constant relative humidity) for three months prior to postharvest evaluation.

Morphological characterisation was carried out using the UPOV Test Guidelines for garlic (UPOV TG/162/4 Rev., 2022). The assessment included 27 qualitative characteristics covering foliage, leaf, pseudostem, bulb and clove traits, and eight quantitative measurements. The quantitative traits leaf length (cm) and width (mm) were measured using a sewing meter with an accuracy of 0.1 mm. Qualitative traits were scored using the prescribed UPOV 1–9 scale, while quantitative traits included leaf length and width, bulb weight, bulb height and diameter, bulb height/diameter ratio, number of cloves per bulb, and clove weight. Where more than one state of expression occurred within a variety, combined UPOV notes (e.g., 5/7) were recorded.

For postharvest evaluation, six fully developed bulbs per variety were assessed for bulb traits, and ten representative cloves per variety were used for clove traits. The quantitative traits 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. Quantitative data are presented as mean $\pm$ standard deviation. Results are presented descriptively, supported by numerical ranges and UPOV descriptor states, to enable morpho-numeric comparison among varieties.

Results and Discussion

The evaluated Slovenian garlic varieties exhibited clear morphological differentiation in both quantitative and qualitative traits. Vegetative traits varied considerably among varieties, with mean leaf length ranging from 35.5 cm (Jesenski Anka) to 63.7 cm (Primorski), and mean leaf width from 20.7 mm (Jesenski Anka) to 30.8 mm (Markovski) (Tab. 1), corresponding to the UPOV classes from short to long and from medium to broad. Foliage density ranged from loose to dense, while foliage attitude varied from erect to semi-erect (Tab. 2). Leaf green colour was mainly medium to dark, and waxiness ranged from medium to very strong, indicating marked canopy differences useful for varietal distinction and potentially relevant for agronomic performance.

Tab. 1 - Mean values ($\pm$ SD) of quantitative morphological traits of seven Slovenian garlic (*Allium sativum* L.) varieties

Variety	Leaf length (cm)	Leaf width (mm)	Bulb weight (g)	Bulb height (mm)	Bulb diameter (mm)	Ratio height/diameter	Number of cloves per bulb	Clove weight (g)
Ptujski jesenski	53.0 $\pm$ 4.0	26.3 $\pm$ 1.8	47.2 $\pm$ 3.7	43.1 $\pm$ 1.1	56.7 $\pm$ 2.7	0.76 $\pm$ 0.02	9.8 $\pm$ 1.6	4.6 $\pm$ 1.5
Ptujski spomladanski	55.8 $\pm$ 3.5	21.8 $\pm$ 3.2	27.1 $\pm$ 3.5	35.8 $\pm$ 1.0	46.9 $\pm$ 3.2	0.77 $\pm$ 0.04	13.8 $\pm$ 1.3	2.5 $\pm$ 0.7
Jesenski Anka	35.5 $\pm$ 1.3	20.7 $\pm$ 2.4	27.6 $\pm$ 4.5	37.2 $\pm$ 1.6	42.6 $\pm$ 2.9	0.88 $\pm$ 0.04	5.8 $\pm$ 1.2	4.3 $\pm$ 1.1
Štrigon	57.8 $\pm$ 5.1	23.5 $\pm$ 2.4	26.2 $\pm$ 2.9	35.2 $\pm$ 1.1	43.5 $\pm$ 2.6	0.81 $\pm$ 0.06	12.2 $\pm$ 0.9	2.3 $\pm$ 0.8
Haloški	38.8 $\pm$ 3.0	25.0 $\pm$ 2.8	28.7 $\pm$ 6.1	38.6 $\pm$ 3.1	44.1 $\pm$ 3.7	0.88 $\pm$ 0.05	6.8 $\pm$ 0.7	3.8 $\pm$ 1.4
Primorski	63.7 $\pm$ 4.6	27.8 $\pm$ 4.5	56.5 $\pm$ 7.5	45.3 $\pm$ 2.2	57.0 $\pm$ 2.6	0.79 $\pm$ 0.02	17.5 $\pm$ 1.5	3.4 $\pm$ 1.3
Markovski	42.5 $\pm$ 2.8	30.8 $\pm$ 1.7	23.0 $\pm$ 9.5	38.8 $\pm$ 4.1	45.0 $\pm$ 8.3	0.88 $\pm$ 0.08	7.2 $\pm$ 1.3	3.1 $\pm$ 1.0

Values represent mean $\pm$ SD ($n=6$ bulbs; $n=10$ cloves per variety).

The UPOV pseudostem characteristic flowering stem clearly separated the varieties into softneck and hardneck types. Ptujski jesenski and Ptujski spomladanski did not develop a flowering stem and were therefore classified as softneck types, while all other varieties were classified as hardneck. This distinction is of practical importance as it affects crop management, bulb structure, and market use, and is recommended as a grouping characteristic in the UPOV guidelines.

Tab. 2 - Selected qualitative characteristics of Slovenian garlic varieties scored according to UPOV TG/162/4 Rev. (2022)

Variety / UPOV descriptor		Ptujski jesenski	Ptujski spomladanski	Jesenski Anka	Štrigon	Haloški	Primorski	Markovski
Foliage	1. Density	5	3	5	5	7	5	5/7
	2. Attitude	2	2	1/2	1	1	1/2	1
Leaf	3. Green colour	5	5/7	7	7	5	7	5/7
	4. Waxiness	5	7	9	7	5	7	5
	7. Shape in cross section	2	1/2	2	2/3	2	1/2	3
Pseudostem	10. Flowering stem	1	1	9	9	9	9	9
Bulb	15. Shape in longitudinal section	2	2	2	2	2/3	2/3	2
	16. Shape in cross section	2	1	2	1/2	2	2	2
	17. Position of cloves at tip of bulb	2	3	2	2	2	2	2
	18. Position of root disc	2	2	2	2	2	2	2
	19. Shape of base	2	2	2/3	2/3	2	2	2
	20. Compactness of cloves	5/7	7	7	3/5	7	5/7	5
	21. Ground colour of dry external scales	2	1	1	3	2	1	2
	22. Anthocyanin stripes on dry external scales	1	1	1	9	9	1	9
	23. Skin adherence of dry external scales	5	5	7	5	7	5	5
	24. Thickness of dry external scales	5	5	7	5	5	5	5
	26. Distribution of cloves	2	2	1	1	1	1	1
	27. External cloves	9	9	1	1	1	1	1
	29. Colour of scale	2	2/3	5	3/4	5	3/4/5	5
	30. Intensity of colour of scale	5	3	7	7	7	7	7
	31. Anthocyanin stripes on scale	9	9	9	9	9	9	1
Clove	32. Colour of flesh	2	2	2	2	2	2	2

UPOV notes: 1. (3 loose, 5 medium, 7 dense); 2. (1 erect, 2 erect to semi-erect); 3. (5 medium, 7 dark); 4. (5 medium, 7 strong, 9 very strong); 7. (1 strongly concave, 2 slightly concave, 3 flat); 10. (1 absent, 9 present); 15. (2 transverse broad elliptic, 3 circular); 16. (1 elliptic, 2 circular); 17. (2 at same level, 3 exerted); 18. (2 flat); 19. (2 flat, 3 rounded); 20. (3 loose, 5 medium, 7 compact); 21. (1 white, 2 yellowish white, 3 reddish white); 22. (1 absent, 9 present); 23. (5 medium, 7 strong); 24. (5 medium, 7 thick); 26. (1 radial, 2 non-radial); 27. (1 absent, 9 present); 29. (2 cream, 3 pink, 4 purple, 5 brown); 30. (3 weak, 5 medium, 7 strong); 31. (1 absent, 9 present); 32. (2 yellowish).

Pronounced variability was also observed in bulb traits. Mean bulb weight ranged from 23.0 g (Markovski) to 56.5 g (Primorski), spanning medium to large UPOV size classes (Tab. 1). Bulb height and diameter varied accordingly, and bulb shape in longitudinal and cross section was predominantly transverse elliptic to circular. Structural bulb descriptors, including compactness of cloves, position of root disc, and shape of the bulb base, further contributed to varietal differentiation (Tab. 2).

The number of cloves per bulb ranged from 5.8 (Jesenski Anka) to 17.5 (Primorski), while mean clove weight ranged from 2.3 g (Štrigon) to 4.6 g (Ptujski jesenski). A general trade-off between clove number and clove size was observed, which is relevant for both propagation and commercial use. UPOV class-based scoring of these traits enabled consistent comparison among varieties despite differences in absolute values.

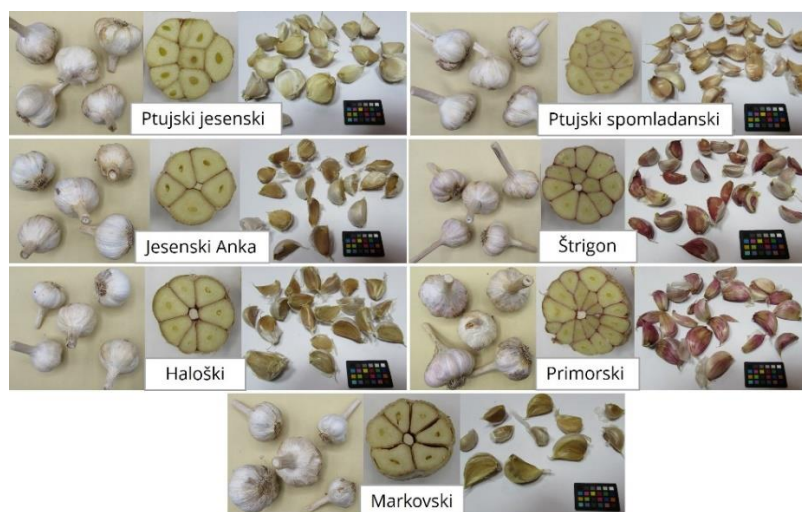


Fig. 1 - Bulb and clove size, shape and colour, and bulb cross-sections of seven Slovenian garlic (*Allium sativum* L.) varieties

Colour-related characteristics of bulbs and cloves proved highly discriminative (Fig. 1). The ground colour of dry, external bulb scales ranged from white to reddish white among varieties, and anthocyanin stripes on dry external scales were present in some varieties but absent in others. Clove scale colour ranged from white and cream to pink, purple, and brown, with generally medium to strong colour intensity. Anthocyanin stripes on clove scales were common, although absent in Markovski. Clove flesh colour was consistently yellowish across all varieties. These qualitative traits are especially useful for

variety identification at the postharvest stage and as UPOV grouping characteristics.

Overall, the combined use of quantitative measurements and UPOV qualitative descriptors enabled robust morpho-numeric characterisation of the studied varieties. The results demonstrate that Slovenian garlic varieties developed over the last four decades encompass substantial morphological diversity. Although the evaluation was conducted in a single environment, many qualitative traits are considered stable and suitable for variety description. Nevertheless, multi-year and multi-location testing would be beneficial for assessing the environmental stability of quantitative traits related to bulb size and yield components.

Conclusion

Seven Slovenian-registered garlic varieties were characterised using the UPOV TG/162/4 Rev. (2022) descriptor system combined with quantitative morphometric measurements under uniform cultivation and storage conditions. Clear varietal differentiation was observed at both vegetative and postharvest stages. Leaf length ranged from 35.5 to 63.7 cm and leaf width from 20.7 to 30.8 mm, while bulb weight ranged from 23.0 to 56.5 g. The number of cloves per bulb varied from 5.8 to 17.5, and clove weight from 2.3 to 4.6 g. Ptujski jesenski and Ptujski spomladanski were classified as softneck types due to the absence of a flowering stem, while the remaining varieties were classified as hardneck types.

Further varietal differentiation was based on foliage habit and waxiness, bulb structure, and bulb and clove scale colour traits, including the presence or absence of anthocyanin striping. The resulting morpho-numeric dataset provides a harmonised and detailed description of Slovenian garlic varieties developed over the past three decades and represents a valuable baseline for variety identification, genetic resource documentation, and future studies linking morphological variation with yield and quality traits. These data may also support future breeding programmes and quality-oriented evaluation of garlic varieties.

Acknowledgements

This study was funded by the Agrobiodiversity Research Programme (P4-0072) and by bilateral projects between Slovenia and Bosnia and Herzegovina (BI-BA/26-27-033 and BI-BA/24-25-043) financed by the Slovenian Research and Innovation Agency.

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Морфолошко-нумеричка карактеризација словеначких сорти бијелог лука (*Allium sativum* L.)

Ловро Синкович, Мојца Шкоф, Барбара Пипан

Пољопривредни институт Словеније, Љубљана, Словенија

Сажетак

Бијели лук је широко коришћена луковичаста култура која се првенствено употребљава као зачин у кулинарству и у фармацеутским препаратима. Словенија има дугу традицију гајења бијелог лука, о чему свједоче традиционалне сорте поријеклом из сјевероисточног дела земље. Током последње четири деценије развијено је и регистровано седам сорти бијелог лука на Сортној листи Републике Словеније: Птујски јесенски, Птујски спомладански, Јесенски Анка, Штригон, Халошки, Приморски и Марковски. Ове сорте су окарактерисане и оцијењене примјеном прописаних дескриптора за *Allium sativum*, морфометријских мјерења и фотографске документације. Пољски огледи су спроведени вегетативним размножавањем у негријаном пластенику на Кметијском институту Словеније током вегетационе сезоне 2023/2024. Особине биљака и листова процјењиване су у дефинисаним фазама развоја. Бијели лук је убран у технолошкој зрелости луковице, осушен и морфолошки окарактерисан након три месеца складиштења, користећи шест луковица или десет репрезентативних ченова по сорти. За сваку сорту оцијењено је осам квантитативних и 27 квалитативних особина које обухватају карактеристике биљке, листа, луковице и чена. Утврђене су значајне сортне разлике како у квантитативним, тако и у квалитативним особинама. Дужина листа кретала се од 36 до 64 cm, а ширина листа од 21 до 31 mm. Број ченова по луковичи варирао је од 6 до 18, маса луковице од 23 до 57 g, а маса чена од 2,3 до 4,6 g. СORTE су се разликовале по густини и положају лишћа, боји листа, воштаној превлаци и облику попречног пресека листа. СORTE Птујски јесенски и Птујски спомладански нису развиле цвјетну стабљику и класификоване су као типови са меким вратом (*softneck*). Основна боја сувих спољашњих љуски луковице и боја љуске чена биле су условљене сортом. Добијени подаци пружају свеобухватну морфолошко-нумеричку карактеризацију и детаљан опис словенских сорти бијелог лука развијених током последње четири деценије.

Кључне ријечи: сорте бијелог лука, биљни гентички ресурси, морфонумеричка својства, UPOV.

Corresponding author: Lovro Sinkovič

E-mail: lovro.sinkovic@kis.si

Received: March, 02, 2026

Accepted: September, 03, 2026