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Yield of commercial garlic (*Allium sativum* L.) varieties at three locations in Slovenia over two growing seasons

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Abstract

Garlic is an important crop for domestic consumption in Slovenia, used fresh or cooked in traditional and modern cuisine. However, there is little data available on the yield performance of commercial garlic varieties grown under different climatic conditions, which could help farmers to select the best-performing variety for cultivation. Field trials were conducted at three locations (Jablje, Ivanci, Šempeter) in Slovenia during two consecutive growing seasons (2020/21 and 2021/22) to evaluate the response of different garlic varieties. Ten commercial garlic varieties were used as experimental material: Ptujski jesenski, Garcua, Sabagold, Garpek, Gardacho, Germidour, Messidrome, Arno, Messidor, and Ptujski spomladanski. The same cultivation method and fertilisation regimes were applied in three replicates at each trial site. At Jablje, an unheated tunnel was used, while the trials at the other two sites were conducted under open field conditions. Marketable and non-marketable yields were determined five days after harvest. The total yield varied considerably from 3.13 t/ha for the Ptujski jesenski variety to 20.49 t/ha for Sabagold. The non-marketable yield was significantly higher (up to 40%) for the Slovenian varieties Ptujski jesenski and Ptujski spomladanski, due to their susceptibility to virus diseases and the lack of quality seed material. The best-performing marketable yields were recorded for the Sabagold, Messidrome, and Gardacho varieties with an average of over 11.5 t/ha. Among the different locations, the sub-Mediterranean climate proved to be less favourable for the production of market garlic, especially for late varieties. Results of statistical analysis have shown that the year, location, and variety all

had a significant effect on marketable yield. Each factor contributes independently to yield variation, with year having the strongest effect, followed by location and variety. The data clearly show that the choice of garlic variety is the key to achieving high marketable yields.

Key words: garlic variety, *Allium sativum*, marketable yield, climate, experimental site.

Introduction

Garlic (*Allium sativum* L.) is one of the oldest herbaceous plants with its centre of origin considered to be Central Asia, from where it spread to the Mediterranean region and beyond (Dhall et al., 2023; Condor et al., 2019). Today, it is cultivated worldwide for its edible bulbs, which consist of a variable number of cloves used both as food and as a pharmaceutical raw material (Kıraç et al., 2022). However, its cultivation is hampered by the infertility of commercial varieties and the accumulation of pathogens over time as a consequence of vegetative or clonal propagation (Leišová-Svobodová et al., 2024; Parreño-Montoro et al., 2023). The genotype, temperature, photoperiod, and planting time significantly affect the growth period, plant height, bulb weight, and flowering rate (Wu et al., 2016). Garlic bulbs and cloves are influenced by day length and temperature, with low initial temperatures followed by long days required for optimal development (Bandara et al., 2000).

Worldwide, nearly 29 million tonnes of garlic are produced each year, of which Europe accounts for 2.5%. The largest producers are China, India, Korea, and Egypt (Food and Agriculture Organization Statistics [FAOSTAT], 2025). Garlic cultivation also has a long tradition in Slovenia, both in small family gardens and for market production. The best-known and most widespread local varieties are Ptujski jesenski and Ptujski spomladanski, which have had faced significant problems with viruses in recent years, leading to large crop losses. According to the Statistical Office of the Republic of Slovenia (SI-STAT), the average annual production over the last five years has been about 1000 tonnes of garlic on around 175 hectares, with 100 hectares devoted to intensive marketable production (SI-STAT, 2025). Average yields are between 4.5 and 6.0 tonnes per hectare, although they can be much higher in intensive commercial garlic production. In Slovenia, it is recommended to plant garlic in the autumn, preferably in October or November. This allows the first roots to develop well before the onset of low winter temperatures, and further root and leaf growth to continue rapidly in the spring when the temperatures rise.

Over the last decade, commercial garlic growers have adopted modern machinery for planting, hoeing, and harvesting garlic, but the cleaning process is

still done manually and is a major cost factor. In addition, there is little data on how well different commercial garlic varieties grow in different climates, which could help farmers choose the best variety to grow. This study aims to evaluate the marketable yield potential of several commercial garlic varieties at different locations in Slovenia with diverse climates over two years of field trials.

Material and Methods

The ten varieties of garlic (*Allium sativum* L.) were obtained from commercial suppliers of plant material: Ptujski jesenski and Ptujski splomladanski (origin/supplier Semenarna Ljubljana, Slovenia), Garcua, Sabagold, Garpek, and Gardacho (origin Planasa; supplier Aspega, Slovenia), Germidour and Messidrome (origin Top Onion Sets B.V., Netherlands; supplier Roko, Slovenia), Arno and Messidor (origin Agri Obtentions, France; supplier HP hybrid, Slovenia). Three locations in Slovenia with different climates, namely sub-alpine (Jablje), temperate continental (Ivanci), and sub-Mediterranean (Šempeter), were tested (Figure 1). Field trials were conducted at each site in three replicates during the 2020/2021 and 2021/2022 growing seasons, using the same cultivation practices and fertilization regimes. An unheated tunnel was used at Jablje, while the trials at the other two sites were conducted under open field conditions. The field trials were set up in four-row strips with a planting density of 20 cm × 10 cm (285.000 plants/ha) and a plot size of 1.4 m2. Garlic cloves were planted by hand in late October or early November and mature bulbs were harvested in late June or early July of each growing season. The garlic plants were fertilized once during growth in early spring with 96 kg/ha N, 64 kg/ha P_2O_5, 128 kg/ha K_2O, 24 kg/ha MgO, and 80 kg/ha SO_3 and irrigated as needed.

In 2021, February was very warm with average rainfall, March warm and dry, April cold with average rainfall, May cold with a lot of precipitation, while June was dry and warm above average according to the data from the Slovenian Environment Agency. In contrast to the season 2021, February 2022 was above average warm and dry, March mostly warm and extremely dry, April cold and rainy, and May and June above average warm and dry. The garlic bulbs were harvested at the commercial maturity stage, depending on the variety. They were left over to dry in a dark place about five days after harvest. For yield evaluation, all bulbs in each plot were cleaned and leaves removed and weighted as non-marketable yield, while the remainder represented marketable yield. An electronic field scale (reading to 2 g) was used to weigh the yield. Total yield was calculated as the sum of non-marketable and marketable yield. The results of yield are expressed as weight in t/ha and were calculated as the mean of three replicates. Data was analyzed using R Commander software (version 4.0.3),

statistical significance of differences between varieties, locations, and years was determined by analysis of variance (ANOVA) at $p \leq 0.05$.

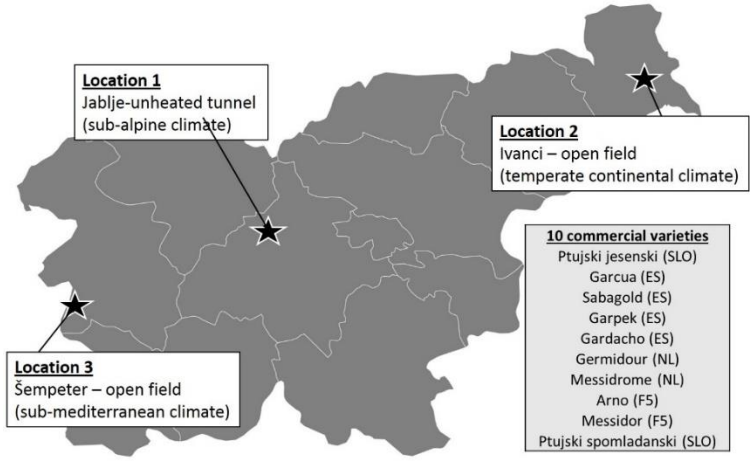

Fig. 1 Trial sites in Slovenia under different climate types and a list of the garlic varieties tested

Results and Discussion

The technological yield trials with different varieties available on local markets provide valuable information for garlic producers, helping them identify the most productive and resilient garlic varieties suitable for their specific growing conditions. Fig. 2 summarises the results of the total yield over two growing seasons at three locations for ten garlic varieties studied. The total yield varied considerably depending on the variety, growing season, and location, ranging from a minimum of 3.13 t/ha for the Ptujski jesenski variety to a maximum of 20.49 t/ha for Sabagold. On average, the marketable yield reached 60.8 to 98.7% of the total yield, while the non-marketable yield was between 1.3 and 39.2%. Among the varieties with low non-marketable yield (< 7%) were Sabagold, Messidrome, Gardacho, Garpek, and Garcua, medium non-marketable yield (7–15%) Germidour, Arno, and Messidor, and high non-marketable yield (>15%) Prujski jesenski and Ptujski spomladanski. The different rates in the range between 6–35% and 2–11% for non-marketable yield were previously reported for garlic from Lithuania and Ethiopia, respectively (Galgaye and Deresa, 2023; Juškevičienė et al, 2022).

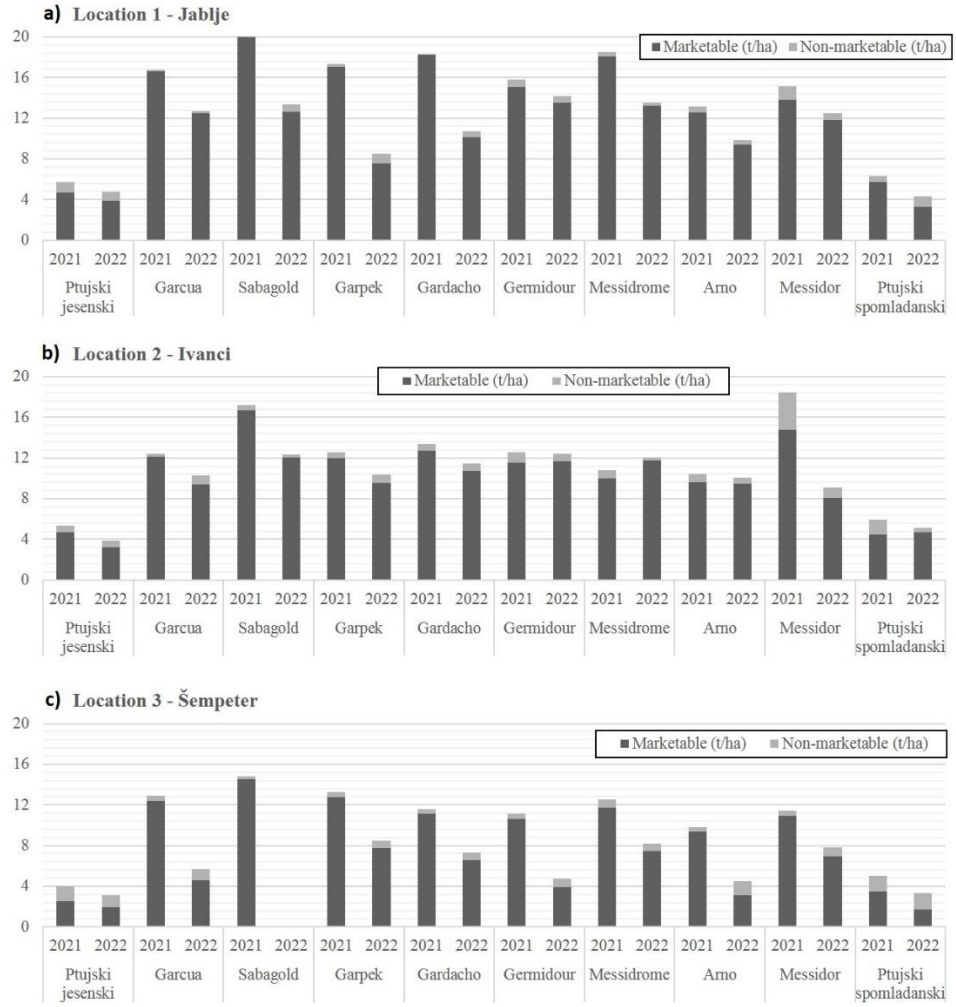

Fig. 2 Total yield (t/ha) over two growing seasons at three locations a) Jablje, b) Ivanci, and d) Šempeter

In the two years tested, it can be seen that the 2020/2021 growing season was more favourable for garlic production than the 2021/2022 growing season, as the total yield was higher at all locations and for all varieties. In addition, location 3 (Šempeter) with the sub-Mediterranean climate showed a lower total yield for most varieties compared to the other two locations, especially in the second growing season. When comparing different production locations, the sub-

Mediterranean climate proved to be less favourable for the production of market garlic compared to the sub-alpine or temperate continental climate, especially for late garlic varieties harvested in late June or early July and thus exposed to the first heat waves.

The marketable yield, irrespective of the growing season, for ten garlic varieties investigated is shown in Tab. 1. The results show that the Sabagold variety achieved the best marketable yield at all three locations with ≥ 14.39 t/ha. A group of six varieties, i.e., Messidrome, Germidour, Gardacho, Garcua, Garpek, and Messidor have also shown high and stable marketable yields in different growing climates. The Arno variety, on the other hand, had lower marketable yields, but these were still almost 10 t/ha. In contrast to the other varieties studied, Ptujski jesenski and Ptujski spomladanski did not exceed a marketable yield of 5 t/ha even under the most favourable conditions. The average marketable yields were highest for all varieties at location 1 (Jablje), where the cultivation was covered by an unheated tunnel and protected from direct rain. In general, the data on the marketable yield of garlic is consistent with previously published data, all ranging from 3.8 to 17.1 t/ha (Juškevičienė et al, 2022; Ayed et al, 2019; Dubey et al, 2010). The study has shown that the amount of marketable garlic production is comparable to that in other European countries such as Spain, where average yields reach from 7.6 to 10.6 t/ha (FAOSTAT, 2025).

Tab. 1 Marketable yield at three locations regardless the growing season for ten garlic varieties studied

Variety	Marketable yield (t/ha)		
	Jablje	Ivanci	Šempeter
Ptujski jesenski	4.31 ± 0.95	3.97 ± 0.38	2.20 ± 0.34
Garcua	14.57 ± 0.52	10.77 ± 1.29	8.46 ± 0.44
Sabagold	16.43 ± 0.75	14.39 ± 0.82	14.55 ± 1.23
Garpek	12.30 ± 1.58	10.77 ± 0.84	10.28 ± 0.60
Gardacho	14.17 ± 0.76	11.72 ± 0.78	8.85 ± 0.73
Germidour	14.26 ± 1.20	11.63 ± 1.55	7.27 ± 0.76
Messidrome	15.62 ± 0.92	10.89 ± 1.36	9.60 ± 0.35
Arno	10.98 ± 1.20	9.53 ± 1.06	6.27 ± 0.18
Messidor	12.83 ± 0.91	11.44 ± 1.56	8.92 ± 1.42
Ptujski spomladanski	4.51 ± 0.53	4.59 ± 0.78	2.61 ± 0.41

Data are means (n=6) ± standard deviation

Statistical analysis has shown that the year, location, and variety all have a significant influence on the marketable yield (Tab. 2). Each of these factors contributes independently to yield variations, with year showing the strongest effect, followed by location and variety. Furthermore, the interactions between

these factors are significant, suggesting that the influence of one factor on yield is dependent on the others. In particular, the effect of year on yield varied by location, and the performance of different varieties varied by year and location. The combined interaction of all three factors further emphasises their interrelated influence on marketable yield.

Tab. 2 Three-way ANOVA for marketable yield - effects of year, location, and variety with interactions

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	1	688.51	688.51	445.03	< 2.2e-16 ***
Location	2	704.18	352.09	227.58	< 2.2e-16 ***
Variety	9	1779.91	197.77	127.83	< 2.2e-16 ***
Year*Location	2	111.50	55.75	36.03	5.812e-13 ***
Year*Variety	9	222.43	24.71	15.97	< 2.2e-16 ***
Location*Variety	18	203.52	11.31	7.31	2.621e-12 ***
Year*Location*Variety	18	185.65	10.31	6.67	3.080e-11 ***
Residuals	119	184.11	1.55		

***, $p < 0.001$

Conclusion

Based on the results obtained, the following conclusions can be drawn: (i) commercial garlic production can be suitable throughout Slovenia with the right variety selection and production technology; (ii) most local garlic varieties have significant problems with viruses leading to large crop losses; (iii) under favourable conditions during the growing season, garlic producers in Slovenia can expect an average marketable yield of 12 to 15 t/ha; and (iv) the recommended garlic varieties for cultivation include Sabagold, Messidrome, and Gardacho. The Ptujski jesenski and Ptujski spomladanski garlic varieties, which represent the local plant genetic heritage, require treatment for viruses to prevent genetic erosion in the future, despite their adaptability to the local climate.

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Принос комерцијалних сората бијелог лука (*Allium sativum* L.) на три различите локације у Словенији током двије сезоне узгоја

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Сажетак

Бијели лук је важна култура за домаћу потрошњу у Словенији, гдје се користи у свјежем облику или термички обрађен у традиционалним и модерним јелима. Ипак, постоји мало података о приносима комерцијалних сората бијелог лука узгојеног у различитим климатским условима, што би могло бити од помоћи произвођачима приликом избора најбоље сорте за узгој. На три локације у Словенији (Јабље, Иванци, Шемпетер) вршена су испитивања током двије узастопне сезоне узгоја (2020/21 and 2021/22) како би се оцијенили резултати добијени за различите сорте бијелог лука. Као експериментални материјал коришћено је десет комерцијалних сората бијелог лука: Птујски јесенски, Garcua, Sabagold, Garpek, Gardacho, Germidour, Messidrome, Arno, Messidor и Птујски спомладански. Примијењени су идентични методи узгоја и режими прихрањивања на три понављања у оквиру сваке експерименталне локације. У Јабљу је коришћен незагријани тунел, док су истраживања на друге двије локације спроведена у условима отвореног поља. Тржишни и нетржишни приноси су одређивани пет дана након бербе. Укупан принос је значајно варирао од 3.13 t/ha за сорту Птујски јесенски до 20.49 t/ha за Sabagold. Нетржишни принос је био знатно виши (до 40%) за словеначке сорте Птујски јесенски и Птујски спомладански, због њихове склоности ка вирусним болестима и недостатка квалитетног садног материјала. Најбољи резултати за тржишни принос добијени су за сорте Sabagold, Messidrome и Gardacho са просјечних преко 11.5 t/ha. Међу различитим локацијама, субмедитеранска клима се показала као мање повољна за производњу тржишног бијелог лука, нарочито за касне сорте. Резултати статистичке анализе су показали да година, локација и сорта имају значајан утицај на тржишни принос. Сваки фактор засебно доприноси варијацијама у приносу, при чему година има најјачи утицај, а након ње слиједе локација и сорта. Подаци јасно показују да је избор сорте бијелог лука кључан за постизање високих тржишних приноса.

Кључне ријечи: сорта бијелог лука, , *Allium sativum*, тржишни принос, клима, експериментална локација.

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