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Research Paper

Variations in the nutritional profile and colour parameters of sweet potato varieties with different flesh colours: Effects of cropping system, mulching and growing season

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ABSTRACT

The study investigated the effects of cropping system (CS), mulching (M) and year (Y) on the nutritional profile and colour parameters of four sweet potato varieties, namely Purple Speclet, Martina, Janja and Lučka. The results showed that the variations were mainly due to the genetic makeup of the varieties, with Purple Speclet having the highest dry matter, protein, vitamin C content, total phenolic content, antioxidant potential and total soluble solids. Lučka had the highest total sugar content, while Martina and Janja only stood out in terms of glucose content. The nutritional parameters correlated strongly with the colour parameters, suggesting that colour could be a useful indicator for predicting the nutritional quality of sweet potatoes. Nutritional parameters such as total phenolic content (TPC), vitamin C, antioxidant activity (AOP) and dry matter (DM) were significantly influenced by growing season, cropping system and mulching. The growing season had the greatest influence on TPC, vitamin C, AOP and DM. Mulching had the highest impact on DM, glucose content and vitamin C, while the cropping system had the highest impact on vitamin C, AOP and protein content. In particular, organic farming without PE mulching during the growing season resulted in higher levels of vitamin C, TPC and AOP, especially in relatively less favourable weather conditions. However, when PE mulch was used, there was a significant decrease in TPC and AOP. In contrast, no significant environmental influence was observed for the colour parameters, evidently differentiated in the purple-fleshed genotype with respect to the others, indicating that they are predominantly under strong genetic control. The results could help to introduce nutrient-rich sweet potato varieties into sustainable cropping systems and promote the production of sweet potatoes in Europe, particularly the Slovenian varieties Lučka, Martina and Janja, which have not been widely cultivated to date.

1. Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.) is the sixth most important crop worldwide (Pandiselvam et al., 2023). Its production and consumption were originally concentrated in developing countries, where it is an important product for improving human nutrition (Laurie et al., 2015). However, because its management and production require low inputs, it is well adapted to marginal soils in areas ranging from the tropics to temperate zones, and especially because of its importance as a food, feed, industrial material and energy source, sweet potato cultivation has spread to different continents (Lado et al., 2021; Neela and Fanta, 2019). In recent years, awareness of the high nutritional value of sweet potato has increased consumer demand for this crop in Europe, and imports have almost tripled from 96,000 tonnes in 2013 to 244,000 tonnes in 2017 (Amankwaah et al., 2023; Kwak, 2019).

Previous studies have reported that sweet potato is a rich source of vitamins, fibre, minerals and antioxidants such as phenolic acids, anthocyanins, tocopherol and β-carotene (Alam et al., 2020; Chintha et al., 2023; Rosero et al., 2020). Worldwide, sweet potato varieties differ greatly in terms of the taste of the storage root and the size, shape and colour of the skin and flesh. The main colours of skin and flesh are white, cream, yellow, orange, pink, red, and purple (Yang et al., 2020), and this diversity, which is mainly influenced by biochemical composition, is closely related to the nutritional quality of sweet potato (Wang et al., 2018). The mixed clonal/sexual reproductive system of the sweet potato facilitates the frequent recombination of newly introduced genotypes

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with local material. An analysis of historical collections has revealed patterns of diffusion of the sweet potato in Oceania that have been obscured by modern plant movements and local recombination. The tri-partite hypothesis posits that the Kumara line represents a pre-Columbian diffusion of the sweet potato from South America into Polynesia (Roullier et al., 2012). Several recent studies focusing on variation in nutrient profile have shown a large difference between sweet potato varieties that differ in the colour of the flesh. The varieties with coloured flesh are generally distinguished from the white-fleshed varieties by their high content of secondary metabolites, sugars, proteins and fibres (Park et al., 2016; Rosero et al., 2020; Wang et al., 2018). However, in recent studies, contrasting nutritional profiles were observed in the varieties with coloured flesh. Some studies reported that the orange-fleshed varieties (OFSP) are particularly characterized by their high content of carotenoids, phenolic acids and flavonoids (Neela and Fanta, 2019; Wang et al., 2018) and contain considerable amounts of minerals, vitamins B and C and dietary fibre (Alam et al., 2020), while the red, pink and purple-fleshed varieties (RFSP, PiFSP, and PFSP) are particularly rich in anthocyanins (Park et al., 2016). In contrast, other studies reported that the total phenolic and flavonoid content was much higher in PFSP than in white (WFSP), yellow (YFSP) and orange-fleshed (OFSP) varieties, while the total starch content was positively correlated with flesh brightness (Azeem et al., 2021; Cartier et al., 2017; Chintha et al., 2023), suggesting that the nutritional composition of sweet potato, although determined by flesh colour, is variety dependent. On the other hand, previous studies have shown that sweet potato productivity and nutritional composition are influenced by the effects of genotype and environmental conditions, including growing season, agro-ecological zone, mulching and soil fertility, and genotype-environment interaction (Alam et al., 2024; Gurmu et al., 2020; Rosero et al., 2020, 2022; Sapakhova et al., 2024). There are many factors to consider when weighing up the advantages of organic and conventional farming, and there is no simple method to determine a clear "winner" for all potential farming scenarios. The higher selling price, lower yield and lower unit costs result in a higher net profit return for organic sweet potato production systems (Nwosisi et al., 2021). The organic sweet potato cultivation showed higher concentrations of minerals, such as Ca, Cu, Fe, K, Mg, Mn and P, indicating that this may be a suitable alternative for nutritional supplementation. However, no significant difference was observed in the centesimal composition (moisture, protein, lipid, ash, carbohydrate) between organic and conventional cultivation (Dos Santos et al., 2019).

In the present study, the variation in nutritional and colour parameters in four sweet potato varieties with different flesh colours (white, orange and purple) grown conventionally and organically with and without mulching over two consecutive years was analysed. To our knowledge, such combined data have not been reported before. Our overall objectives were (i) to investigate the influence of environmental factors on colour and nutritional parameters, and (ii) to characterize and differentiate the studied varieties under diverse agro-ecological conditions. The results of this research will be valuable for the improvement of local sweet potato varieties so that they can be directly utilised or promoted to improve food security, as well as for the promotion of sweet potato biodiversity and the long-term improvement of the biodiversity of agricultural ecosystems.

2. Materials and methods

2.1. Experimental design

The experiments were conducted on conventionally and organically managed experimental fields at the Biotechnical Centre in Naklo, Slovenia (46°16′18″N, 14°18′56″E, 420 m a.s.l.) from June to September in two consecutive years (2021 and 2022). The average temperature, monthly average temperature, minimum temperature, relative humidity and rainfall data of the experimental site are shown in Fig. S1. The plant material consisted of an American variety with purple skin and purple flesh that is commercially available (Purple Speclet) and three other Slovenian varieties that were registered as protected varieties in the Slovenian national variety list in 2016 (Martina, Janja and Lučka). Martina has a purple skin and white flesh, Janja has a white skin and white flesh, and Lučka has an orange skin and orange flesh (Fig. 1). The four varieties were grown in each of the trial fields both with and without polyethylene (PE) mulching during each growing season. For each trial, 20 cm high seedlings were initially vegetatively propagated in the greenhouse using cuttings derived from tubers obtained from previous growing seasons, and subsequently transplanted to the prepared trial fields. The plant spacing was 40 cm in the row and 120 cm between rows, and the trial was conducted using a randomized complete-block design with four replications of 15 seedlings. The soil type is Umbrian planosols, characterised by a silty loam texture and a bulk density of 1.61 in the top 30 cm. The pH value was 6.8, and the organic carbon content was 5.3 %. The plants were fertilised twice during the growth period with the organic fertiliser Tiger Dung 3:6:12+2MgO (Fomet, Italy) and the mineral fertiliser NPK 15–15–15 (Petrokemija Plc., Fertilizer Co., Kutina, Croatia). The application rate corresponded to the manufacturer's recommendations. At harvest, the tubers were collected and stored in a dark place at a temperature of 13–16 °C and a relative humidity of 70–80 % for further analyses. In the present study, for each variety, three healthy, marketable tubers ($\geq$ 150 g) were selected from each field block trial and used to measure a range of nutritional and colour parameters in three replicates for each sample.

2.2. Measurement of nutritional parameters

All colour and nutritional parameters were measured in both test years after three months of storage under controlled conditions (temperature 13–16 °C, relative humidity 70–80 %). For this purpose, 16 bulk samples of marketable tubers weighing $>$ 150 g were prepared, which had previously been washed and cleaned of all impurities. Each bulk sample consisted of a mixture of twelve tubers, with three tubers from each of the four field replicates. For nutritional component analysis, the homogenized fresh tubers were used to determine a range of nutritional parameters in triplicate, including dry matter (DM) content (g/kg), glucose content (g/L), total soluble solids (TSS) (°Brix), total sugars (TS) (g/kg fresh weight), protein content (% fresh weight), vitamin C (mg/100 g fresh weight), total phenolic compounds (TPC) (mg GAE/100 g fresh weight) and antioxidant potential (AOP) (mg TE/100 g fresh weight). The DM content per variety was determined as the percentage of root dry weight to fresh weight by oven-drying the homogenized fresh tubers at 103 °C for 48 h (internal method). Glucose content was measured in the juice of homogenised fresh tubers using a portable blood glucose meter (Accu-Chek® Guide). The TSS was determined in freshly pressed tuber juice using a digital refractometer (KERn Optics). The TS content was determined following inversion and expressed as glucose, with a conversion factor of 0.95 in accordance with the methodology for the analysis of feed (EC No. 152/2009, Annex III, Part J). The sugars were extracted in diluted ethanol, and the solution was clarified using Carrez solutions I and II. Subsequently, the ethanol was removed, and the quantities before and after inversion were determined using the Luff-Schoorl method (Sinkovič et al., 2023). The protein content was determined by Kjeldahl distillation unit (semi-micro method) and using the coefficient 6.25 for the calculation according to protocol AOAC 960.52 (Association of Official Analytical Chemists (AOAC, 1990). Vitamin C (L-ascorbic acid; Sigma-Aldrich, USA) was determined as described by Fatariah et al. (2015). The analysis was performed with an HPLC (Agilent 1260 Infinity, Agilent Technologies, USA) using a DAD detector with the wavelength set to 265 nm. The homogenised samples were extracted with metaphosphoric acid. Subsequently, the dehydro-L(+)-ascorbic acid was reduced to L(+)-ascorbic acid by addition of L-cysteine. The samples were centrifuged at 4000 rpm for 5 min (Eppendorf 5415D) and the upper phase was filtered through a

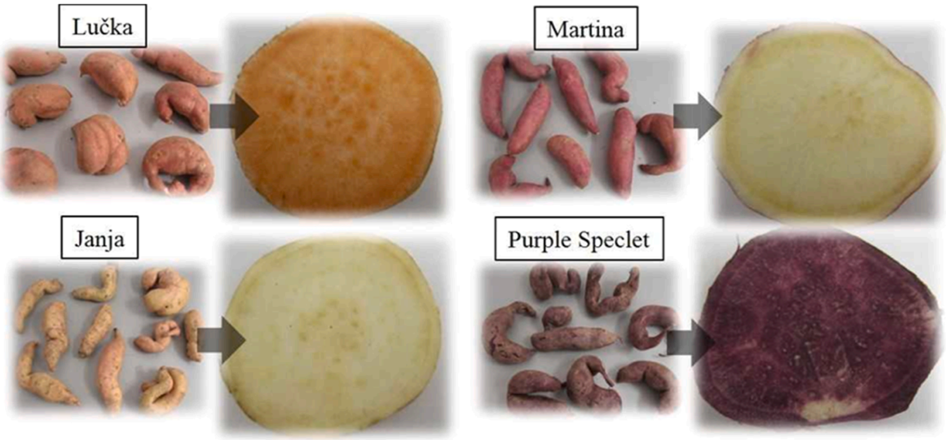


Fig. 1. Cross-sections of tubers showing colour differences in the four sweet potato varieties.

filter (17 mm syr filter CA 0.45) into vials (PK100 1.5 ml ABC vial, clear glass). The prepared samples were analysed by HPLC under the following chromatographic conditions: gradient pump (Maxi Star, Knauer); injection system 30 µL loop injection; Gemini C18 column (250 × 4.6 mm; 5 µm; Phenomenex); mobile phase: 0.004 M H_2SO_4; initiation volume 10 µL; flow rate 0.7 mL/min; retention time 5.15 min. Vitamin C concentrations were calculated using an internal standard method. For the determination of TPC and AOP, 15 g of the sample was homogenized with 15 g of ethanol using a T25 UltraTurrax homogenizer (IKA® Werke GmbH&Co. KG, Staufen, Germany) at 20,000 rpm. The homogenized samples were then centrifuged at 13,200 rpm for 10 min, and the extract (supernatant) was transferred to fresh samples and stored at −20 °C until further analysis (Sinkovič et al., 2023). TPC was determined using a modified Folin-Ciocalteu method as described by Baba and Malik (2015). Absorbance was measured after 50 min of incubation at room temperature using a spectrophotometer (Agilent Technologies Cary 8454 UV–Vis) at 765 nm against deionized water as a zero point. Gallic acid (Fluka) was used as a standard, and a 7-point calibration curve ($R^2 = 0.9990$) was constructed at concentrations of 50–500 mg/L. Using the equation of the calibration curve, the TPC of each sample was calculated from the absorbance of the samples, and the values were expressed in mg GAE/100 g fresh weight (GAE, gallic acid equivalents) (Sinkovič et al., 2023). The AOP was determined using the DPPH test (2,2-diphenyl-1-picrylhydrazyl; Sigma-Aldrich, Darmstadt, Germany), which is based on the modified method of Brand-Williams et al. (1995). The absorbance was measured after 40 min of incubation at room temperature using a spectrophotometer (Agilent Technologies Cary 8454 UV–Vis) at 520 nm against methanol as the zero point. The Trolox (a synthetic analog of vitamin E) was used as a standard. Calibration was performed using a 6-point standard curve of Trolox ($R^2 = 0.9997$) at concentrations of 32–240 mg/L. Based on the equation of the calibration curve from the difference in absorbance of reference samples and extracts, the AOP of each sample was calculated and expressed in mg TE/100 g fresh weight (TE, Trolox equivalents).

2.3. Measurement of colour parameters

A portable colourimeter (CR-400, Konica Minolta Sensing, Inc., Japan) was used to measure various colour parameters of the fresh sweet potato flesh. The sweet potato tubers were cut in half in axial cross-section and 24 individual measurements were taken per bulk sample (n = 24) in a short time to evaluate the Hunter L*a*b* parameters. Using illuminant C and an aperture of 8 mm, Hunter colour values L* (lightness), a* (redness-greenness) and b* (blueness-yellowness) were determined via the computerized system using the colour data software (Spectra Magic Nx, version CM-S100W 2.03.0006, Konica Minolta Company, Japan). The device was calibrated with standard white tiles before analysis. The Chroma (C*) was also calculated to estimate the colour intensity/saturation as $C^* = \sqrt{a^{*2} + b^{*2}}$ and the hue angle as $\arctan\left(\frac{b^*}{a^*}\right)$ (Rodríguez-Mena et al., 2023). In addition, the whiteness index (WI) was estimated as $WI = 100 - \sqrt{(100 - L^*)^2 + \left(a^{*2} + b^{*2}\right)}$ and the browning index (BI) as $BI = \frac{100 \times (x - 0.31)}{0.17}$, where $x = \frac{a^* + 1.75 \times L^*}{5.645 \times L^* + a^* - 0.3012 \times b^*}$ according to Pandiselvam et al. (2023).

2.4. Data analysis

All data analyses were performed with the statistical programming environment version 3.4.4 (R Core Team, 2021). In order to examine the variance and significance of the investigated parameters as a function of all factors and their interactions at a significance level of $P \leq 0.05$, a multivariate analysis of variance (MANOVA) was first performed, comprising the entire experimental design (V, CS, M and Y). The Pillai trace test was used to calculate the P-value. Individual ANOVAs followed by Tukey's HSD post hoc test were performed to complement the analysis and were performed to delve into the effect on individual variables. The Shapiro-Wilk test and Levene's test were used to determine whether the requirements of the MANOVA were met, specifically the normal distribution of residuals and homogeneity of variance. As most of the variance was explained by variety, its effect on the nutritional and colour parameters was further investigated separately with a MANOVA graphical biplot representation using the PERMANOVA package (Vicente-Gonzalez and Vicente-Villardon, 2021). Bonferroni circles were drawn to represent the confidence intervals ($\alpha = 0.05$).

Linear discriminant analysis (LDA) was applied to the nutritional and colour variables separately and then both sets of variables were combined to identify the variables that most strongly characterized each variety using the packages MASS version 7.3–60.0.1 (Ripley et al., 2024) and KlarR version 1.7–3 (Roever et al., 2023). A stepwise technique based on Wilks' Λ test with the usual probabilities of F-values for parameter selection was applied. This procedure combines a series of forward selection and backward elimination steps in which the significance of all previously included variables is tested before adding a variable with discriminatory ability (Sampaio et al., 2021). To verify the significance of the canonical discriminant functions, Wilk's Λ test was used. Finally, to gain deeper insight into these varietal differences under combined environmental factors (CM*Y*M), principal component analysis (PCA) was performed using FactoMinerR (Husson et al., 2023) and Factoextra (Kassambara and Mundt, 2020). The pattern of correlations between all pairwise parameters was analysed with Pearson's coefficient (r) using the package CorrPlot version 0.92 (Wei et al., 2021).

3. Results and discussion

3.1. Impact of variety, cropping system and cultivation method on nutritional and colour parameters

Due to their great influence on soil properties, the question of how cropping systems (CS), including organic systems, and mulching (M) affect crop performance and nutritional value is still unresolved (Mazzoncini et al., 2015). Giampieri et al. (2022) reviewed studies on numerous crops and concluded that organic farming significantly reduces yields but does not significantly improve nutrient quality. In contrast, Mditshwa et al. (2017) reported that nutritional parameters such as vitamins, phenolic components and antioxidant activity are higher in organically produced fruits. On the other hand, mulching with plastic film, which improves the moisture and temperature balance of the soil and reduces the loss of valuable nutrients through leaching, has been shown to stimulate plant growth and improve crop yields and nutritional quality (Lee et al., 2021; Singh et al., 2021; Ye et al., 2021). However, in addition to nutritional parameters, colour criteria are also an important factor that influences the customer's impression when selecting and accepting food (Cai et al., 2020). Recent studies have shown that the yield and nutritional quality of sweet potatoes are influenced by genotypes, environmental conditions and their interactions (Alam et al., 2024; Pazos et al., 2022; Rahmawati et al., 2021). In this study, the dry matter, nutritional properties and colour parameters of sweet potato varieties grown conventionally and organically for two years, with and without mulch were investigated, to determine the influence of genetic and environmental factors on these parameters and the performance of the varieties studied.

3.2. Dry matter and nutritional parameters

The qualitative criteria of multifactorial analysis of variance (MANOVA), namely Pillai's Trace, revealed that variety (V), year (Y), cropping system (CS) and mulching (M) and their interactions significantly affected all analysed parameters when considered as multivariables ($P \leq 0.05$) (Table 2). In agreement with our results, recent studies on sweet potatoes have demonstrated the significant influence of genotypic and environmental factors on various nutritional parameters such as protein, glucose, total sugar and vitamin C contents as well as total soluble solids (Alam et al., 2024; Gurmu et al., 2020; Karan and Şanli, 2021; Rosero et al., 2020). However, when each parameter was analysed separately, the results showed that all factors were highly significant ($P < 0.0001$) or marginally significant ($P \approx 0.05$) for most of the nutritional traits studied, with most parameters being significant, except for the non-significant effects of cropping system on total sugars (TS) and cultivation method on total soluble solids (TSS) (Table 3). The variance partitioning showed that variety had the largest influence on DM and all nutritional parameters, except for vitamin C, where the largest variance (57.08%) was explained by the main effects of variety and year (36.74% and 20.24%, respectively), with an average of 73.82% explained variance for all parameters. Although significant for most parameters, the variance explained by most interaction effects was small (< 10%) (Table 3). These results suggest that the differences in nutritional traits between the varieties studied are due to the genetic basis of individual variety performance rather than environmental factors.

As expected, of the four varieties tested, the PFSP variety (Purple Speclet) had the highest average DM content (DM = 302.89 ± 3.26 g/kg), which was about 1.5 times higher than the WFSP and OFSP varieties. This indicates that Purple Speclet is more suitable for flour production, as there is a high probability that the soluble components present in the roots will be recovered (Jiang et al., 2020; Mello et al., 2022). Shekhar et al. (2015) reported a similar pattern and suggested that the high DM of PFSP could be due to its excellent photosynthetic carbon metabolism, which is crucial for plant growth and productivity. Our results also showed that Purple Speclet had the highest contents of various nutritional components, such as total soluble solids (TSS = 12.84 ± 0.32 °Brix), protein content (1.69 ± 0.08%), vitamin C content (11.08 ± 0.33 mg/100 g), total phenolic content (TPC = 471.13 ± 22.65 mg GAE/100 g), and antioxidant potential (AOP = 462.48 ± 24.99 mg TE/100 g). However, it had the lowest glucose content (8.69 ± 0.55 g/L). In contrast, the OFSP variety (Lučka) had the highest total sugar content (68.69 ± 1.24 g/kg) and came in second place after Purple Speclet for TSS (9.19 ± 0.28 °Brix) and vitamin C (10.98 ± 0.39 mg/100 g). Among the WFSP varieties, Martina had the highest glucose content (38.92 ± 1.41 g/L and 32.97 ± 1.15 g/L, respectively), but the lowest TPC (58.30 ± 2.54 mg GAE/100 g) and AOP (58.45 ± 1.90 mg TE/100 g), while Janja had the lowest values for most nutritional parameters (Table 1). To gain a deeper insight into the different levels of variation between the varieties, the MANOVA biplot analysis was performed with the values of their nutritional parameters in the two cropping systems and cultivation methods over the two years. The biplot (Fig. 2A) clearly separated the PFSP variety from the other varieties by the negative side of its first component, which explained 84.16 of the variation. This component was mainly negatively related to DM, protein, TPC, AOP and TSS. As already mentioned, the PFSP variety has the highest values for these parameters. The second component, which explained 12.57 % of the variation, was also strongly negatively associated with TS and separated the Lučka variety from the Janja and Martina varieties on its negative side. Overall, these results are consistent with previous studies reporting that varieties with pigmented flesh (orange and purple) are characterized by higher TPC, AOP, TS and protein contents, reflecting their higher nutritional quality compared to varieties with white-cream flesh (Chintha et al., 2023; Guclu et al., 2023; Neela and Fanta, 2019; Ruttarattanamongkol et al., 2016; Wang et al., 2018) and suggested the considerable nutritional value of the OFSP variety (Lučka) compared to the PFSP and WFSP varieties. Nevertheless, our results showed that the TSS content of the four varieties studied was within the range of values observed in previous studies on sweet potatoes (7.30–14.57 °Brix) (Alam et al., 2024; Rosero et al., 2020), while the vitamin C content observed in our study, although lower than the peak values observed by Yvonne and Pontsho (2023) (21.03 mg/100 g) and Alam et al. (2024) (23.89 mg/100 g), was much higher than the values determined by Alam et al. (2020) in the orange-fleshed varieties (< 6 mg/100 g), suggesting that the varieties analysed in our study, including the white-fleshed ones, were characterized by excellent nutritional value. A comparison with data from the US Department of Agriculture (USDA, 2022) for the vitamin C and total sugar content (14.8 mg/100 g and 60.6 g/kg, respectively) of the orange-fleshed sweet potato showed good agreement with the data obtained in this study.

However, as the PFSP variety clearly stood out from the others, a new analysis of variance (ANOVA) was carried out using only the data from the other three varieties. This was done to gain a better understanding of the environmental impact on the parameters analysed. The results confirmed that most of the variation in all parameters was due to the variety effect, which accounted for 42.95 % on average. The influence of growing season was the second most influential factor after variety, affecting dry matter (DM) and nutrient parameters with an average explained variance of 18.86 %. Other environmental factors had a smaller influence, with the effects of mulching and cropping system explaining 3.96 % and 2.27 % of the variation in all parameters, respectively. However, the influence of the year is unpredictable and beyond the control of farmers. Therefore, even if one knows which climatic conditions are best suited to maximize the accumulation of nutrient-rich components, the possibilities to change them are limited. According to George et al. (2024), temperature and rainfall are the most important factors affecting sweet potato yield and quality. In our study, although temperatures in both growing seasons were in line with values considered favourable for sweet potato growth (Conz et al., 2021; Mulovhedzi et al., 2020), the slightly higher weather variables (maximum and minimum temperatures, precipitation) observed in the 2022 growing season compared to the previous season (2021), as shown

Table 1

Variation in nutritional profile and colour parameters between varieties, years, cropping systems and with or without PE-mulching (mean ± SE). Numbers with different letters are statistically different $P \leq 0.05$ (Tukey's test).

	Variety				Year		Cropping system		PE-mulching	
	Janja	**Lučka**	**Martina**	**Purple Speclet**	**2021**	**2022**	**Conventional**	**Organic**	**Non-mulching**	**Mulching**
DM (g/kg)	177.49 ± 1.62 d	188.72 ± 1.91 c	194.59 ± 1.97 b	302.89 ± 3.26 a	221.95 ± 7.95 a	209.90 ± 0.39 b	216.36 ± 7.89 a	215.49 ± 7.18 b	212.79 ± 7.63 b	219.06 ± 7.43 a
TSS (°Brix)	7.24 ± 0.17 c	9.19 ± 0.28 b	7.57 ± 0.16 c	12.84 ± 0.32 a	9.51 ± 0.39 a	8.86 ± 0.32 b	9.44 ± 0.38 a	8.93 ± 0.32 b	9.20 ± 0.38 a	9.17 ± 0.33 a
Glucose (g/L)	32.97 ± 1.15 b	21.27 ± 1.08 c	38.92 ± 1.41 a	8.69 ± 0.55 d	23.12 ± 1.79 b	27.81 ± 1.85 a	26.30 ± 1.91 a	24.62 ± 1.78 b	27.53 ± 1.83 a	23.39 ± 1.82 b
TS (g/kg)	43.47 ± 1.51 d	68.69 ± 1.24a	57.82 ± 1.11 b	52.13 ± 2.10 c	51.67 ± 1.64 b	59.38 ± 1.59 a	55.56 ± 1.76 a	55.49 ± 1.66 b	59.63 ± 1.43 a	51.43 ± 1.76 b
Protein (%)	1.23 ± 0.04 d	1.08 ± 0.04 c	0.88 ± 0.03 b	1.69 ± 0.08 a	1.39 ± 0.06 a	1.05 ± 0.04 b	1.30 ± 0.06 a	1.15 ± 0.04 b	1.21 ± 0.06 b	1.23 ± 0.05 a
Vitamin_C (mg/100 g	7.96 ± 0.32 c	10.98 ± 0.39 a	9.85 ± 0.31 b	11.08 ± 0.33 a	10.90 ± 0.27 a	9.04 ± 0.26 b	9.39 ± 0.29 b	10.54 ± 0.284 a	9.41 ± 0.30 b	10.53 ± 0.27 a
TPC (mg GAE/ 100 g)	70.93 ± 3.08 b	69.43 ± 1.98 b	58.30 ± 2.54 c	471.13 ± 22.65 a	195.82 ± 30.67 a	139.07 ± 21.55 b	164.49 ± 26.96 b	170.40 ± 26.6 a	181.53 ± 29.97 a	153.36 ± 23.07 b
AOP (mg TE/ 100 g)	66.20 ± 2.67 c	81.92 ± 3.54 b	58.45 ± 1.90 c	462.48 ± 24.99 a	195.79 ± 31.11 a	138.73 ± 19.87 b	160.10 ± 26.12 b	174.43 ± 26.70 a	179.55 ± 29.77 a	154.97 ± 22.47 b
L*	82.78 ± 0.32 a	70.57 ± 0.46 b	83.00 ± 0.31 a	29.81 ± 0.67 c	66.89 ± 3.22 a	66.19 ± 3.16 a	66.36 ± 3.29 a	66.72 ± 3.17 a	66.11 ± 3.26 a	66.97 ± 3.12 a
a*	−1.43 ± 0.08 b	26.77 ± 0.65 a	−2.10 ± 0.08 b	26.86 ± 0.57 a	12.46 ± 2.10 a	12.58 ± 2.11 a	12.51 ± 2.11 a	12.54 ± 2.11 a	12.43 ± 2.08 a	12.62 ± 2.13 a
b*	20.78 ± 0.49 b	45.91 ± 0.85 a	21.27 ± 0.55 b	1.81 ± 0.17 c	23.49 ± 2.3 a	21.40 ± 2.23 b	22.29 ± 2.32 a	22.59 ± 2.31 a	22.72 ± 2.34 a	22.16 ± 2.29 a
C*	20.84 ± 0.49 c	53.15 ± 1.06 a	21.38 ± 0.55 c	26.94 ± 0.57 b	31.34 ± 2.07 a	29.82 ± 1.91 a	30.49 ± 1.99 a	30.66 ± 1.99 a	30.73 ± 2.00 a	30.43 ± 1.98 a
h*	85.94 ± 0.29 a	59.80 ± 0.20 c	84.31 ± 0.26 b	3.94 ± 0.40 d	58.73 ± 4.81 a	58.27 ± 4.86 a	58.32 ± 4.86 a	58.68 ± 4.82 a	58.65 ± 4.86 a	58.35 ± 4.81 a
BI	1.23 ± 0.12 c	32.66 ± 0.92 b	0.70 ± 0.09 c	56.73 ± 0.91 a	22.56 ± 3.32 a	23.08 ± 3.57 a	22.96 ± 3.49 a	22.69 ± 3.41 a	23.21 ± 3.51 a	22.44 ± 3.39 a
WI	72.90 ± 0.45 a	39.22 ± 1.12 b	72.62 ± 0.49 a	24.74 ± 0.53 c	51.83 ± 3.08 a	52.91 ± 3.12 a	52.28 ± 3.12 a	52.46 ± 3.09 a	51.83 ± 3.13 a	52.91 ± 3.07 a

DM, dry matter; TSS, total soluble solids; TS, total sugars; TPC, total phenolic compounds; GAE, gallic acid equivalents; AOP, antioxidant potential; TE, Trolox equivalents; C, Chroma; h, hue angle; BI, browning index; WI, whiteness index.

Table 2

Multifactorial analysis of variance of all nutritional and colour parameters analysed separately and in combination.

Sources of variance	Df	Nutritional parameters			Colour parameters			All parameters		
		Pillai	F-value	Sig.	Pillai	F-value	Sig.	Pillai	F-value	Sig.
V	3	2.99	2251.8	***	2.34	698.93	***	2.99	1673.6	***
Y	1	1.00	7678.3	***	0.49	7.95	***	0.99	3901.7	***
M	1	1.00	1939.1	***	0.09	0.87	0.54	0.99	1151.7	***
CS	1	0.98	462.9	***	0.07	0.66	0.70	0.98	246.9	***
V*Y	3	2.35	26.7	***	0.82	3.58	***	2.43	14.9	***
V*CM	3	2.42	31.1	***	0.21	0.65	0.89	2.47	16.4	***
Y*CM	1	0.99	612.5	***	0.07	0.65	0.71	0.98	322.9	***
V*CS	3	2.31	25.0	***	0.20	0.59	0.92	2.38	13.5	***
Y*CS	1	1.00	1939.0	***	0.08	0.71	0.66	0.99	999.8	***
CM*CS	1	0.99	1363.2	***	0.06	0.52	0.82	0.99	703.8	***
V*Y*CM	3	2.67	59.8	***	0.37	1.21	0.24	2.71	31.3	***
V*Y*CS	3	2.31	25.1	***	0.30	0.98	0.51	2.36	13.0	***
V*CM*CS	3	2.43	31.9	***	0.11	0.33	1.00	2.51	17.5	***
Y*CM*CS	1	0.94	110.0	***	0.08	0.71	0.66	0.94	59.9	***
V*Y*CM*CS	3	2.66	57.9	***	0.15	0.44	0.98	2.71	31.3	***

V, variety; Y, year; M, mulching; CS, cropping system; CM, cultivation method.

in Table 1, may have led to a significant, albeit small, decrease in most nutritional traits. On the other hand, rainfall was higher and more evenly distributed in both seasons, with most rain falling in August 2021 and September 2022. On the other hand, soil moisture in 2021 was closest to the optimum for tuber development with an average of 74.5%, which according to Conz et al. (2021) corresponds to 80% of field capacity and was measured in August and September (79% and 80 %, respectively), while in 2022, despite the relatively low average moisture (70.25%), a surplus was recorded in the month before harvest (84%). This pattern could explain the relatively large year variations in TPC, which accounted for 59.81 % of the observed changes. TPC decreased 0.2–0.3-fold between the two growing seasons, decreasing from 85.05, 75.77, 63.35 and 553.13 in 2021 to 56.81, 63.09, 47.25 and 389.13 in 2022 for the varieties Janja, Lučka, Martina and Purple Speclet, respectively. The protein content, which showed a 25.55 %-year effect, decreased 0.25-fold, with values decreasing from 1.36, 1.21, 0.99 and 1.98 to 1.08, 0.96, 0.78 and 1.42 for the same varieties. Vitamin C content, which showed an 18.92 %-year effect, decreased by 0.15 to 0.20 times, with values decreasing from 8.87, 12.02, 10.64 and 12.07 to 7.06, 10.14, 9.07 and 9.87, respectively. Finally, AOP showed a 15.42 %-year effect, decreasing by 0.02 to 0.3 times, from 77.76, 82.65, 65.67 and 557.12 to 54.65, 81.19, 51.23 and 367.85 for the respective

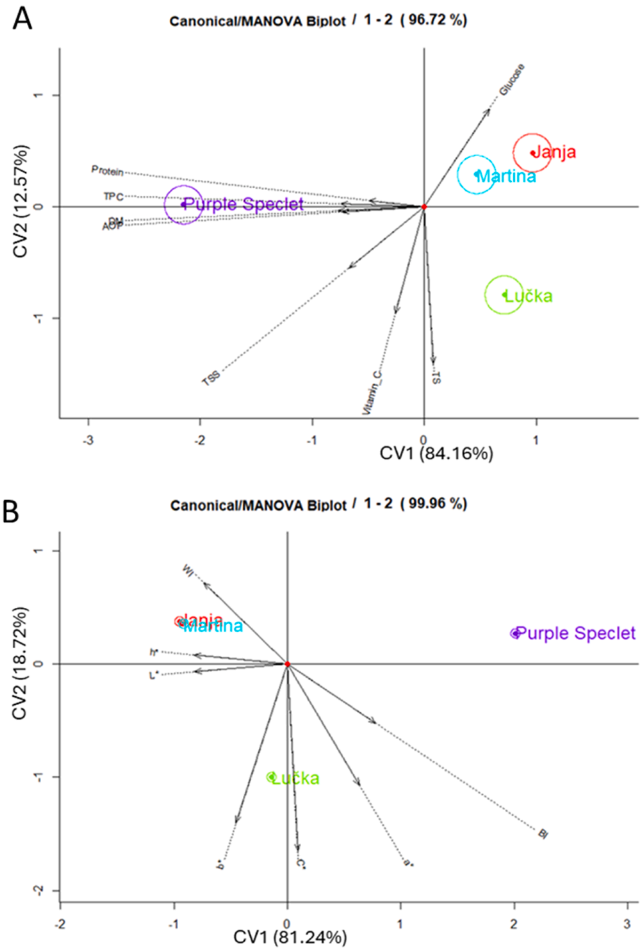


Fig. 2. MANOVA biplots of the nutritional (A) and colour parameters (B) taking into account the variety factor. The circles represent the Bonferroni confidence intervals.

varieties. These results indicate the sensitivity of vitamin C, protein content, TPC and AOP to a slight increase in temperature and excess moisture in sweet potatoes (Purcell et al., 1976; Sui et al., 2019). The relatively low variance explained by variety*year, averaging 1.79 %, indicated that the changes in nutrient parameters between the two growing seasons were similar for all varieties. In contrast, our results showed that with a 7.01 %-year effect, the TS across all varieties (51.67 ± 1.64 g/kg vs. 59.38 ± 1.59 g/kg) and glucose content (23.12 ± 1.79 g/L vs. 27.81 ± 1.85 g/L) increased significantly in 2022 compared to 2021. Within varieties, TS increased 0.15- to 0.20-fold from 40.65, 64.64, 55.13 and 46.28 to 46.31, 72.75, 60.51 and 57.98 in Janja, Lučka, Martina and Purple Speclet, respectively (Table S1).This suggests that higher temperatures promote the conversion of starch to reducing sugars, which is consistent with previous studies (Muthoni and Shimelis, 2020).

On the other hand, although mulching had a significant effect, it was rather small for most parameters, averaging only 3.96 %. The strongest effect was on DM (11.72 %), followed by glucose (6.44 %), TS (5.43 %), vitamin C (3.17 %), TPC (0.64 %) and AOP (0.58 %). Mulching increased the DM content of all varieties from 212.79 ± 7.63 g/kg to 219.06 ± 7.43 g/kg. Specifically, the DM increased from 176.92, 183.90, 187.21 and 302.01 in the soil-grown tubers to 178.07, 193.55, 201.97 and 303.79 in the PE-grown tubers of Janja, Lučka, Martina and Purple Speclet, respectively. Similarly, the overall vitamin C content increased from 9.41 ± 0.30 to 10.53 ± 0.27, with increases from 7.83, 10.92, 9.09 and 9.82 in soil-grown tubers to 8.10, 11.25, 10.63 and 12.14 in PE-grown tubers. In contrast, mulching significantly decreased the overall glucose content from 27.53 ± 1.83 to 23.39 ± 1.82, with specific decreases from 34.86, 23.57, 41.90 and 9.81 to 31.09, 18.97, 35.95 and 7.59 in the same varieties. Similarly, TS decreased from 59.63 ± 1.43 to 51.43 ± 1.76 overall, with decreases from 47.26, 70.58, 60.59 and 60.10 to 39.70, 66.81, 55.06 and 44.17, respectively. TPC decreased from 181.53 ± 29 to 153.36 ± 23.07 overall, with specific decreases from 72.39, 71.82, 62.49 and 524.22 to 69.47, 67.04, 54.12 and 418.05, respectively. Finally, overall AOP decreased from 179.55 ± 29.77 to 154.97 ± 22.47, with reductions from 68.13, 86.39, 55.83 and 409.55 to 64.28, 77.45, 61.07 and 515.41 for the same varieties, respectively (Table S1).

A significant influence of the cropping system was also found for most parameters (Table 1). This is due to the fact that conventional cultivation of sweet potatoes requires a high use of fertilizers and pesticides to ensure optimal tuber development, resulting in fully mature tubers with a higher dry matter content (Dramićanin et al., 2018). However, although significant, the effect of the cropping system was relatively low, averaging 2.07 % for all parameters. Parameters such as DM, TSS, glucose, TS, and protein content were higher in the conventional system, while vitamin C, TPC and AOP were higher in the organic system for all four varieties studied (Table 1). The strongest effect of cropping system (6.63 %) was observed for vitamin C content, which increased from 7.14, 10.84, 9.36 and 10.25 mg/100 g in conventionally grown tubers to 8.79, 11.33, 10.36 and 11.71 mg/100 g in organically grown tubers, followed by AOP (3.59 %), which increased from 65.29, 74.74, 57.15 and 443.20 μmol TE/g in conventionally grown tubers to 67.13, 89.10, 59.76 and 481.77 μmol TE/g in organically grown tubers for Janja, Lučka, Martina and Purple Speclet, respectively. In contrast, the cropping system decreased the protein content from 1.23, 1.16, 0.94 and 1.87 in the conventional system to 1.21, 1.02, 0.83 and 1.53 in the organic system for the same varieties. For the other parameters, the effect of the cropping system was 1.55 % for TSS, which decreased from 7.05, 9.40, 7.92 and 13.43 mg/g in conventional tubers to 7.05, 8.82, 7.23 and 12.26 mg/g in organic tubers. The glucose content showed a difference of 1.25% and decreased from 34.51, 21.02, 40.79 and 8.91 mg/g in conventional tubers to 31.44, 21.51, 37.06 and 8.49 mg/g in organic tubers for Janja, Lučka, Martina and Purple Speclet (Table S1).

3.3. *Colour parameters*

Colour is a decisive factor that influences the quality and sensory acceptance of food by consumers (Geraldi et al., 2021; Rodríguez-Mena et al., 2023). In the case of sweet potatoes, it is the colour of the flesh that most strongly influences consumers' sensory and hedonic expectations (Lado et al., 2021). In our study, the MANOVA showed that the colour parameters were significantly influenced by variety, year and their interactions in a multivariable approach. Nevertheless, variety proved to be the most important factor influencing flesh colour based on the variance partitioning analysis, which explained over 90 % of the variance of all colour parameters (Table 3). This indicates that colour parameters in the studied varieties were very stable and under strong genetic control, while environmental factors had little or no effect. In agreement with our results, Tripodi et al. (2021) showed that colour-related parameters are not influenced by the environment in traditional Italian sweet pepper varieties. In contrast, previous studies have shown that colour parameters in barberry (*Berberis vulgaris* L.) (Khayyat et al., 2023) and strawberry (*Fragaria* × *ananassa* Duch.) grown in organic farming (Kilic et al., 2021) were significantly improved by mulching. In our study, the L*, a*, b*, C*, h*, BI and WI values showed different colours in the four sweet potato varieties, which confirmed the visual appearance of the tuber flesh (Fig. 1). The white-creamy fleshed varieties Martina and Janja were characterized by the highest flesh lightness (L*) (83.00 ± 0.31 and 82.78 ± 0.32, respectively), the highest hue angle (h*) (85.94 ± 0.29 and 84.31 ± 0.26, respectively) and the highest whiteness index (72.62 ± 0.49 and 72.90 ± 0.45, respectively), the lowest chroma (C*) (21.38 ± 0.55 and

Table 3
Explained variance (% SS) for variety (V), year (Y), cropping system (CS), mulching (M) and their interactions for nutritional and colour parameters.

		DM	TSS	Glucose	TS	Protein	Vitamin_C	TPC	AOP	L*	a*	b*	C*	h*	BI	WI
V	SS (%)	39.23	46.53	60.90	73.36	31.26	40.38	17.19	34.78	91.32	98.13	93.28	94.64	98.94	97.13	95.06
	P-value	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Y	SS (%)	13.91	2.19	8.05	7.01	25.55	18.92	59.81	15.42	0.51	0.06	1.18	0.84	0.01	0.10	0.31
	P-value	***	ns	***	***	***	***	***	***	0.18	ns	**	*	ns	ns	ns
CS	SS (%)	0.48	1.55	1.25	0.03	2.94	6.63	0.05	3.59	0.01	0.00	0.01	0.01	0.00	0.00	0.00
	P-value	***	ns	**	***	***	***	*	***	0.49	ns	ns	ns	ns	ns	ns
M	SS (%)	11.72	1.07	6.44	5.43	2.58	3.17	0.64	0.58	0.05	0.00	0.11	0.05	0.04	0.00	0.05
	P-value	***	ns	***	***	***	***	***	ns	0.10	ns	ns	ns	ns	ns	ns
V*Y	SS (%)	0.79	0.04	0.53	0.26	0.57	0.11	5.54	7.22	0.12	0.14	0.04	0.06	0.02	0.11	0.10
	P-value	***	ns	ns	***	***	ns	***	***	0.59	ns	ns	ns	ns	ns	ns
V*CS	SS (%)	2.23	4.10	0.97	1.95	1.61	1.38	0.45	2.99	0.05	0.00	0.09	0.06	0.02	0.00	0.04
	P-value	***	ns	*	***	***	**	***	***	0.71	ns	ns	ns	ns	ns	ns
Y*CS	SS (%)	0.06	0.01	1.19	0.88	16.52	0.30	0.47	0.19	0.08	0.01	0.00	0.00	0.00	0.01	0.02
	P-value	***	ns	**	***	***	ns	***	ns	0.85	**	ns	*	ns	**	ns
V*M	SS (%)	8.59	2.35	0.23	0.41	2.58	2.09	3.94	3.14	0.02	0.00	0.01	0.00	0.01	0.00	0.00
	P-value	***	ns	ns	***	***	***	***	***	0.87	ns	ns	ns	ns	ns	ns
Y*M	SS (%)	4.28	0.07	4.99	0.07	4.04	2.39	2.14	7.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	P-value	***	ns	***	***	***	***	***	***	0.85	ns	ns	ns	ns	ns	ns
CS*M	SS (%)	4.66	0.38	8.30	2.16	8.35	2.27	0.33	0.14	0.00	0.01	0.09	0.06	0.04	0.01	0.03
	P-value	***	ns	***	***	***	***	***	ns	ns	ns	ns	ns	ns	ns	ns
V*Y*CS	SS (%)	4.37	0.77	0.89	1.07	0.01	5.06	0.22	0.18	0.03	0.02	0.27	0.18	0.01	0.05	0.14
	P-value	**	ns	*	***	ns	***	***	ns	ns	ns	ns	ns	ns	ns	ns
V*Y*M	SS (%)	6.99	0.25	0.24	3.47	1.01	1.60	4.80	9.96	0.08	0.00	0.24	0.14	0.03	0.00	0.11
	P-value	***	ns	ns	***	***	***	***	***	ns	ns	ns	ns	ns	ns	ns
V*CS*M	SS (%)	1.48	0.24	0.26	0.22	1.37	4.21	1.42	2.57	0.03	0.00	0.02	0.01	0.03	0.00	0.01
	P-value	***	ns	ns	***	***	***	***	***	ns	ns	ns	ns	ns	ns	ns
Y*CS*M	SS (%)	0.01	0.00	0.04	0.08	1.41	0.01	0.05	0.99	0.11	0.00	0.01	0.00	0.00	0.00	0.01
	P-value	ns	ns	ns	***	***	ns	*	*	ns	ns	ns	ns	ns	ns	ns
V*Y*CS*M	SS (%)	1.01	0.04	0.70	3.48	0.07	6.72	2.44	3.47	0.01	0.00	0.01	0.01	0.02	0.00	0.00
	P-value	***	ns	*	***	***	***	***	***	ns	ns	ns	ns	ns	ns	ns
Residuals	SS (%)	0.19	40.40	5.03	0.11	0.11	4.77	0.49	7.06	7.57	1.61	4.64	3.93	0.83	2.58	4.11

ns, not significant; *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$; SS, sum of squares. V, variety; Y, year; M, mulching; CS, cropping system; DM, dry matter; TSS, total soluble solids; TS, total sugars; TPC, total phenolic compounds; AOP, antioxidant potential; C, Chroma; h, hue angle; BI, browning index; WI, whiteness index.

20.84 ± 0.49, respectively) and browning index (BI) (0.70 ± 0.09 and 1.23 ± 0.12, respectively) and a negative a* (−2.10 ± 0.08 and −1.43 ± 0.08, respectively). In contrast, the purple-fleshed variety Purple Speclet had the lowest L*, h* and WI (29.81 ± 0.67, 24.74 ± 0.53 and 3.94 ± 0.40, respectively) and the highest BI (56.73 ± 0.91). However, it did not differ significantly from the orange-fleshed Lučka variety in terms of redness/greenness (a*) (26.86 ± 0.57 and 26.77 ± 0.65, respectively). The latter had the highest flesh yellowness/blueness (b*) (45.91 ± 0.85) and chroma (C*) (53.15 ± 1.06), as well as relatively high L* (70.57 ± 0.46) and WI (39.22 ± 1.12) (Table 1). Overall, the values and patterns observed for all colour parameters were similar to those observed in sweet potato varieties with different flesh colours (Leite et al., 2022). In addition, our results showed that there were only small and insignificant decreases in lightness (L*) and slight changes in colour parameters a* and b* in the three Slovenian varieties and the American variety (Purple Speclet) between 2021 and 2022. The American variety in particular recorded a slight increase in a* and a slight decrease in b* in 2022. Chroma values (C*) also decreased slightly from 2021 to 2022, indicating a less vivid colour in 2022. However, these changes were not statistically significant, highlighting the stability of the colour parameters over the years. The effect of mulching was minimal, with only small and non-significant increases in lightness (L*) and chroma (C*) under non-mulched conditions, especially in the Janja and Lučka varieties. The hue angle (h*) remained constant, further highlighting the stable colour characteristics regardless of the mulch treatment. The cropping system also had a minimal effect on the colour parameters, with organic systems in some cases showing only small, non-significant increases in L* and C* values, as in the Janja and Martina varieties (Table S2). Overall, the slight variations observed between the different conditions were not significant, indicating that the colour traits of the studied varieties, especially the Slovenian ones, are genetically stable and resistant to changes in environmental factors such as year, mulching and cropping systems.

On the other hand, the MANOVA biplot showed that Purple Speclet differed from Martina and Janja along the first axis, which was negatively associated with L*, b*, h* and WI, and from Lučka along the second axis, which was negatively associated with all parameters except* and WI (Fig. 2B). In our study, Purple Speclet had a lower L* value compared to other purple-fleshed varieties (Ginting et al., 2020; Laryea et al., 2019), suggesting that the studied variety is more suitable for use as a flour ingredient and natural colourant (Ginting et al., 2020). It is worth noting that Purple Speclet and Lučka had a relatively high a* value, indicating that they are rich in carotenoids and anthocyanins (Lagnika et al., 2021; Lindqvist-Kreuze et al., 2023). Although the latter had a relatively high L* value, indicating a high brightness and low anthocyanins (Fernández-Lara et al., 2015), its a* and b* values are still higher than those of OFSP varieties (Rosero et al., 2022), suggesting that this variety is still rich in carotenoids and anthocyanins. In agreement with our results, Jiang et al. (2020) pointed out that the sweet potato varieties with purple flesh are rich in anthocyanins, while those with orange flesh are mainly rich in carotenoids, while the main component of the sweet potato varieties with white flesh is starch due to the very high L*. The browning index confirmed the observed pattern, which was highest in Purple Speclet, as PFSP are reported to be susceptible to browning due to polyphenols and anthocyanins (Huang et al., 2021).

3.4. Linear discriminant analysis

Since variety was the main factor influencing the variation of all nutritional and colour parameters and the interactions were not strong, a linear discriminant analysis (LDA) was applied separately to the nutritional parameters (NP) and the colour parameters (CP). Then both sets of parameters (NP+CP) were combined to examine the patterns of differentiation between the studied varieties and to determine the most discriminating parameters. In all three cases, the Wilk's lambda value (λ) was highly significant for all parameters (P-value < 0.0001), indicating significant differences between varieties for all parameters and was thus retained for the statistical model. Three statistically significant discriminant functions were formed in each of the cases examined (Table S3). Remarkably, the first function (DF1) explained most of the total variance (84.18%, 81.23% and 80.50% for NP, CP and NP+CP, respectively). The second function (DF2) explained 12.52%, 17.72% and 19.10%, while the third function (DF2) explained 3.30%, 1.05% and 0.4% of the total variance for NP, CP and NP+CP, respectively. The classification rate was 98.96% based on NP and 89.58% based on CP, while 100% classification was achieved based on both parameter sets. The plots formed by the first two discriminant functions showed that the sweet potato varieties could be distinguished based on their flesh colour. The PFSP variety characterized by a remarkable content of anthocyanins (Purple Speclet) was separated from the other varieties by DF1, while the OFSP variety (Lučka) was distinguished from the WFSP varieties (Martina and Janja) along DF2 (Fig. 3). Strikingly, in the three cases, most parameters were strongly associated with DF1 (> |0.6|), indicating that the Lučka variety could be distinguished from the other varieties by

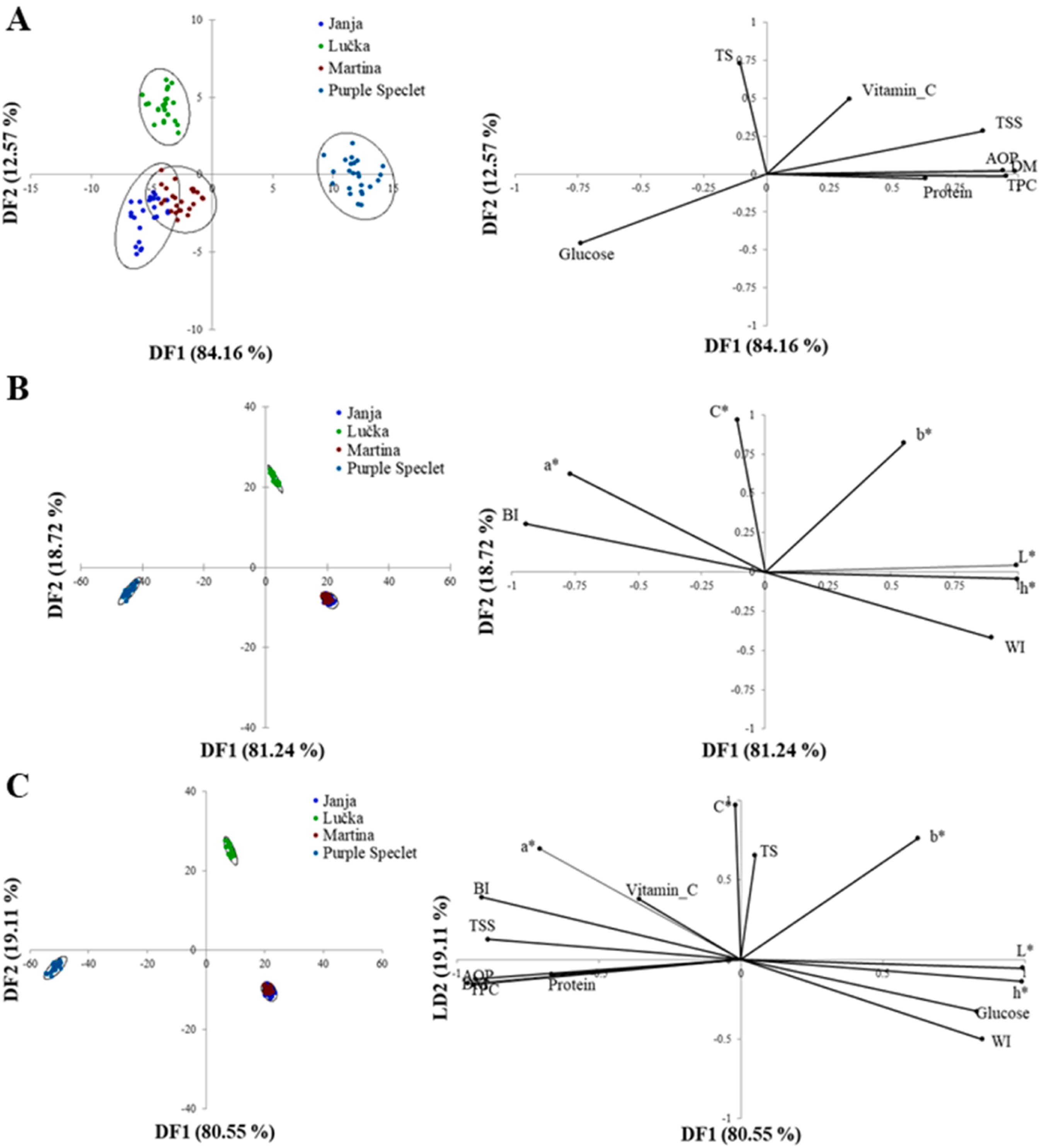


Fig. 3. LDA biplots showing the differentiation of varieties based on nutritional parameters (A), colour parameters (B), and the combination of nutritional and colour parameters (C).

most parameters, with the exception of TS and C*, which were strongly associated with DF2 ($> |0.6|$) and thus enabled the differentiation of Lučka from Martina and Janja. Vitamin C, on the other hand, showed a relatively low loading for both functions ($< |0.5|$). Although highly significant for all parameters (P-value < 0.0001), the Wilk's lambda values (λ) for the colour parameters were much lower, ranging from 0.002 for h* to 0.06 for C*, compared to DM ($\lambda = 0.05$) and the nutritional parameters ($\lambda = 0.09$ for TPC to $\lambda = 0.63$ for vitamin C), indicating a higher discriminatory power of the colour parameters (Table 4).

3.5. Principal component analysis and correlation between parameters

Given the differences found between the four varieties studied, principal component analysis (PCA) should provide further comprehensive insight into these varietal differences under combined environmental factors (CM*Y*M). The results showed that the first two principal components (PC1 and PC2) with eigenvalues of 9.57 and 3.27 explained 85.61% of the total variance (63.83% and 21.77%, respectively). The two-dimensional diagram formed by PC1 and PC2 showed similar variety grouping determined by LDA without being affected by environmental factors, confirming the great influence of variety on nutritional and colour parameters. As shown in Fig. 4, the Purple Speclet variety samples from all environments were grouped on the negative side of PC1. The tubers of this variety seem to be characterized by the highest DM, TSS, TPC, AOP and protein content, as well as the highest a* and BI, which are strongly loaded with PC1 ($r < -0.70$). In contrast, all Martina and Janja samples were grouped on the positive side of PC1 and appeared to be characterized only by high glucose content of all nutritional parameters, while having the highest L*, h* and WI values strongly positively associated with PC1 ($r > 0.90$). However, the Lučka variety was close to the PC1-PC2 origin and was separated from the other varieties by PC2, which showed a strong positive association with TS content as well as b* and C* ($r > 0.70$), indicating that this variety was characterized by the highest TS content as well as b* and C*. The correlation diagram created to examine the correlations between all analysed parameters using the Bonferroni correction ($P \leq 0.05$) (Fig. 5) also showed that most nutritional and colour parameters were highly correlated with each other. The nutritional parameters TSS, protein, TPC and AOP showed strong positive correlations with each other and with DM ($r > 0.90$), suggesting that polyphenols in sweet potatoes are important antioxidants (Chintha et al., 2023; Kourouma et al., 2020). This is consistent with previous studies that reported strong positive correlations between total phenolics and antioxidant activity in sweet potato (Suárez et al., 2016) and Jerusalem artichoke (Amarowicz et al., 2020) tubers. Similarly, the strong positive correlation between DM and TSS observed in our study suggested that the dry matter content in sweet potato tubers plays a crucial role in determining the total soluble solids content, which is consistent with the findings of Alam et al. (2024). Furthermore, the high positive correlation between DM and protein content could be explained by increased photosynthetic rate, which according to Shekhar et al. (2015) is crucial for higher yields in sweet potatoes. However, in agreement with the study by Amankwaah et al. (2023), which reported strong negative correlations between DM and total sugars as well as the individual free sugars (fructose, glucose, and sucrose), our results showed a negative correlation between DM and TS ($r = -0.16$) and glucose ($r = -0.78$). This was to be expected as sweet potato tubers contain about 70% starch, which is strongly positively correlated with DM (Mourtala et al., 2023). For the colour parameters, the strongest positive correlations were found for pairs a*–BI ($r = 0.93$), h*–WI ($r = 0.91$), b*–C* ($r = 0.76$) and a*–C* ($r = 0.71$), while the strongest negative correlations were between BI–WI ($r = -0.99$), a*–WI ($r = -0.96$) and h*–BI ($r = -0.96$), L*–BI ($r = -0.93$) and a*–h* ($r = -0.80$). Importantly, our results showed strong correlations between colour and nutritional parameters, suggesting that the colour parameters could be good indicators for predicting the nutritional quality of sweet potatoes. Our results showed that a* and BI had strong positive correlations ($r > 0.4$) with all nutritional parameters except glucose ($r = -0.82$ and $r = -0.89$, respectively). In contrast, L*, h* and WI showed strong negative correlations with most nutritional parameters, except for their strong correlations with glucose ($r > 0.8$). In agreement with our results, previous studies have reported that the flesh colour of sweet potatoes is related to their nutritional content, taste, and texture (Aina et al., 2009; Leite et al., 2022).

Table 4
Contribution of the investigated parameters to the differentiation between sweet potato varieties.

	Parameter	Wilk's lambda (λ)	F-value	P-value
Nutritional parameters	Vitamin C	0.632	17.887	< 0.0001
	Protein	0.455	36.697	< 0.0001
	TS	0.395	47.051	< 0.0001
	TSS	0.193	127.989	< 0.0001
	Glucose	0.171	148.688	< 0.0001
	AOP	0.113	239.684	< 0.0001
	TPC	0.091	307.842	< 0.0001
	DM	0.045	654.221	< 0.0001
Colour parameters	C*	0.062	464.685	< 0.0001
	b*	0.030	987.474	< 0.0001
	WI	0.025	1193.652	< 0.0001
	a*	0.022	1391.250	< 0.0001
	BI	0.017	1746.561	< 0.0001
	L*	0.011	2876.574	< 0.0001
	h*	0.002	16,116.228	< 0.0001

TS, total sugars; TSS, total soluble solids; AOP, antioxidant potential; TPC, total phenolic compounds; DM, dry matter; C, Chroma; h, hue angle; WI, whiteness index; BI, browning index.

4. Conclusion

In this study, the variation of nutritional and colour parameters in four sweet potato varieties with different flesh colours (white, orange and purple) was investigated and analysed. The sweet potatoes were grown conventionally, organically, with and without mulch for two years. The aim was to determine the influence of genetic and environmental factors on these parameters and on the performance of the varieties studied. The results indicate that the observed variation in the nutritional profile was predominantly attributable to varietal differences, with environmental factors exerting a relatively minor, albeit statistically significant, influence. It is important to note that the cropping season, growing season, and mulching had a significant influence on the vitamin C, TPC and AOP content. Higher values were observed in organic farming without PE mulching during the growing season, especially with relatively lower weather variables, except for a significant decrease in TPC and AOP when PE mulching was used. Overall and as expected, the PFSP variety Purple Speclet was at the top, followed by the OFSP variety Lučka and the WFSP varieties Janja and Martina. However, our results indicate that all varieties tested have a high nutritional value. For most parameters assessed, the values obtained were either similar or higher than in previous studies. In contrast, our study showed that the variation in colour parameters seems to be

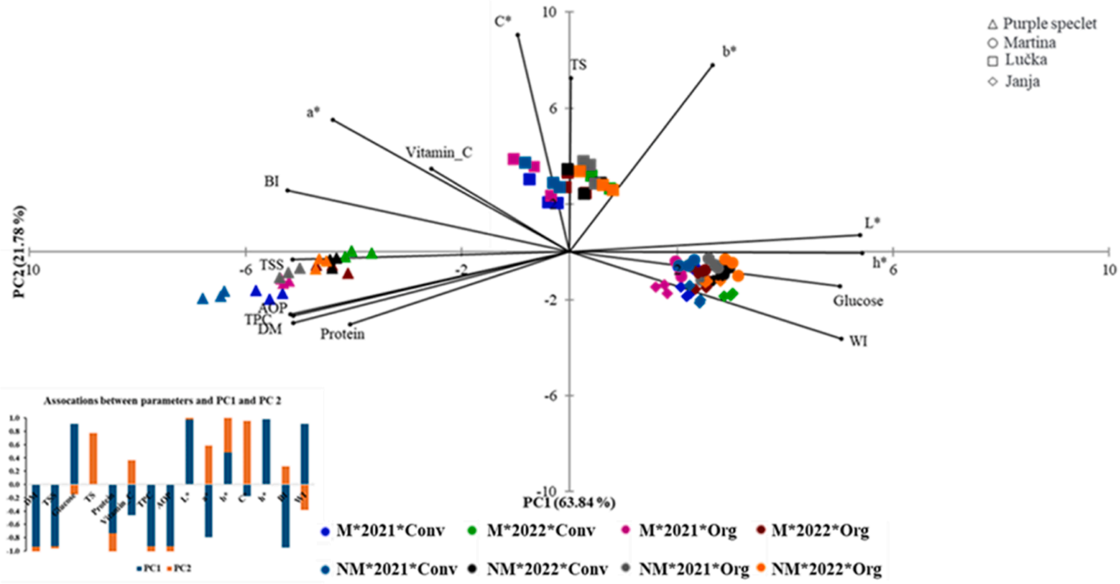
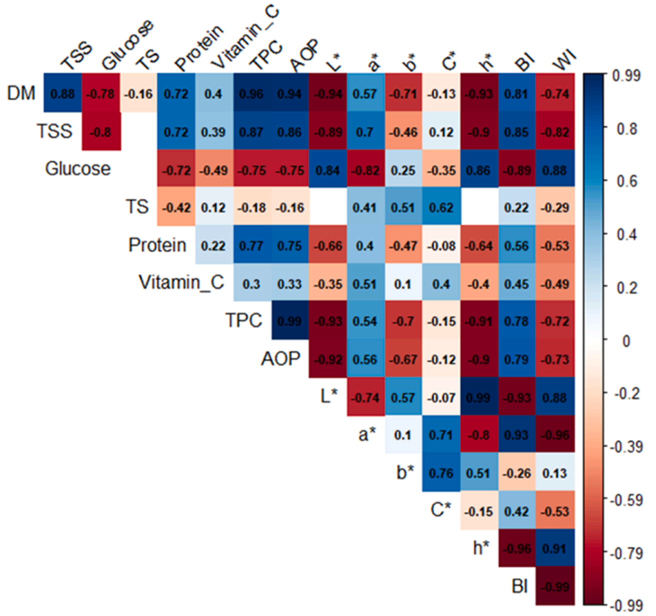


Fig. 4. PCA biplot showing the variation between sweet potato varieties in different environments.



	TSS	Glucose	TS	Protein	Vitamin_C	TPC	AOP	L*	a*	b*	C*	h*	BI	WI
DM	0.88	-0.78	-0.16	0.72	0.4	0.96	0.94	-0.94	0.57	-0.71	-0.13	-0.93	0.81	-0.74
TSS		-0.8		0.72	0.39	0.87	0.86	-0.89	0.7	-0.46	0.12	-0.9	0.85	-0.82
Glucose				-0.72	-0.49	-0.75	-0.75	0.84	-0.82	0.25	-0.35	0.86	-0.89	0.88
TS				-0.42	0.12	-0.18	-0.16		0.41	0.51	0.62		0.22	-0.29
Protein					0.22	0.77	0.75	-0.66	0.4	-0.47	-0.08	-0.64	0.56	-0.53
Vitamin_C						0.3	0.33	-0.35	0.51	0.1	0.4	-0.4	0.45	-0.49
TPC							0.99	-0.93	0.54	-0.7	-0.15	-0.91	0.78	-0.72
AOP								-0.92	0.56	-0.67	-0.12	-0.9	0.79	-0.73
L*									-0.74	0.57	-0.07	0.99	-0.93	0.88
a*										0.1	0.71	-0.8	0.93	-0.96
b*											0.76	0.51	-0.26	0.13
C*												-0.15	0.42	-0.53
h*													-0.96	0.91
BI														-0.99

Fig. 5. Correlation patterns between nutritional and colour parameters in different environments based on the Pearson coefficient. Only significant correlations are shown ($P \leq 0.05$). DM, dry matter; TSS, total soluble solids; TS, total sugars; TPC, total phenolic compounds; AOP, antioxidant potential; C, Chroma; h, hue angle; BI, browning index; WI, whiteness index.

exclusively related to the genetic makeup of the varieties, with no significant effect of environmental factors. Interestingly, MANOVA, LDA and PCA biplots separated the studied varieties according to their flesh colour, indicating that each type was characterized by a distinct nutritional profile. This was confirmed by the higher discriminatory power of LDA, which was higher for the colour parameters than for the nutritional parameters. Our results also suggest that the studied varieties can be discriminated based on their nutritional parameters, in particular dry matter (DM), total phenolic content (TPC) and antioxidant potential (AOP). Interestingly, these parameters were correlated strongly with the colour parameters, suggesting that colour could be a useful indicator for predicting the nutritional quality of sweet potatoes. In conclusion, this multi-approach study was reliable and potentially useful, as to our knowledge, no comprehensive characterization of the nutritional profile and colour parameters of sweet potato varieties under complex environmental conditions has been conducted to date. The differences between the varieties studied suggest that their nutritional profiles can be manipulated through molecular biotechnology approaches and/or conventional breeding programmes to develop new sweet potato varieties or new crops with improved health benefits.

CRediT authorship contribution statement

Lovro Sinkovič: Writing – review & editing, Visualization, Supervision, Formal analysis, Data curation. **Mohamed Neji:** Writing – original draft, Software, Methodology, Conceptualization. **Nataša Kunstelj:** Resources, Formal analysis, Data curation. **Barbara Pipan:** Writing – review & editing, Resources, Investigation, Formal analysis. **Vladimir Meglič:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they are not aware of any competing financial interests or personal relationships that could have influenced the work in this publication.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scienta.2024.113807.

Data availability

Data will be made available on request.

References

Aina, A.J., Falade, K.O., Akingbala, J.O., Titus, P., 2009. Physicochemical properties of twenty-one Caribbean sweet potato cultivars. Int. J. Food Sci. Technol. 44 (9), 1696–1704. https://doi.org/10.1111/j.1365-2621.2009.01941.x.

Alam, M.K., Sams, S., Rana, Z.H., Akhtaruzzaman, M., Islam, S.N., 2020. Minerals, vitamin C, and effect of thermal processing on carotenoids composition in nine varieties orange-fleshed sweet potato (*Ipomoea batatas* L.). J. Food Compos. Anal. 92, 103582. https://doi.org/10.1016/j.jfca.2020.103582.

Alam, Z., Akter, S., Khan, M.A.H., Amin, M.N., Karim, M.R., Rahman, M.H.S., Rashid, M. H., Rahman, M.M., Mokarroma, N., Sabuz, A.A., 2024. Multivariate analysis of yield and quality traits in sweet potato genotypes (*Ipomoea batatas* L.). Sci. Hortic. 328, 112901.

Amankwaah, V.A., Williamson, S., Olukolu, B.A., Truong, V., Carey, E., Ssali, R., Yencho, G.C., 2023. Interrelations of α- and β-amylase activity with starch, sugars, and culinary and nutritional quality attributes in sweetpotato storage roots. J. Sci. Food Agric. https://doi.org/10.1002/jsfa.12832 jsfa.12832.

Amarowicz, R., Cwalina-Ambroziak, B., Janiak, M.A., Bogucka, B., 2020. Effect of N fertilization on the content of phenolic compounds in Jerusalem artichoke (*Helianthus tuberosus* L.) tubers and their antioxidant capacity. Agronomy 10 (8), 8. https://doi.org/10.3390/agronomy10081215.

AOAC, BAM (1990). Association of official analytical chemists. *Official Methods of Analysis*, 12.

Azeem, M., Mu, T., Zhang, M., 2021. Influence of particle size distribution on nutritional composition, microstructural and antioxidant properties of orange and purple-fleshed sweet potato flour. J. Food Process. Preserv. 45 (4). https://doi.org/10.1111/jfpp.15283.

Baba, S.A., Malik, S.A., 2015. Determination of total phenolic and flavonoid content, antimicrobial and antioxidant activity of a root extract of *Arisaema jacquemontii* Blume. J. Taibah Univ. Sci. 9 (4), 449–454. https://doi.org/10.1016/j.jtusci.2014.11.001.

Brand-Williams, W., Cuvelier, M.E., Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. LWT Food Sci. Technol. 28 (1), 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5.

Cai, W., Tang, F., Shan, C., Hou, Q., Zhang, Z., Dong, Y., Guo, Z., 2020. Pretreatment methods affecting the color, flavor, bioactive compounds, and antioxidant activity of jujube wine. Food Sci. Nutr. 8 (9), 4965–4975. https://doi.org/10.1002/fsn3.1793.

Cartier, A., Woods, J., Sismour, E., Allen, J., Ford, E., Githinji, L., Xu, Y., 2017. Physiochemical, nutritional and antioxidant properties of fourteen Virginia-grown sweet potato varieties. J. Food Meas. Charact. 11 (3), 1333–1341. https://doi.org/10.1007/s11694-017-9511-8.

Chintha, P., Sarkar, D., Pecota, K., Dogramaci, M., Hatterman-Valenti, H., Shetty, K., 2023. Phenolic bioactive-linked antioxidant, anti-hyperglycemic, and antihypertensive properties of sweet potato cultivars with different flesh color. Hortic. Environ. Biotechnol. 64 (5), 877–893. https://doi.org/10.1007/s13580-023-00515-0.

Conz, R.F., Six, J., Andrade, M.I., Pereira, E.I.P., 2021. Soil fertility maintenance with organic amendments to orange fleshed sweetpotato. Nutr. Cycl. Agroecosyst. 119 (2), 213–229. https://doi.org/10.1007/s10705-020-10111-8.

Dos Santos, A.M., Lima, J.S., Dos Santos, I.F., Silva, E.F., de Santana, F.A., de Araujo, D. G., Dos Santos, L.O., 2019. Mineral and centesimal composition evaluation of conventional and organic cultivars sweet potato (*Ipomoea batatas* (L.) Lam) using chemometric tools. Food Chem. 273, 166–171. https://doi.org/10.1016/j.foodchem.2017.12.063.

Dramićanin, A.M., Andrić, F.Lj., Poštić, D.Ž., Momirović, N.M., Milojković-Opsenica, D. M, 2018. Sugar profiles as a promising tool in tracing differences between potato cultivation systems, botanical origin and climate conditions. J. Food Compos. Anal. 72, 57–65. https://doi.org/10.1016/j.jfca.2018.06.005.

Fatariah, Z., Tengku Zulkhairuazha, T.Y., Wan Rosli, W.I., 2015. Ascorbic acid quantification in *Benincasa hispida* fruit extracted using different solvents. Int. Food Res. J. *EBSCOhost* https://openurl.ebsco.com/contentitem/gcd:101824144?sid=ebsco:plink:crawler&id=ebsco:gcd:101824144.

Fernández-Lara, R., Gordillo, B., Rodríguez-Pulido, F.J., Lourdes González-Miret, M., del Villar-Martínez, A.A., Dávila-Ortiz, G., Heredia, F.J, 2015. Assessment of the differences in the phenolic composition and color characteristics of new strawberry (*Fragaria* x *ananassa* Duch.) cultivars by HPLC–MS and imaging tristimulus colorimetry. Food Res. Int. 76, 645–653. https://doi.org/10.1016/j.foodres.2015.07.038.

George, J., Reddy, G.V.P., Wadl, P.A., Rutter, W., Culbreath, J., Lau, P.W., Rashid, T., Allan, M.C., Johaningsmeier, S.D., Nelson, A.M., Wang, M.L., Gubba, A., Ling, K.-S., Meng, Y., Collins, D.J., Ponniah, S.K., Gowda, P.H., 2024. Sustainable sweetpotato production in the United States: current status, challenges, and opportunities. Agron. J. 116, 630–660. https://doi.org/10.1002/agj2.21539.

Geraldi, M.V., Betim Cazarin, C.B., Dias-Audibert, F.L., Pereira, G.A., Carvalho, G.G., Kabuki, D.Y., Catharino, R.R., Pastore, G.M., Behrens, J.H., Cristianini, M., Maróstica Júnior, M.R., 2021. Influence of high isostatic pressure and thermal pasteurization on chemical composition, color, antioxidant properties and sensory evaluation of jabuticaba juice. LWT 139, 110548. https://doi.org/10.1016/j.lwt.2020.110548.

Giampieri, F., Mazzoni, L., Cianciosi, D., Alvarez-Suarez, J.M., Regolo, L., Sánchez-González, C., Capocasa, F., Xiao, J., Mezzetti, B., Battino, M., 2022. Organic vs conventional plant-based foods: a review. Food Chem. 383, 132352. https://doi.org/10.1016/j.foodchem.2022.132352.

Ginting, E., Yulifianti, R., & Indriani, F.C. (2020). Selected purple-fleshed sweet potato genotypes with high anthocyanin contents. Proceedings of the IOP Conference Series: Earth and Environmental Science, 456(1), 012023. https://iopscience.iop.org/article/10.1088/1755-1315/456/1/012023/meta.

Guclu, G., Dagli, M.M., Aksay, O., Keskin, M., Kelebek, H., Selli, S., 2023. Comparative elucidation on the phenolic fingerprint, sugars and antioxidant activity of white, orange and purple-fleshed sweet potatoes (*Ipomoea batatas* L.) as affected by different cooking methods. Heliyon 9 (8). https://www.cell.com/heliyon/pdf/S2405-8440(23)05892-9.pdf.

Gurmu, F., Shimelis, H., Laing, M., Mashilo, J., 2020. Genotype-by-environment interaction analysis of nutritional composition in newly-developed sweetpotato clones. J. Food Compos. Anal. 88, 103426. https://doi.org/10.1016/j.jfca.2020.103426.

Huang, Y., Zhou, S., Zhao, G., Ye, F., 2021. Destabilisation and stabilisation of anthocyanins in purple-fleshed sweet potatoes: a review. Trends. Food Sci. Technol. 116, 1141–1154. https://doi.org/10.1016/j.tifs.2021.09.013.

Husson, F., Josse, J., Le, S., & Mazet, J. (2023). *FactoMineR: multivariate exploratory data analysis and data mining* (2.9) [Computer software]. https://cran.r-project.org/web/packages/FactoMineR/index.html.

Jiang, H., Ling, B., Zhou, X., Wang, S., 2020. Effects of combined radio frequency with hot water blanching on enzyme inactivation, color and texture of sweet potato. Innov. Food Sci. Emerg. Technol. 66, 102513.

Karan, Y.B., Şanli, Ö.G., 2021. The assessment of yield and quality traits of sweet potato (*Ipomoea batatas* L.) genotypes in middle Black Sea region, Turkey. PLoS One 16 (9), e0257703.

Kassambara, A., & Mundt, F. (2020). *factoextra: extract and visualize the results of multivariate data analyses* (1.0.7) [Computer software]. https://cran.r-project.org/web/packages/factoextra/index.html.

Khayyat, M., Mazhari-Majd, A., Samadzadeh, A., 2023. Alternate bearing, chlorophyll fluorescence performance, vegetative growth and fruit quality of seedless barberry under different mulching treatments. Erwerbs-Obstbau 65 (1), 171–180. https://doi.org/10.1007/s10341-022-00770-y.

Kilic, N., Burgut, A., Gündesli, M.A., Nogay, G., Ercisli, S., Kafkas, N.E., Ekiert, H., Elansary, H.O., Szopa, A., 2021. The effect of organic, inorganic fertilizers and their combinations on fruit quality parameters in strawberry. Horticulturae 7 (10), 10. https://doi.org/10.3390/horticulturae7100354.

Kourouma, V., Mu, T., Zhang, M., Sun, H., 2020. Comparative study on chemical composition, polyphenols, flavonoids, carotenoids and antioxidant activities of various cultivars of sweet potato. Int. J. Food Sci. Technol. 55 (1), 369–378. https://doi.org/10.1111/ijfs.14336.

Kwak, S.-S., 2019. Biotechnology of the sweetpotato: ensuring global food and nutrition security in the face of climate change. Plant Cell Rep. 38 (11), 1361–1363. https://doi.org/10.1007/s00299-019-02468-0.

Lado, J., Vicente, E., Moltini, A.I., Alcaire, F., Ares, G., 2021. Integrating consumer perception in the selection of purple-skin sweet potato cultivars. J. Sci. Food Agric. 101 (9), 3620–3629. https://doi.org/10.1002/jsfa.10991.

Lagnika, C., Riaz, A., Jiang, N., Song, J., Li, D., Liu, C., Wei, Q., Zhang, M., 2021. Effects of pretreatment and drying methods on the quality and stability of dried sweet potato slices during storage. J. Food Process. Preserv. (10), 45. https://doi.org/10.1111/jfpp.15807.

Laryea, D., Koomson, D., Oduro, I., Carey, E., 2019. Evaluation of 10 genotypes of sweetpotato for fries. Food Sci. Nutr. 7 (2), 589–598. https://doi.org/10.1002/fsn3.881.

Laurie, S.M., Booyse, M., Labuschagne, M.T., Greyling, M.M., 2015. Multienvironment performance of new orange-fleshed sweetpotato cultivars in South Africa. Crop Sci. 55 (4), 1585–1595. https://doi.org/10.2135/cropsci2014.09.0664.

Lee, J.G., Chae, H.G., Hwang, H.Y., Kim, P.J., Cho, S.R., 2021. Effect of plastic film mulching on maize productivity and nitrogen use efficiency under organic farming in South Korea. Sci. Total Environ. 787, 147503.

Leite, C.E.C., Souza, B., de, K.F., Manfio, C.E., Wamser, G.H., Alves, D.P., de Francisco, A., 2022. Sweet potato new varieties screening based on morphology, pulp color, proximal composition, and total dietary fiber content via factor analysis and principal component analysis. Front. Plant Sci. 13. https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2022.852709.

Lindqvist-Kreuze, H., Bonierbale, M., Grüneberg, W.J., Mendes, T., De Boeck, B., Campos, H., 2023. Potato and sweetpotato breeding at the international potato center: approaches, outcomes and the way forward. Theor. Appl. Genet. 137 (1), 12. https://doi.org/10.1007/s00122-023-04515-7.

Mazzoncini, M., Antichi, D., Silvestri, N., Ciantelli, G., Sgherri, C., 2015. Organically vs conventionally grown winter wheat: effects on grain yield, technological quality, and on phenolic composition and antioxidant properties of bran and refined flour. Food Chem. 175, 445–451.

Mditshwa, A., Magwaza, L.S., Tesfay, S.Z., Mbili, N., 2017. Postharvest quality and composition of organically and conventionally produced fruits: a review. Sci. Hortic. 216, 148–159. https://doi.org/10.1016/j.scienta.2016.12.033.

Mello, A.F.S., da Silva, G.O., da Silva Minguita, A.P., dos Santos, F.N., Samborski, T., Ferreira, J.C., de Carvalho, J.L.V., Nuti, M.R., Siquieroli, A.C.S., Severo, J., 2022. Quality parameters in orange flesh sweetpotato grown in different Brazilian states. J. Food Compos. Anal. 107, 104406. https://doi.org/10.1016/j.jfca.2022.104406.

Mourtala, I.Z.M., Innocent, N.M., Habibou, M., Oselebe, H., 2023. Recent progress in breeding for beta-carotene, dry matter content and sugar in sweet potato [*Ipomoea Batatas* (L.) Lam] - a review. Eur. J. Agric. Food Sci. 5 (1), 1. https://doi.org/10.24018/ejfood.2023.5.1.551.

Mulovhedzi, N.E., Araya, N.A., Mengistu, M.G., Fessehazion, M.K., Du Plooy, C.P., Araya, H.T., Van der Laan, M., 2020. Estimating evapotranspiration and determining crop coefficients of irrigated sweet potato (*Ipomoea batatas*) grown in a semi-arid climate. Agric. Water. Manage 233, 106099.

Muthoni, J., Shimelis, H., 2020. Heat and drought stress and their implications on potato production under dry African tropics. Aust. J. Crop. Sci. 14 (9), 1405–1414.

Neela, S., Fanta, S.W., 2019. Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. Food Sci. Nutr. 7 (6), 1920–1945. https://doi.org/10.1002/fsn3.1063.

Nwosisi, S., Illukpitiya, P., Nandwani, D., Arebi, I.T., Nwosisi, O., 2021. Organic and conventional sweetpotato production in the Southeastern of United States: a comparative analysis. Agric. Food Secur. 10, 1–9. https://doi.org/10.1186/s40066-021-00298-6.

Pandiselvam, R., Mitharwal, S., Rani, P., Shanker, M.A., Kumar, A., Aslam, R., Barut, Y. T., Kothakota, A., Rustagi, S., Bhati, D., Siddiqui, S.A., Siddiqui, M.W., Ramniwas, S., Aliyeva, A., Mousavi Khaneghah, A., 2023. The influence of non-thermal technologies on color pigments of food materials: an updated review. Curr. Res. Food Sci. 6, 100529. https://doi.org/10.1016/j.crfs.2023.100529.

Park, S.-Y., Lee, S.Y., Yang, J.W., Lee, J.-S., Oh, S.-D., Oh, S., Lee, S.M., Lim, M.-H., Park, S.K., Jang, J.-S., Cho, H.S., Yeo, Y., 2016. Comparative analysis of phytochemicals and polar metabolites from colored sweet potato (*Ipomoea batatas* L.) tubers. Food Sci. Biotechnol. 25 (1), 283–291. https://doi.org/10.1007/s10068-016-0041-7.

Pazos, J., Zema, P., Corbino, G.B., Gabilondo, J., Borioni, R., Malec, L.S., 2022. Growing location and root maturity impact on the phenolic compounds, antioxidant activity and nutritional profile of different sweet potato genotypes. Food Chem. Mol. Sci. 5, 100125. https://doi.org/10.1016/j.fochms.2022.100125.

Purcell, A.E., Walter, W.M., Giesbrecht, F.G., 1976. Distribution of protein within sweet potato roots (*Ipomea batatas* L.). J. Agric. Food Chem. 24 (1), 64–66. https://doi.org/10.1021/jf60203a045.

Rahmawati, N., Sipayung, R., Widya, R., 2021. Analysis of yields quantity and quality of several sweet potatoes genotypes at different harvest ages. In: Proceedings of the IOP Conference Series: Earth and Environmental Science, 782, 042047. https://iopscience.iop.org/article/10.1088/1755-1315/782/4/042047/meta.

Ripley, B., Venables, B., Bates, D.M., Hornik, K., Gebhardt, A. & Firth, D. (2024). *MASS: support functions and datasets for Venables and Ripley's MASS* (7.3-60.0.1) [Computer software]. https://cran.r-project.org/web/packages/MASS/index.html.

Rodríguez-Mena, A., Ochoa-Martínez, L.A., González-Herrera, S.M., Rutiaga-Quiñones, O.M., González-Laredo, R.F., Olmedilla-Alonso, B., Vega-Maturino, S., 2023. Coloring potential of anthocyanins from purple sweet potato paste: ultrasound-assisted extraction, enzymatic activity, color and its application in ice pops. Food Chem. Adv. 3, 100358. https://doi.org/10.1016/j.focha.2023.100358.

Roever, C., Raabe, N., Luebke, K., Ligges, U., Szepannek, G., Zentgraf, M., & Meyer, D. (2023). *klaR: classification and Visualization* (1.7-3) [Computer software]. https://cran.r-project.org/web/packages/klaR/index.html.

Rosero, A., Pastrana, I., Martínez, R., Perez, J.-L., Espitia, L., Araujo, H., Belalcazar, J., Jaramillo, A., Gallego-Castillo, S., 2022. Nutritional value and consumer perception of biofortified sweet potato varieties. Ann. Agric. Sci. 67 (1), 79–89.

Rosero, A., Sierra, C., Pastrana, I., Granda, L., Pérez, J.-L., Martínez, R., Morelo, J., Espitia, L., Araujo, H., De Paula, C., 2020. Genotypic and environmental factors influence the proximate composition and quality attributes of sweetpotato (*Ipomoea batatas* L.). Agric. Food Secur. 9 (1), 14. https://doi.org/10.1186/s40066-020-00268-4.

Roullier, C., Benoit, L., McKey, D.B., Lebot, V., 2013. Historical collections reveal patterns of diffusion of sweet potato in Oceania obscured by modern plant movements and recombination. In: Proceedings of the National Academy of Sciences, 110, pp. 2205–2210. https://doi.org/10.1073/pnas.1211049110.

Ruttarattanamongkol, K., Chittrakorn, S., Weerawatanakorn, M., Dangpium, N., 2016. Effect of drying conditions on properties, pigments and antioxidant activity retentions of pretreated orange and purple-fleshed sweet potato flours. J. Food Sci. Technol. 53 (4), 1811–1822. https://doi.org/10.1007/s13197-015-2086-7.

Sampaio, S.L., Barreira, J.C.M., Fernandes, Â., Petropoulos, S.A., Alexopoulos, A., Santos-Buelga, C., Ferreira, I.C.F.R., Barros, L., 2021. Potato biodiversity: a linear discriminant analysis on the nutritional and physicochemical composition of fifty genotypes. Food Chem. 345, 128853. https://doi.org/10.1016/j.foodchem.2020.128853.

Sapakhova, Z., Islam, K.R., Toishimanov, M., Zhapar, K., Daurov, D., Daurova, A., Raissova, N., Kanat, R., Shamekova, M., Zhambakin, K., 2024. Mulching to improve sweet potato production. J. Agric. Food Res. 15, 101011. https://doi.org/10.1016/j.jafr.2024.101011.

Shekhar, S., Mishra, D., Buragohain, A.K., Chakraborty, S., Chakraborty, N., 2015a. Comparative analysis of phytochemicals and nutrient availability in two contrasting cultivars of sweet potato (*Ipomoea batatas* L.). Food Chem. 173, 957–965. https://doi.org/10.1016/j.foodchem.2014.09.172.

Singh, S.P., Mahapatra, B.S., Pramanick, B., Yadav, V.R., 2021. Effect of irrigation levels, planting methods and mulching on nutrient uptake, yield, quality, water and fertilizer productivity of field mustard (*Brassica rapa* L.) under sandy loam soil. Agric. Water. Manage 244, 106539. https://doi.org/10.1016/j.agwat.2020.106539.

Sinkovič, L., Sinkovič, D.K., Ugrinović, K., 2023. Yield and nutritional quality of soil-cultivated crisphead lettuce (*Lactuca sativa* L. var. *capitata*) and corn salad (*Valerianella* spp.) harvested at different growing periods. Food Sci. Nutr. 11 (4), 1755–1769. https://doi.org/10.1002/fsn3.3205.

Suárez, M.H., Hernández, A.I.M., Galdón, B.R., Rodríguez, L.H., Cabrera, C.E.M., Mesa, D.R., Rodríguez-Rodríguez, E.M., Romero, C.D., 2016. Application of multidimensional scaling technique to differentiate sweet potato (*Ipomoea batatas* (L.) Lam) cultivars according to their chemical composition. J. Food Compos. Anal. 46, 43–49.

Sui, W., Mu, T., Sun, H., Yang, H., 2019. Effects of different drying methods on nutritional composition, physicochemical and functional properties of sweet potato leaves. J. Food Process. Preserv. 43 (3), e13884. https://doi.org/10.1111/jfpp.13884.

R Core Team, 2021. R: a language and environment for statistical computing. Published online 2020 Suppl. Inf. Refs. S 1, 371–378.

Tripodi, P., Francese, G., Sanajà, V.O., Di Cesare, C., Festa, G., D'Alessandro, A., Mennella, G., 2021. A multi-methodological approach to study genomic footprints and environmental influence on agronomic and metabolic profiles in a panel of Italian traditional sweet pepper varieties. J. Food Compos. Anal. 103, 104116. https://doi.org/10.1016/j.jfca.2021.104116.

USDA (2022). Department of agriculture. Agricultural Research Service, FoodData Central for Sweet potatoes, orange flesh, without skin, raw. *Available online*: https://fdc.nal.usda.gov/fdc-app.html#/food-details/2346404/nutrients (accessed on 7 August 2024).

Vicente-Gonzalez, L., & Vicente-Villardon, J.L. (2021). *PERMANOVA: multivariate analysis of variance based on distances and permutations* (0.2.0) [Computer software]. https://cran.r-project.org/web/packages/PERMANOVA/index.html.

Wang, A., Li, R., Ren, L., Gao, X., Zhang, Y., Ma, Z., Ma, D., Luo, Y., 2018. A comparative metabolomics study of flavonoids in sweet potato with different flesh colors (*Ipomoea batatas* (L.) Lam). Food Chem. 260, 124–134. https://doi.org/10.1016/j.foodchem.2018.03.125.

Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y., Zemla, J., Freidank, M., Cai, J., & Protivinsky, T. (2021). *Corrplot: visualization of a correlation matrix* (0.92) [Computer software]. https://cran.r-project.org/web/packages/corrplot/index.html.

Yang, Y., Shi, D., Wang, Y., Zhang, L., Chen, X., Yang, X., Xiong, H., Bhattarai, G., Ravelombola, W., Olaoye, D., Yang, G., Shi, A., 2020. Transcript profiling for regulation of sweet potato skin color in Sushu8 and its mutant Zhengshu20. Plant Physiol. Biochem. 148, 1–9. https://doi.org/10.1016/j.plaphy.2019.12.035.

Ye, H.-L., Chen, Z.-G., Jia, T.-T., Su, Q.-W., Su, S.-C., 2021. Response of different organic mulch treatments on yield and quality of *Camellia oleifera*. Agric. Water. Manage 245, 106654. https://doi.org/10.1016/j.agwat.2020.106654.

Yvonne, M., Pontsho, T., 2023. Responses of the nutritional value of the orange fleshed 'Bophelo' sweet potato (*Ipomoea batatas* L.) cultivar under various processing techniques. Res. Crops 24 (1), 139–148.