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# Managing the Nutraceutical and Sensorial Qualities of Pisanello, an Ancient Tomato Landrace, in Soilless Conditions

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**Abstract:** Recently, there has been significant consumer demand for traditional tomato varieties due to their favourable organoleptic qualities; however, the cultivation of these ancient varieties is becoming more restricted due to inadequate shelf life and low productivity. The "Pisanello" is a Tuscany tomato variety mainly cultivated in the provinces of Pisa, Lucca, and Livorno, and the main producers of this ancient tomato are small local farmers. The purpose of this work was, firstly, to study the range of quality parameters of this landrace tomato grown using different cultivation techniques, both in soil and soilless systems. For this purpose, the physicochemical parameters of Pisanello tomatoes grown in six different farms in Tuscany using both soilless and soil methods were investigated. Secondly, Pisanello tomatoes grown using different soilless techniques (rockwool and aeroponics) and soil-grown tomatoes (Pisanello and Goldmar F1) were evaluated from organoleptic and nutraceutical points of view. The sensory profile evaluation of all types of tomatoes under investigation was carried out. The aeroponic cultivation of Pisanello induced higher organoleptic qualities than those of tomatoes cultivated in rockwool (+34% for titratable acidity and +18% for total soluble solids). On the other hand, soilless rockwool-grown tomatoes showed a better sensory profile with respect to aeroponic cultivation. Nevertheless, the Goldmar F1 tomato, morphologically similar to 'Pisanello', received lower scores from the sensory panel compared to the Tuscany landrace tomato. This indicates that ancient tomato varieties selected over decades remain the preferred choice for consumers. Therefore, from a long-term viewpoint, the valorisation of local tomato varieties such as Pisanello can promote the regional commercialization of novel niche products originating from ancient fruit thanks to their acceptability by consumers.

**Keywords:** *Solanum lycopersicum*; tomato quality; hydroponics; aeroponics; soil; nutraceutical profile; sensory analysis; local landrace

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## 1. Introduction

Tomatoes (*Solanum lycopersicum* L.) are one of the most widely consumed agricultural products worldwide, cultivated under various conditions, including open fields, greenhouses, and small home gardens [1]. Several studies have demonstrated a correlation between tomato consumption and a reduced risk of cardiovascular diseases, coronary heart disease, and cancer. This protective action is attributed to the presence of bioactive compounds, including polyphenols, flavonoids, lycopene, carotenoids, and anthocyanins [2–7]. A multitude of tomato varieties with deep roots in Southern Europe have emerged following five centuries of cultivation and selection. These varieties likely result from farmer-driven selection, adapting to specific growing conditions and local preferences [8]. Local tomato varieties are excellent nutritional resources, as they represent adaptive responses to local ecosystems [9]. Italian farmers have carefully selected tomato varieties based on taste, considering their agronomic characteristics, including marketability, productivity, and transportation durability [10–12]. Valorising local fruit and vegetables can be an important aspect of ensuring the survival of traditional agricultural practices from old generations to new ones.

Decades of cultivating tomato varieties in restricted areas have led to local varieties that have adapted to the environment, standing as important sources of genetic variability and local biodiversity [13]. The cultivation of these local tomato varieties by growers has gradually reduced, since they are less productive and profitable than other varieties. However, the consumption of local products and old fruit and vegetable varieties is increasingly being viewed favourably by consumers as a return to an "ancient" agriculture [14], serving as a gastronomic identifier for regions. For this reason, some local varieties of vegetables are now receiving increased consumer attention [15,16]. The renewed consumer interest in traditional tomato landraces has prompted seed companies to develop numerous tomato hybrids similar to the landrace varieties. These hybrids of tomato exhibit striking morphological similarity, but often lack the organoleptic qualities of their predecessors [1,17,18].

The implementation of techniques such as herbaceous grafting and soilless cultivation has frequently enhanced the yield of traditional varieties [19–21]. Soilless cultivation systems offer higher yields compared to open-field cropping systems and enable off-season production, significantly improving the chemical composition and bioactive profile of the final product [21]. The independence of soilless cultivation systems from soil allows for the optimization of both physical and chemical characteristics in the root zone, as well as the more effective control of pathogens [22]. Consequently, in hydroponics, it is feasible to achieve increased yields at a reasonable production cost with lower levels of fertilizers and minimal pesticide use, while gathering a superior product [23].

Due to the high expenses associated with phenotyping specific characteristics, such as the gustatory excellence of the fruit, and limited understanding of their origins, diversity, and interrelationships, the application of landraces in breeding initiatives is regrettably limited [24]. In contrast to newly developed tomato hybrids, locally adapted Tuscan tomato landraces, such as the Pisanello tomato, exhibit distinct physiological responses and fruit-level concentrations of polyphenols and antioxidants [1,11,13,14,25,26]. Thanks to its reduced pulp deliquescence, the Pisanello tomato is very well adapted to the Tuscan region diet [27].

The purpose of this study was to investigate the overall quality of the local and ancient Tuscan landrace tomato named "Pisanello", contrasting it with a modern commercial competitor (Goldmar F1 hybrid) in terms of quality parameters and customer preferences and perception through a sensory profile study. Additionally, an evaluation of the influence of growing techniques (soil or soilless systems) on the Pisanello tomato's organoleptic and nutraceutical quality, as well as sensory profile quality, was used to demonstrate that innovative cultivation methods can achieve the landrace tomato's optimal qualities.

## 2. Materials and Methods

### *2.1. Experimental Setup and Growth Conditions*

The primary objective of this research was to evaluate the quality performance of Pisanello tomato, a locally grown variety, under various soil and hydroponic growing conditions. During this preliminary study carried out in July 2020, Pisanello tomato fruit were collected from six different farms located in various provinces of Tuscany, utilizing different growing techniques (soil and soilless).

Subsequently, in the summer 2021, a second study was conducted to better understand the fruit quality of Pisanello tomatoes grown in two soilless cultivations: (i) rockwool soilless cultivation and (ii) aeroponic cultivation. During the same period, Pisanello tomatoes and Goldmar F1 hybrid (ISI Sementi s.p.a, Fidenza, Parma, Italy) tomatoes were purchased from a local farm that cultivated tomatoes in soil in a greenhouse. Tomatoes from the 6th truss were collected in July 2021. Additionally, a sensory profile panel test was performed to determine if consumers could distinguish between different types of tomatoes grown in soil and soilless systems and between the Pisanello tomato and the Goldmar F1 tomato.

#### 2.1.1. Experiment 1 (2020)

A preliminary evaluation of the quality of the Pisanello fruit throughout the Tuscany region was carried out in July 2020. Pisanello tomato fruit were collected from six different farms located in various provinces of Tuscany, Italy: (i) Livorno, (ii) Lucca, and (iii) Pisa. In each province, two farms were selected for the evaluation. In all farms, samples of tomato fruit were collected from the 4th–6th trusses when they were fully ripe and ready for the market. The fruit were stored at a controlled temperature of 6 °C and analysed within 2 days of harvesting. Some information regarding the tomato cultivation cycle across different farms is presented in Table 1.

**Table 1.** General information about the cultivation of Pisanello tomatoes grown on different farms in Tuscany in soilless and soil systems during spring/summer 2020 (harvested in July 2020).

| **Farm Site** | | **Livorno 1** | **Lucca 1** | **Lucca 2** | **Pisa 1** | **Livorno 2** | **Pisa 2** |
|---|---|---|---|---|---|---|---|
| Cultivation system | | Soilless | Soilless | Soilless | Soil | Soil | Soil |
| Cultivation cycle | Transplant (date/month) | 1–5/2 | 1–7/2 | 1–7/2 | 1–5/3 | 20–25/2 | 10–15/5 |
| | Harvest started (date/month) | 10–15/5 | 10–15/5 | 10–15/5 | 20–25/5 | 15–20/5 | 10–15/7 |
| | Harvest finished (date/month) | 31/8 | 31/8 | 31/8 | 15/8 | 15/8 | 30/9 |

Several quality parameters were assessed in fully ripe tomato fruit, including fruit firmness, electrical conductivity (EC), pH of the tomato juice, citric acid content, total soluble solids, lycopene, total phenolic content, and antioxidant activity (DPPH).

#### 2.1.2. Experiment 2 (2021)

In summer 2021, a second study was conducted to compare the fruit quality of Pisanello tomatoes with Goldmar F1 hybrid tomatoes grown in soil. Moreover, Pisanello tomatoes grown using different soilless techniques (rockwool soilless cultivation and aeroponic cultivation) were also compared and analysed.

In aeroponic cultivation, tomato plants were positioned within modified plastic boxes where the nutrient solution was sprayed on the root zone using the same recipe utilized for the cultivation in rockwool. Each tomato plant was contained within a polystyrene panel that was close to the top of each plastic box. The roots of the plants developed inside the aeroponic system, and were kept wet by the nutrient solution activated by an intermittent pump connected to a collection tank filled with the nutritional solution. Transplantation in the aeroponic system took place in the same period for soilless rockwool tomatoes using the nutrient solution, as described by Cela et al. [27]. The average air temperature for the soilless cultivations throughout the cultivation cycle was 25.2 °C ($T_{min}$ = 18.4 °C and $T_{max}$ = 31.8 °C), while the average relative humidity was approximately 58.3% ($RH_{min}$ = 27.3% and $RH_{max}$ = 84.0%). The daily global radiation was 12.20 $MJm^{-2}$, with a minimum of 2.27 $MJm^{-2}$ and a maximum of 17.85 $MJm^{-2}$ inside the greenhouse.

Pisanello and Goldmar F1 tomatoes were soil-grown in a multitunnel plastic greenhouse with a metal structure and a single plastic film covering, reaching an approximate 4 m height. The mean air temperature during the cultivation cycle at Livorno 2 farm was 25.9 °C ($T_{min}$ = 16.3 °C and $T_{max}$ = 34.3 °C), and the mean relative humidity was about 64.1% ($RH_{min}$ = 32.8% and $RH_{max}$ = 89.3%). The average daily inside global radiation was 13.70 $MJm^{-2}$ ($GR_{min}$ = 2.81 $MJm^{-2}$ and $GR_{max}$ = 19.67 $MJm^{-2}$).

For this investigation, only tomato fruit harvested from the 4th–6th trusses in July 2021 were analysed. Different analyses were carried out, including organoleptic and nutraceutical analysis, as well as sensory profile evaluation.

### 2.2. Fruit Organoleptic Quality

A digital penetrometer with an 8 mm diameter tip (model 53205 TR Turoni & Co., Forlì, Italy) was used to measure the firmness of the tomato fruit samples from each treatment. The maximal force (kg) needed to penetrate the tomato pulp was registered. For every fruit, three measurements were made, and the mean value was then calculated and expressed in kg $cm^{-2}$. The tomato fruit were sliced into small pieces and mixed after the firmness of the fruit was measured. To determine the dry matter content (DMC), a portion of the puree was dried in an oven (Memmert GmbH + Co. KG Universal Oven UN30, Schwabach, Germany) and heated to 70 °C until a consistent weight was obtained. To obtain the tomato juice (supernatant), another portion of the tomato puree was centrifuged at 3500 rpm for 15 min. The titratable acidity (TA), pH, electrical conductivity (EC), and total soluble solids (TSS) were measured utilizing the resulting supernatant. A bench pH meter (XS pH50+ DHS XS Instruments, Carpi (MO), Italy) with automatic temperature compensation was used to measure the pH of the tomato juice. A bench EC meter with automated temperature compensation (XS COND 51+ XS Instruments, Carpi (MO), Italy) was used to measure the EC, which was expressed as dS $m^{-1}$. Using an Abbe refractometer, the TSS in the tomato juice were calculated and expressed as °Brix. The TA was calculated by titrating against a 0.1 M NaOH solution using phenolphthalein as an indicator, and is represented as gram citric acid 100 $g^{-1}$ fresh weight (FW).

### 2.3. Total Phenolic Content, Free Radical Scavenging Assay, and Lycopene Content

The total amount of phenolic compounds was calculated using Dewanto et al. [28] procedure, while, for the free radical scavenging activity, the 2,2-Diphenyl-1-picrylhydrazyl hydrate (DPPH) assay was used to measure the antioxidant activity in accordance with the procedure reported by Brand-Williams et al. [29]. The procedure described by Adejo et al. [30] was applied in order to extract and quantify the lycopene content from the tomato fruit.

### 2.4. Sensory Profile

The sensory profiles of the tomatoes were determined by members of an "expert panel" of the University of Pisa, as described by Cela et al. [27]. Concerning the training process, the method was validated in accordance with Billeci et al. [31], the Good Senses commercial procedure [32], and Marchioni et al. [33]. The panellists settled on a final set of 24 descriptive indicators that included both quantitative and hedonic attributes. They also created a novel sensory wheel that was customized for tomato tasting, as described by Cela et al. [27] (Figure 1).

The panel test took place in the morning in an adequately ventilated room with a comfortable atmosphere. The panel test was conducted on completely mature tomatoes two hours after they had been removed from the refrigerator. In order to prevent expectation error, each tomato was assigned a code at random and given to the evaluators in a double-blind presentation, as explained by Sanmartin et al. [34].

### 2.5. Statistical Analysis

The results derived from the soil-cultivated Pisanello and Goldmar F1 tomatoes, as well as those from the two soilless systems, were compared with a two-tailed Student's $t$-test using a significance level of 0.05. Data are expressed as mean ± standard deviation. GraphPad Prism 9 software (GraphPad, La Jolla, CA, USA) was utilized to conduct the statistical analysis.


**Figure 1.** Sensory wheel specifically designed for tomato panel evaluation, described by Cela et al. [27].

Biometrical and sensorial measured variables underwent comprehensive multivariate statistical analyses using JMP software (SAS Institute Inc. JMP®. Version 17, SAS Institute Inc., Cary, NC, USA, 2021). Principal Component Analysis (PCA) was performed on a correlation matrix of three replicates of each treatment of 32 × 12 (32 variables × 12 samples = 384 data). The PCA results were plotted by choosing the two principal components obtained from linear regressions performed on centre-unscaled data that had the largest variance explained. This analysis, which used an unsupervised approach, sought to maintain most of the variance while decreasing the dimensionality of the matrix's multivariate data. Furthermore, Ward's approach was utilized to perform a two-way Hierarchical Cluster Analysis (HCA), with squared Euclidean distances serving as a similarity metric.

## 3. Results and Discussion

### *3.1. Organoleptic and Nutraceutical Quality of Soil- and Soilless-Grown Tomatoes in the Preliminary Experiment (2020)*

Soil cultivation led to higher levels of dry matter content (DMC) and TSS in tomato fruit compared to soilless cultivation, without taking into consideration the different pedo-climatic conditions between the cultivation techniques. The principal aim of soilless cultivation is to improve the marketable yield through the precise control of water and nutrient supply [35,36]. This challenge is very difficult in soil-grown vegetables [37,38].

Moreover, soil-grown tomatoes exhibited a higher concentration of total phenols, compounds known for their antioxidant properties, compared to soilless-grown tomatoes (Table 2). This could be attributed to the controlled environment of soilless cultivation, which can provide an equilibrium between water and nutrients, minimizing several stress factors often responsible for higher total phenol content [39,40]. These findings agree with previous research that has shown the impact of cultivation technique and genetic character on the nutritional and sensory quality of tomatoes [1,14,18,25].

**Table 2.** Quality parameters of Pisanello tomatoes grown on six different farms in Tuscany in soilless and soil systems during spring/summer 2020 (harvested in July 2020).

| Farm Site | Cultivation System | DMC (%) | pH Juice | TA (g Citric Acid 100 $g^{-1}$ FW) | TSS (°Brix) | Lycopene (mg 100 $g^{-1}$ FW) | Total Phenols (mg GAE 100 $g^{-1}$ FW) | DPPH (mg TE 100 $g^{-1}$ FW) |
|---|---|---|---|---|---|---|---|---|
| Livorno 1 | Soilless | 4.9 ± 0.2 | 4.4 ± 0.0 | 0.67 ± 0.0 | 4.9 ± 0.0 | 3.9 ± 0.5 | 42.8 ± 6.3 | 47.6± 7.3 |
| Lucca 1 | Soilless | 4.9 ± 0.2 | 4.5 ± 0.0 | 0.53 ± 0.0 | 3.9 ± 0.2 | 2.3 ± 0.2 | 39.2 ± 4.7 | 38.7 ± 10.1 |
| Lucca 2 | Soilless | 5.5 ± 0.1 | 4.5 ± 0.0 | 0.61 ± 0.0 | 4.0 ± 0.0 | 3.9 ± 0.6 | 46.2 ± 7.3 | 90.5 ± 9.2 |
| Pisa 1 | Soil | 5.5 ± 0.3 | 4.5 ± 0.0 | 0.61 ± 0.0 | 5.0 ± 0.0 | 5.6 ± 0.6 | 61.6 ± 6.7 | 57.9 ± 13.8 |
| Livorno 1 | Soil | 5.9 ± 0.6 | 4.6 ± 0.0 | 0.50 ± 0.0 | 5.0 ± 0.0 | 2.5 ± 0.8 | 43.2 ± 5.7 | 56.7 ± 22.3 |
| Pisa 2 | Soil | 6.5 ± 0.1 | 4.3 ± 0.0 | 0.60 ± 0.0 | 4.8 ± 0.0 | 3.2 ± 0.5 | 81.7 ± 3.1 | 62.2 ± 13.4 |
| | LSD | 0.58 | 0.11 | 0.06 | 0.35 | 1.26 | 13.00 | 20.67 |
| | Soilless | 5.1 ± 0.3 b | 4.5 ± 0.1 a | 0.60 ± 0.1 a | 4.3 ± 0.5 b | 3.4 ± 0.49 a | 43.2 ± 6.2 b | 56.1 ± 25.2 a |
| | Soil | 6.0 ± 0.8 a | 4.5 ± 0.1 a | 0.57 ± 0.1 a | 4.9 ± 0.1 a | 3.9 ± 1.50 a | 60.1 ± 17.3 a | 60.2 ± 14.9 a |

Mean values of three independent biological determinations (n = 3) ± standard deviation (SD) followed by different letters are statistically different ($p < 0.05$) according to the Least Significant Difference test (LSD).

The pH in the tomato juice, the concentration of lycopene, and the total phenol content were relatively constant across both soil and soilless systems. This finding suggests the presence of stable conditions that facilitate the synthesis of advantageous compounds (Table 2).

The qualitative characteristics of tomatoes are substantially influenced by cultivation method and climate conditions [41,42]. Environmental factors such as growing systems, maturity stage, and harvest time all have a significant impact on the final tomato fruit quality [18]. The observed values in this preliminary study (Table 2) are consistent with those reported by numerous authors investigating tomato fruit in the Mediterranean basin, as shown in Table 3.

**Table 3.** Summary of some studies referring the range of bioactive compounds in tomato fruit in the Mediterranean area.

| Tomato Varieties and County | Growing Conditions | TPC [1] | DPPH [2] | Lycopene [3] | Reference |
|---|---|---|---|---|---|
| Pisanello tomato, spring–summer 2021. Pisa, Tuscany, Italy | Soilless greenhouse | 36.9–117.2 | 20.6–80.3 | 4.05–7.87 | Department of Agriculture, Food and Environment University of Pisa. Data not published yet |
| Eight traditional varieties and one commercial variety (Liscio da Serbo Toscano, Rosso di Pitigliano, Quarantino ecotipo (ec.) Valdarno, Fragola, Canestrino di Lucca, Costoluto Fiorentino, Giallo di Pitigliano, Pisanello, and Cuore di Bue, Tuscany, Italy) | Open field | 51.4–90.4 | | 4.02–6.21 | [14] |
| Vesuvian Piennolo cherry tomato; six red-pigmented types and one yellow-pigmented tomato type, Southern Italy | Open field | 99.4–134.6 | | 3.63–15.09 | [43] |
| Vesuvian Piennolo cherry tomato, Southern Italy | Open field | 29.6–38.5 | | 2.71–7.35 | [44] |
| Regina tomato, a traditional long-storage landrace with three ecotypes, Puglia, Southern Italy | Open field | | | 4.12–5.37 | [45] |

**Table 3.** *Cont.*

| Tomato Varieties and County | Growing Conditions | TPC [1] | DPPH [2] | Lycopene [3] | Reference |
|---|---|---|---|---|---|
| Local landrace of a long-storage tomato, Catania, Sicily, Southern Italy | Cold greenhouse and open field | 45.0–90.0 | 75.0–85.0 | 5.50–11.00 | [46] |
| Six high-lycopene cultivars and one ordinary tomato cultivar, Lecce, Puglia, Southern Italy | Open field | 10.6–39.5 | | 9.69–23.29 | [47] |
| Different parts of tomato (peel, fruit, pulp, and seeds) of niche cultivars compared with commercial ones, Campania region, Southern Italy | Open field | | 30.4–86.8 (Fruit pulp) | 1.99–3.13 (Fruit pulp) | [48] |
| Five traditional tomato Greek germplasm varieties alongside a commercial F1 hybrid, Greece | Soilless greenhouse | 27.5 (F1 hybrid)—48.3 (traditional) | | 2.24 (F1 hybrid)—7.98 (traditional) | [49] |
| Seven cultivars, comprising two high-pigment varieties, five underutilized ancient tomato genotypes considered as landraces, Tunisia | Open field | 13.98–35.24 | 111.6–196.9 | 7.60–22.78 | [50] |
| Ten Cypriot landraces, eight Greek varieties and one French variety, Cyprus | Soil greenhouse | 4.50–8.87 | | 1.42–5.85 | [51] |
| Nine commercial varieties, Spain | Open field | 25.9–49.9 | | 1.86–6.50 | [52] |

[1]: Total phenolic content (mg GAE 100 $g^{-1}$ FW); [2]: DPPH (mg TE 100 $g^{-1}$ FW); [3]: lycopene (mg 100 $g^{-1}$ FW).

### 3.2. Organoleptic and Nutraceutical Quality of Soilless-Grown Pisanello Tomatoes (2021)

Soilless cultivation is an efficient tool to manage plant-growing parameters such as the EC of the nutrient solution, mineral uptake, and irrigation via modern fertigation equipment and automation technologies for improvements in fruit quality in terms of chemical composition and bioactive compounds [21,22]. For these reasons, the nutraceutical quality was also evaluated for Pisanello tomatoes grown at the Department of Agriculture, Food and Environment (DAFE), University of Pisa, Italy, in two different soilless systems (rockwool soilless system and aeroponic cultivation; Table 4).

**Table 4.** Quality parameters evaluated on Pisanello tomatoes grown at the Department of Agriculture, Food and Environment (DAFE), University of Pisa, Italy, in two different soilless systems (rockwool and aeroponics), harvested in July 2021.

| Treatment | pH | EC (dS $m^{-1}$) | TA (g Citric Acid 100 $g^{-1}$ FW) | TSS (°Brix) | DMC (%) | Firmness (kg $cm^{-2}$) |
|---|---|---|---|---|---|---|
| Pisanello Rockwool | 4.23 ± 0.03 a | 9.00 ± 0.04 b | 0.77 ± 0.01 b | 5.72 ± 0.10 b | 6.58 ± 0.13 b | 1.23 ± 0.05 a |
| Pisanello Aeroponics | 4.10 ± 0.03 b | 10.74 ± 0.15 a | 1.03 ± 0.02 a | 6.77 ± 0.19 a | 7.49 ± 0.11 a | 1.41 ± 0.13 a |
| Significance | ** | *** | *** | ** | *** | ns |

Data were analysed by Student's *t*-test. ns: not significant, **: $p < 0.01$, ***: $p < 0.001$. The mean values ± standard deviation (SD) followed by different letters are statistically different ($p < 0.05$) according to the Student's *t*-test.

The organoleptic analysis of soilless-cultivated Pisanello tomatoes showed higher pH values in rockwool-grown tomatoes compared to those cultivated using aeroponics. Conversely, EC, TA, TSS content, and DMC were higher in aeroponic-grown tomatoes than in those cultivated in rockwool (Table 4). Similar results were reported by other authors [53,54]. Want et al. [54] observed higher DMC in fruit tomatoes cultivated using aeroponics (~2 g fruit$^{-1}$) compared to tomatoes cultivated using a hydroponics system (~1.5 g fruit$^{-1}$). Eldridge et al. [53] suggested that the aeroponic system might lead to higher concentrations of certain nutrients and improved organoleptic quality, as well as higher fruit production due to optimized nutrient delivery and the oxygenation of plant roots. However, the Pisanello tomatoes cultivated in rockwool in the present work showed promising results, since the reported values in all investigated parameters were lower in a precedent study [54]. Unlike the organoleptic results, no significant differences were found among the different soilless cultivation systems in terms of total phenolic and lycopene content and antioxidant activity (Table 5).

**Table 5.** Total phenolic content, lycopene content, and antioxidant capacity of Pisanello tomatoes grown at the Department of Agriculture, Food and Environment (DAFE), University of Pisa, Italy, in two soilless systems (rockwool and aeroponics), harvested in July 2021.

| Treatment | Total Phenols (mg GAE 100 g$^{-1}$ FW) | Lycopene (mg 100 g$^{-1}$ FW) | DPPH (mg TE 100 g$^{-1}$ FW) |
|---|---|---|---|
| Pisanello Rockwool | 66.15 ± 8.24 a | 5.40 ± 0.24 a | 65.60 ± 6.66 a |
| Pisanello Aeroponics | 65.56 ± 1.11 a | 6.33 ± 0.83 a | 65.97 ± 8.77 a |
| Significance | ns | ns | ns |

Data were analysed by Student's *t*-test. ns: not significant. The mean values ± standard deviation (SD) followed by different letters are statistically different ($p < 0.05$) according to the Student's *t*-test.

The values found for the total phenolic content, lycopene, and antioxidant activity of the tomatoes cultivated in the soilless system were in line with our previous results obtained on soilless-cultivated Pisanello tomatoes [27]. Cela et al. [27], using a rockwool soilless cultivation, found similar values of pH juice (4.19); TA (0.79 g citric acid per 100 g); TSS (5.47 °Brix); and DMC (6.08%) in tomatoes grown in similar cultivating conditions (3.00 dS m$^{-1}$ in the nutrient solution).

The lack of significant differences suggests a positive management of tomato quality through the utilization of both efficient soilless cultivation systems. However, the absence of a treatment did not lead to variation in quality, since the accumulation of secondary metabolites is always a response of plants to adverse environmental conditions [55,56].

### 3.3. Organoleptic and Nutraceutical Quality of Soil-Grown Tomatoes (2021)

The nutraceutical quality of Goldmar F1 tomatoes and Pisanello tomatoes grown in soil was also evaluated. The results of the pH and EC of the tomato juice, TA, TSS, DMC, and tomato firmness are reported in Table 6.

**Table 6.** pH, electrical conductivity (EC), titratable acidity (TA), total soluble solids (TSS), dry matter content (DMC), and firmness of soil-grown Pisanello and Goldmar F1 tomatoes cultivated in soil and harvested in July 2021.

| Variety | pH | EC (dS m$^{-1}$) | TA (g Citric Acid 100 g$^{-1}$ FW) | TSS (°Brix) | DMC (%) | Firmness (kg cm$^{-2}$) |
|---|---|---|---|---|---|---|
| Pisanello | 4.57 ± 0.02 a | 8.20 ± 0.09 a | 0.54 ± 0.02 a | 5.02 ± 0.18 a | 4.86 ± 0.35 a | 1.43 ± 0.16 b |
| Goldmar F1 | 4.14 ± 0.03 b | 7.81 ± 0.15 b | 0.53 ± 0.01 a | 4.62 ± 0.12 b | 4.62 ± 0.10 a | 1.99 ± 0.16 a |
| Significance | *** | * | ns | * | ns | * |

Data were analysed by Student's *t*-test. ns: not significant, *: $p < 0.05$, ***: $p < 0.001$. The mean values ± standard deviation (SD) followed by different letters are statistically different ($p < 0.05$) according to the Student's *t*-test.

The pH of the Pisanello variety was higher than that of Goldmar F1, with results falling within the common range for tomato pH. Typically, tomato juice's pH ranges from 3.9 and 4.9, and is influenced primarily by the fruit's acid content, which is a significant indicator of tomato flavour [57]. However, this value did not directly correlate with TA [58].

In this investigation, the TA was similar between Pisanello and Goldmar F1 tomatoes, showing no significant differences. Nevertheless, TA is an important quality parameter in fresh tomato, associated with the perception of both sourness and sweetness [59,60].

The tomato juice EC was higher for soil-cultivated Pisanello tomatoes (8.20 dS $m^{-1}$) compared to Goldmar F1 tomatoes (7.81 dS $m^{-1}$). Regarding TSS, Pisanello fruit had a higher TSS content (5.02 °Brix) than Goldmar F1 fruit (4.62 °Brix).

DMC in tomato is principally related to sugars, determining the sweetness taste [61], and is commonly correlated with TSS content. No significant differences were found in the DMC measurements of the soil-cultivated tomatoes under investigation. Tomato fruit firmness was highest in soil-grown Goldmar F1 (2.0 kg $cm^{-2}$). This trait suggests that Goldmar F1 tomatoes are bred for a longer shelf life [10] compared to Pisanello tomatoes. This parameter is important for modern varieties, ensuring long shelf life and durability during transportation, and thereby reducing marketable production losses [10–12]. This fact explains the higher values of fruit hardness in modern varieties compared to the Pisanello landrace.

No significant differences were observed in terms of total phenolic and lycopene content between the Pisanello and Goldmar F1 tomatoes (Table 7).

**Table 7.** Total phenolic content, lycopene content, and antioxidant capacity by DPPH assay of soil-grown Pisanello and Goldmar F1 tomatoes, harvested in July 2021.

| Treatment | Total Phenolic Content (mg GAE 100 $g^{-1}$ FW) | Lycopene (mg 100 $g^{-1}$ FW) | DPPH (mg TE 100 $g^{-1}$ FW) |
|---|---|---|---|
| Pisanello | 56.52 ± 9.24 a | 4.52 ± 0.56 a | 58.30 ± 1.06 a |
| Goldmar F1 | 49.80 ± 6.03 a | 3.65 ± 0.77 a | 28.82 ± 7.37 b |
| Significance | ns | ns | ** |

Data were analysed by Student's *t*-test. ns: not significant, **: $p < 0.01$. The mean values ± standard deviation (SD) followed by different letters are statistically different ($p < 0.05$) according to the Student's *t*-test.

However, the antioxidant activity was higher in Pisanello tomatoes compared to Goldmar F1 tomatoes. The values of total phenolic were similar to those reported by other authors, confirming our findings [1,11]. Berni et al. [1] reported a value around 60 mg 100 $g^{-1}$ FW in soil-cultivated Pisanello tomatoes following the traditional agronomic practices used in Tuscany. Additionally, a similarity between the total phenolic content of Pisanello tomatoes and that of some commercial tomatoes, such as San Marzano and Fragola tomatoes, was also reported [1]. Cultivating Pisanello and Goldmar F1 tomatoes under the same environmental conditions, as undertaken in this experiment, did not increase the total phenolic content. The same considerations could be made for lycopene content. However, the higher antioxidant activity found in Pisanello tomatoes compared to Goldmar F1 tomatoes might be due to phenols with higher antioxidant capacity, as found by other authors [25].

### *3.4. Sensory Profile of Soil-Grown Pisanello and Goldmar F1 Tomatoes and Soilless-Grown Pisanello Tomatoes (2021)*

A sensory profile was carried out on tomatoes from soil and soilless systems to determine if consumers can distinguish between various types of tomatoes grown in soil versus those cultivated in soilless systems (Figure 2).

The soilless-grown tomatoes received higher scores for sweetness, sapidity, persistence, and intensity of taste (Figure 3).

The TA, an important quality parameter in fresh tomato associated with the perception of sweetness [59,60], was higher in soilless tomatoes than in those cultivated in soil. Conversely, the soil-grown tomatoes, especially the Goldmar F1 hybrid, received lower appreciations during the panel test in comparison to soilless-grown tomatoes (aeroponics and rockwool). For instance, the tomatoes grown in soilless conditions gathered higher scores from the panellists for many factors, such as colour intensity, tonality, and colour homogeneity (Figure 3).

**Figure 2.** Tomato fruit cultivated in soil and soilless systems used for quality and sensory profile analysis.

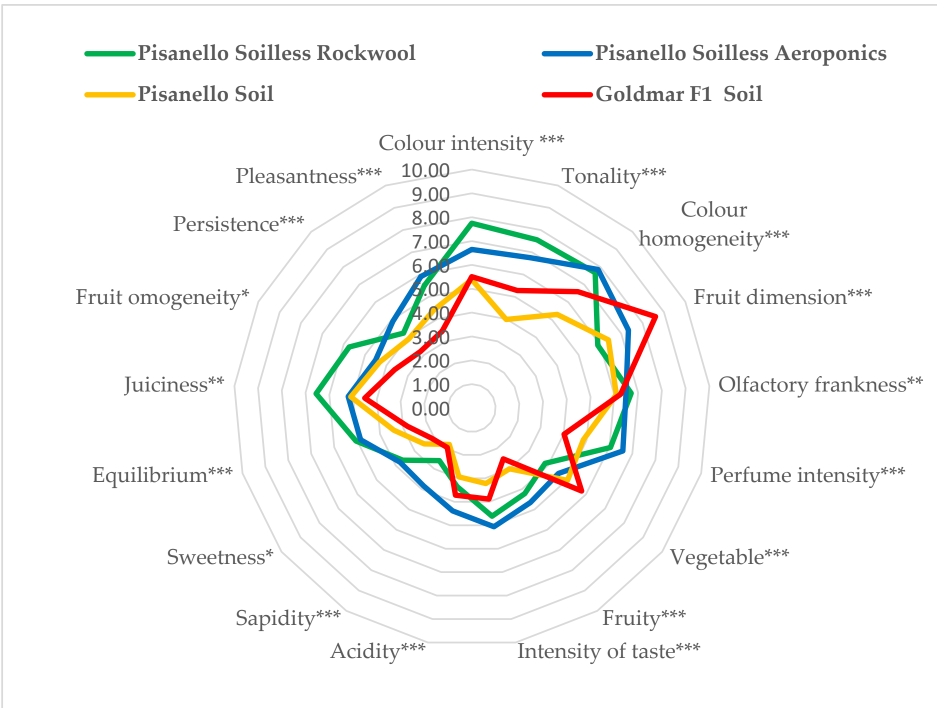



**Figure 3.** Sensory profile analysis comparison between Pisanello soilless rockwool, Pisanello soilless aeroponics, Pisanello soil, and Goldmar F1 soil. Significance level (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$) is based on ANOVA and Tukey post hoc test performed between treatments.

Overall, the sensory evaluation results suggested that Pisanello tomatoes cultivated using aeroponics received the highest scores in most attributes, closely followed by Pisanello tomatoes cultivated using the rockwool soilless system (Figure 3). Although Pisanello tomatoes achieved superior scores to Goldmar F1 soil-grown tomatoes, which had the lowest sensory profile scores, the Pisanello tomatoes grown in soil were less appreciated in comparison with the soilless treatments (Figure 4).

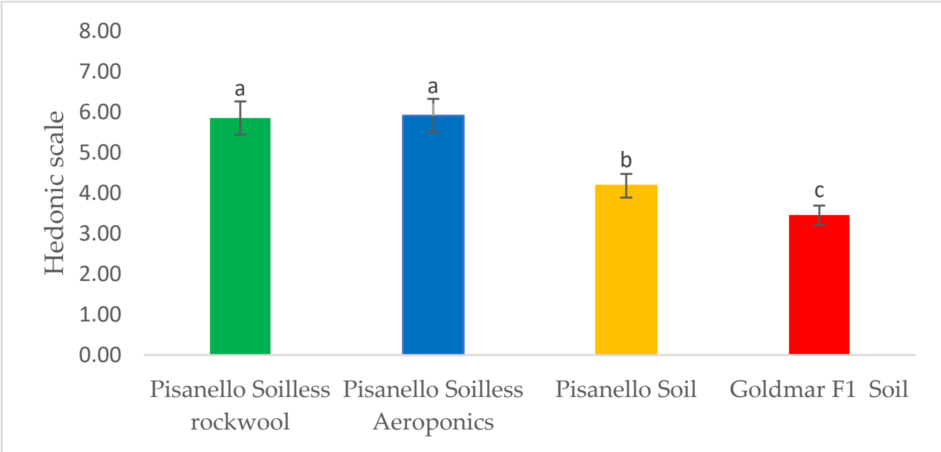


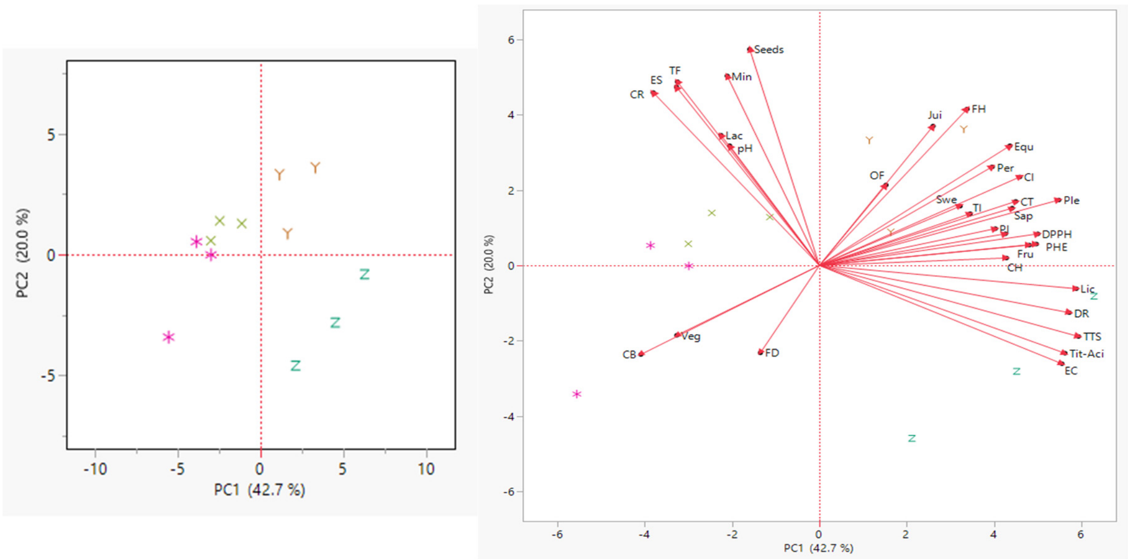

**Figure 4.** Overall hedonic index. Overall hedonic index of pleasantness of tomato fruit attributed by panellists. Mean values (n = 10) ± standard deviation followed by different letters are statistically different according to the LSD test.

Similar results were found by Cela et al. [27]. Indeed, these authors observed that the overall hedonic index of pleasantness (5.89) of the control tomatoes was similar to the values found in the present research (5.85). To analyse the impact of the varieties and cultivation systems, we grouped various datasets, which included 32 variables and 12 samples (each treatment performed in triplicate). This complexity made interpreting the data challenging. Therefore, we utilized statistical methods such as PCA and HCA to visualize variability and group similar samples, providing a comprehensive analysis that uncovered meaningful patterns and relationships.

PCA demonstrated that the first two axes collectively accounted for over 62.7% of the variance (Figure 5).

Specifically, PC1 alone elucidates 42.7% of the variability, effectively distinguishing between varieties cultivated in soil (left quadrant) and those grown aeroponically and without soil (right quadrant). The second axis, contributing 20.0% of the variability, partially distinguished the Pisanello variety (upper left quadrant) from Goldmar F1, where one replicate was on the axis, and another was near it. The main differences between these two varieties were primarily attributed to the higher pH levels in the Pisanello compared to Goldmar F1, as well as the elevated fruit dimension and berry consistency (fruit firmness) in Goldmar F1. Additionally, this axis also differentiated the aeroponic system (lower right quadrant) from the soilless rockwool system, situated in the opposite quadrant. Notably, the latter showed important sensory parameters. HCA further validated this distribution by initially segregating soil-cultivated and soilless varieties into two distinct groups: Group A (soil) and Group B (soilless) (Figure 6).

These clusters were subsequently subdivided into subclusters: subcluster A-a, comprising the Goldmar F1 tomatoes, and subcluster A-b, consisting of the Pisanello tomatoes (Figure 6). Similarly, the soilless group was divided into subcluster B-a, containing two Pisanello aeroponically cultivated samples and one soilless sample, and subcluster B-b, encompassing the remaining soilless samples.




(**a**) (**b**)

**Figure 5.** Principal Component Analysis (**a**) and biplot (**b**) of tomato varieties. 1: Pisanello soilless1; 2: Pisanello soilless2; 3: Pisanello soilless3; 4: Pisanello soil1; 5: Pisanello soil2; 6: Pisanello soil3; 7: Pisanello aeroponics1; 8: Pisanello aeroponics2; 9: Pisanello aeroponics3; 10: GoldmarF1−1: 11: Goldmar F1−2; 12: Goldmar F1−3. *: Goldmar−F; X: Pisanello soil; Y: Pisanello soilless rockwool; Z: Pisanello aeroponics; CB: consistence of berries; Veg: vegetal; FD: fruit dimension; EC: electrical conductivity; Tit-Aci: titratable acidity; TTS: total soluble solids; DR: dry residue; Lic: lycopene; CH: colour homogeneity; Fru: fruit; PHE: total phenols; PI: perfume intensity; Sap: sapidity; Ple: pleasance; CT: colour tonality; TI: taste intensity; Swe: sweetness; Per: persistence; Equ: equilibrium; OF: Olfactive frankness; Jui: juiciness; FH: fruit homogeneity; CI: colour intensity; Seeds: presence of seeds; Min: mineral; Lac: presence of lacerations; TF: taste frankness; ES: evolutionary state; CR: chewing resistance; DPPH: antioxidant activity by DPPH assay.

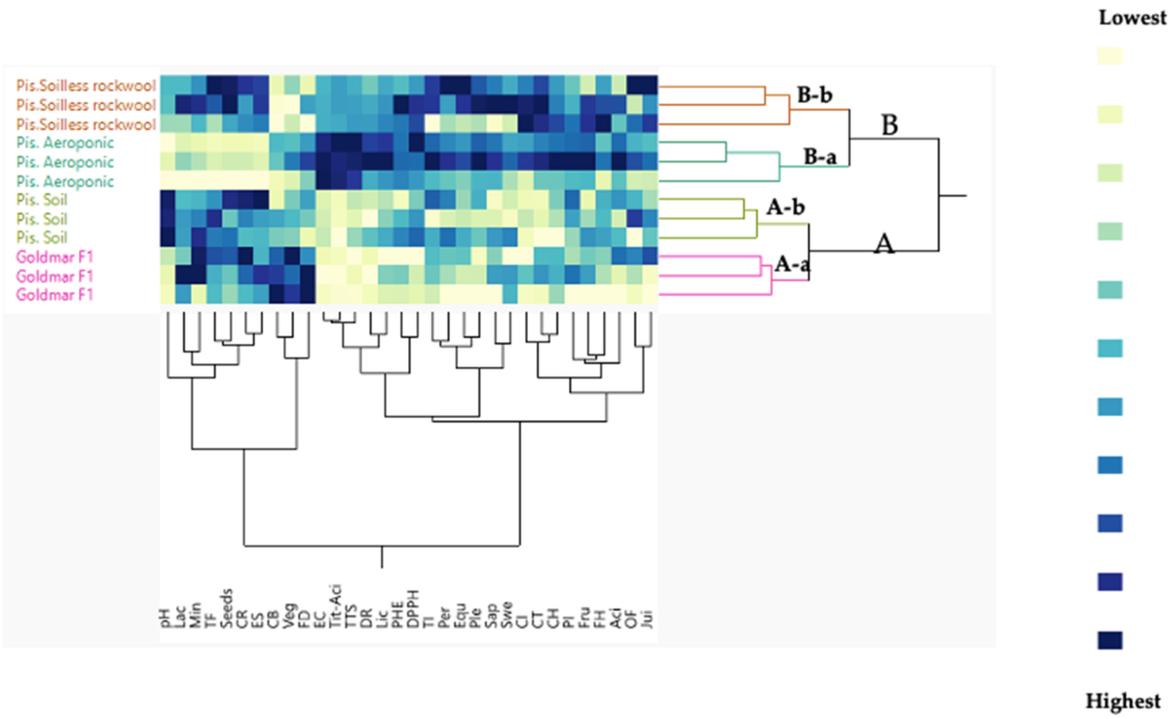



**Figure 6.** Hierarchical Cluster Analysis of tomato varieties. The clusters were subdivided in subclusters: A-a: Goldmar F1 tomatoes; A-b: Pisanello tomatoes; B-a: two aeroponic Pisanello samples and

one rockwool-cultivated Pisanello sample; B-b: the remaining soilless samples. Abbreviations: pH: pH values; Lac: presence of lacerations; Min: mineral; TF: taste frankness; Seeds: presence of seeds; CR: chewing resistance; ES: evolutionary state; CB: consistence of berries; Veg: vegetal; FD: fruit dimension; EC: electrical conductivity; Tit-Aci: titratable acidity; TTS: total soluble solids; DR: dry residue; Lic: lycopene; PHE: total phenols; DPPH: antioxidant activity by DPPH assay; TI: taste intensity; Per: persistence; Equ: equilibrium; Ple: pleasance; Sap: sapidity; Swe: sweetness; CI: colour intensity; CT: colour tonality; CH: colour homogeneity; PI: perfume intensity; Fru: fruit; FH: fruit homogeneity; Aci: acidity taste; OF: Olfactive frankness; Jui: juiciness.

## 4. Conclusions

The diverse world of vegetables and fruits offers an extraordinary opportunity for small farmers through food de-globalization. Mediterranean countries, especially Italy, have preserved traditional landraces that should be promoted to consumers. The Pisanello tomato, rich in bioactive compounds, represents an opportunity for the valorisation of a local product. Our research demonstrated that Pisanello tomatoes cultivated in soil exhibited higher antioxidant activity compared to the common commercial tomato Goldmar F1. Moreover, Pisanello tomatoes grown in soilless rockwool outperformed those grown in soilless aeroponic conditions in terms of organoleptic quality, as evaluated by a sensory profile, although soilless aeroponic conditions showed some higher-quality parameters in terms of titratable acidity and total soluble sugars. When evaluating both soil-cultivated and soilless-grown tomatoes together, the hedonic index indicated that soilless-grown tomatoes were preferred over soil-grown tomatoes in terms of pleasantness. From a long-term perspective, promoting local tomato landraces like Pisanello can enhance the regional commercialization of niche products derived from ancient varieties of fruit and vegetables. Additionally, our research lays the foundation for future studies on the relationship between soilless cultivation systems and the content of functional compounds, as well as the sensory profile of Pisanello tomatoes.

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