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Effect of a New Remediated Substrate on Fruit Quality and Bioactive Compounds in Two Strawberry Cultivars

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Abstract The dredging materials extracted from seaports, considered as contaminants, can be a problem at the time of removal from the environmental point of view. Currently, there is a progressive exhaustion of peatland; and therefore, a substitute for peat mass as a growing substrate is required. These reasons make it a priority to seek solutions in both directions. For this reason has been want to show the suitability of dredged sediment, after being bioremediated for 3 years, as a new substrate in agriculture. Thus, were studied the behavior of dredged remediated sediments on fruit quality and bioactive compounds of two strawberry cultivars "Camarosa" and "Monterrey". The strawberries were grown on three substrate-based treatments: peat 100%, sediment 100% and 50% both (mixture). Fresh weight, firmness, soluble solids content, titratable acidity, maturity index, sugars, sweetness index, acids, vitamin C, sugars-acids ratio, antioxidant activity and total phenol content were determined for each treatment. The results indicated that no significant differences were established on fruit quality within different treatments. The strawberries grown under dredged remediated sediment (DRS) and Peat-DRS substrate (mixture 50%) showed a high content in vitamin C, total phenols and antioxidant activity, also had the highest sweetness index and a good firmness. The present study has shown that the used of DRS as a growing substrate for strawberries are a valid alternative to satisfy the progressive shortage of the traditional substrates and should be further investigated in order to modify European legislation on growing substrates for agricultural uses.

Keywords: *antioxidant activity, organic acids, polyphenols, sugars, dredged remediated sediment*

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1. Introduction

Seaports regularly carry out dredging activities, defined as "the set of operations necessary for the extraction, transport and dump of underwater materials, whether in the marine, river or lake environment, in order to avoid the excessive accumulation of sediments in the areas of maneuvering and docking of ships, with the consequent loss of navigability" [1]. This activity is necessary to allow the operation of the fleet that operates in them and can be of great importance, since the lack of depth of its access channel can represent a disadvantage for the arrival of large ships, reducing competitiveness to other terminals [1]. However, it is accepted that the accumulation of dredging materials extracted from seaports, as well as their removal, can be a problem from the environmental point of view since these are considered as contaminating materials.

These effects usually come from two processes. First as a result of the dredging process itself, where they may arise due to the excavation of sediments in the seafloor, or to the loss of material during transport to the surface. And secondly, as a result of the disposal of such contaminated sediments and their transfer to safe areas, which can become a problem in certain areas, where some materials are contaminated at levels such that environmental limitations must be applied. However, more than 90% of the dredged sediments are not contaminated, which means that in many cases it can be considered as a resource rather than a waste [2].

Peat has being the dominant organic constituent of growing media in many parts of the world for the last 50 years [3], due to its excellent aeration and water retention, low pH and salinity, and pest and diseases free sediments. The peatlands cover an area of 4,000,000 km^2 worldwide, 2,000 km^2 of which are utilized by the peat industry. However, its use can represent a problem, due to the progressive exhaustion of peatland. Thus, there is a need for seeking a reliable growing substrate to replace peat use in agriculture.

To this effect, studies on sediments dredged from ports have demonstrated that decontamination techniques like phytoremediation can be successful for creating substrates for plant growth [4]. This phytoremediation is considered the most cost-effective and environmental friendly soil reclamation strategy [5,6], constantly developing to become an effective and reliable remediation method for sediments contaminated by a wide range of pollutants.

Dredged sediments were firstly pre-treated to improve their physical characteristics. Then phyto-remediated, and afterwards submitted to land farming in order to reduce further the organic contamination, for a total duration of three years [7,8,9].

Strawberry (*Fragaria x ananassa* Duch.) is one of the most important crops worldwide, with an annual output of about four million tons, of which 7% is produced in Spain [10]. In Spain, its cultivation has had a spectacular development in the last decades, so that has become the largest European producer and the second worldwide. In addition to their economic importance, strawberries represent an important resource of bioactive components with antioxidant activity [11,12], which can confer important benefits to human health [13,14]. Studies showed that strawberry consumption inhibits pathogenic bacteria, such as *Salmonella* y *Staphylococcus* [15], presents anticarcinogenic action [16], anticoagulant [17] and reduces cardiovascular diseases [18].

Therefore, the aim of this paper focused on studying the effect of dredged remediated sediments as a substrate on the quality and bioactive components of the fruit from two strawberry cultivars, "Camarosa" and "Monterrey" grown worldwide, as well as to determine the suitability of this sediment as a new substrate valid to satisfy the progressive shortage of traditional growing substrates**.**

2. Materials and Methods

2.1. Plant Material and Experimental Design

The experiment was conducted over 2016 (April-September) in an experimental plot of a School of engineering of Orihuela (Miguel Hernández University) located in Orihuela, SE Spain (38°04'N, 0°58'W, 26 m above sea level). Plant material consisted of strawberry plants (*Fragaria x ananassa* Duch.) cultivars 'Camarosa' and 'Monterrey' planted on two rectangular containers (150 cm x 30 cm x 15 cm) with 5 plants each, arranged on tables for each replication and covered with black polyethylene plastic, which allowed reducing water evaporation and weed growth. Each cultivar was grown in 3 different substrates: Peat and dredged remediated sediments, which were used to create three treatments: (i) Peat 100% (Pt, as a control); (ii) Dredged remediated sediments 100% (DRS); and (iii) mixture 50% each (Pt-DRS). Each treatment (cultivar-substrate) consisted of three replications (10 plants each) in a randomized complete block design (RCBD). A total of 180 plants were used in this study.

Crop irrigation requirements were scheduled according to tensiometers values (Watermark® probes), placed at three different locations per treatment, in the root area at 10 cm deep between two drippers. The irrigation started manually when the tensiometers indicated 10 cb and stopped when the required water volume was reached. To monitor the water status, the tensiometers values were recorded every day.

Irrigation water was supplied through a drip irrigation system, one pipeline for each container, with one drip per plant (delivering 2 L h^{-1} each). All treatments received the same fertilization composed of KNO_3, NH_4NO_3, K_2SO_4, HNO_3, H_3PO_4, and microelements at standard concentration. The pH and electrical conductivity of the nutrient solution were measured when the irrigation tank was refilled. The records showed a pH value of 6 and 2.2 dS/m for e.c.

2.2. Sediment Substrate Properties

The sediments used were obtained from the dredging of the Leghorn Port (Italy). They were partially decontaminated (bioremediation) during 3 year; in a previous European project (AGRIPORT Agricultural Reuse of Polluted dredged Sediments, No. ECO/08/239065/S12.532262), using plants (phyto-treatment) and organic amendment at pilot scale. Once completed, the dredged sediment showed good nutrient content and biological activity, and low contamination level; only a little residual organic contamination. A land farming process, consisting in the periodical sediment aeration by mechanical moving, was selected as an appropriate treatment to make the sediments suitable for the subsequent horticulture trials. Afterwards, a series of analyses were carried out: (i) **Physical**: Soil bulk density; (ii) **Chemical**: Electrical conductivity, pH, cation exchange capacity, total organic C and N, water soluble and total extractable carbon, fractionation of humic substances (humic acids, fulvic acids and not humic carbon), total and available P, Zn, Cd, Ni, Cu, Cr, Pb, Al, Mn, Fe, V, Hg, polychlorobiphenyls (PCB) and Polycyclic Aromatic Hydrocarbons (PAH); and (iii) **Biochemical**: Dehydrogenase activity, hydrolytic enzyme activities, β-glucosidase, acid phosphatase, protease, phosphodiesterase activity, arylesterase activity, arylsulfatase activity, cellulase activity, protease activity, urease activity and dioxygenase activity. Finally, soil toxicity was assessed according to the ISO standard method (ISO 11348-3, 1998). The results obtained in the analyses complied with the Spanish legislation on growing substrates for agricultural uses. (Royal Decree 865/2010, of July 2nd).

2.3. Physical and Chemical Determinations

Samples were harvested at commercial ripeness (visual parameter >75% of the surface showing red color) and immediately transported to the laboratory. Once in the laboratory, 60 strawberries per treatment were randomly selected for analytical determinations. Three subsamples by treatment (each one composed of 20 strawberries) were randomly prepared, and then fruits were washed and the sepals were dissected. Part of the fruits was frozen immediately, and then lyophilized using a freeze drier (Christ Alpha 2–4; Braum Biotech Int., Melsungen, Germany) for 24 h at a pressure of 0.220 mbar. The samples were ground in a mortar to obtain a fine powder and stored under vacuum in a freezer (−80 °C); some other fruits were cut in halves and carefully hand-squeezed using a commercial kitchen juicer. The freshly squeezed juices were centrifuged at 15,000 g for 20 min (Sigma 3–18 K, Germany) and kept at −18 °C until analysis.

To assess fruit quality attributes, the following variables were measured: fruit weight (g), firmness (Kg cm^{-2}), soluble solids content (SSC), titratable acidity (TA) and maturity index (MI). Fruit weight (30 fruits for each treatment and variety) was measured using a digital scale

Sartorius (model BL-600, with an accuracy of 0.01 g); strawberry firmness was also measured in 30 fruits per treatment and variety. The measurements were taken on the broadest side of the fruit with a Bertuzzi penetrometer (model FT327, with a 6 mm deep probe); soluble solids content of strawberry fruits (ºBrix) was measured with a digital Atago refractometer (model N-20; Atago, Bellevue, WA) at 20°C. The titratable acidity (TA) was determined by an acid-base potentiometer (877 Titrino plus; Metrohm ion analyses CH9101, Herisau, Switzerland), using 0.1 N NaOH up to pH 8.1; values were expressed as g of citric acid L^{-1}. The maturity index was calculated as the ratio between SSC/TA. Analyses of SSC and TA were triplicated.

2.4. Antioxidant Activity ABTS, DPPH and FRAP Methods

The solvent for analysis of antioxidant activity was prepared as described previously by Wojdyło et al. [19]. Briefly, freeze-dried strawberry fruits (0.5 g) were mixed with 10 mL of acidified MeOH/water solution (80:20 v/v) + 1 % HCl, sonicated at 20 °C for 15 min, and left for 24 h at 4 °C. Then the extracts were again sonicated for 15 min, and centrifuged at 15,000 g for min. until the separation of the supernatant. The free radical scavenging activities were determined using three standard methods: ABTS (2,2-azinobis-3-ethylbenzothiazoline-6-sulfonic acid radical cation), DPPH (2,2-diphenyl-1-picrylhydrazyl radical) and FRAP (ferric reducing antioxidant power). The ABTS, DPPH and FRAP assays were conducted as previously described by Benzie and Strain [20], Brand-Williams et al. [21] and Re et al. [22], respectively. Determinations by ABTS, DPPH and FRAP methods were performed using an UV–vis spectrophotometer (Termospectromic Helios Gamma UVG 1002 E, Cambridge, UK). The antioxidant activity was evaluated by measuring the variation in absorbance at 734 nm after 6 min for ABTS, at 515 nm after 10 min for DPPH, and at 593 nm after 10 min for FRAP. Calibration curves prepared using different concentrations of Trolox were used for the quantification of the three methods of antioxidant activity showing good linearity ($r^2 \geq 0.998$). All antioxidant activity analyses were performed in triplicate, and results were expressed as mM of Trolox fresh weight (fw).

2.5. Total Phenolic Compounds

Total phenolic compounds (TPC) were determined according to Singleton et al. [23] using Folin–Ciocalteu reagent. Briefly, strawberry fruit extracts (0.1 mL) were mixed with 0.2 mL of Folin–Ciocalteu reagent and 2 mL of H_2O. Then, the mixture was incubated at room temperature for 3 minutes and 1 mL of 20 % sodium carbonate was added to the mixture. TPC were determined after 1 hour of incubation at room temperature. The absorbance of the blue complex formed was measured at 765 nm using an UV–vis spectrophotometer (Termospectromic Helios Gamma UVG 1002 E, Cambridge, UK). Calibrations curves with concentrations of gallic acid as standard were used for quantification. All determinations were performed in triplicates and results were expressed as mg GAE/ 100g of fresh weight (fw).

2.6. Organic Acids and Sugars

Organic acids and sugars profiles were quantified according to Hernández et al. [24]. Two grams of strawberry fruits were homogenised with 10mL of 50 mmol L^{-1} Tris-acetate buffer pH 6.0 and 10 mmol L^{-1} CaCl, and centrifuged at 15,000 g for 20 min (Sigma 3–18 K; Sigma, Osterode am Harz, Germany). Then, one millilitre of the hydrophilic extract centrifuged was filtered through a 0.45 µm Millipore filter, and 10 µL were injected into a Hewlett- Packard HPLC Series 1100 (Wilmington DE, USA) with an autosampler and an UV detector, set at 210 nm and coupled with a refractive index detector (HP 1100, G1362A). A column (Supelcogel TM C-610H column 30 cm x 7.8 mm) and a pre-column (Supelguard 5 cm x 4.6 mm; Supelco, Bellefonte, PA) were used for the analyses of both organic acids and sugars. The elution buffer consisted of 0.1% phosphoric at a flow rate of 0.5 mL min^{-1}, and organic acid absorbance was measured at 210 nm using a diode-array detector (DAD). The same HPLC conditions (elution buffer, flow rate and column) were used for the analysis of sugars. The detection was conducted using a refractive index detector (RID). Standards of organic acids and sugars were obtained from Sigma (St. Louis, MO). Calibration curves were used for the quantification of organic acids and sugars showing good linearity ($r^2 \geq 0.999$). Analyses were run by triplicate, and results were expressed as concentrations of mg/g of fresh weight. In addition, the relation between sugars and acid was calculated as the total sugar content divided by the total acid content of the fruit.

Sweetness index (SI) of the fruit, an estimate of the total sweetness perception, was calculated based on the relative amount and sweetness properties of each individual carbohydrate [25]. Sweetness index (SI) was calculated based on the amount of individual sugars in strawberries as SI = 1 [glucose] + 1.35 [sucrose] + 2.3 [fructose] [26].

2.7. Vitamin C

Vitamin C Total content (ascorbic acid) was determined by redox titration using iodine (TitraLab AT 1000 series). In an Erlenmeyer flask 5 ml of strawberry juice were mixed with 25 ml of water. The mixture was titrated with a standardized iodine solution (0.02N). Results of vitamin C content were expressed as mg of ascorbic acid per 100 mL of juice (mg AA/100 mL juice).

2.8. Statistical Analyses

A weighted analysis of variance was performed for statistical analysis (ANOVA; statistical software IBM SPSS Statistics v. 24 for Windows). The Shapiro–Wilk test was used to evaluate the normality of the data. Tukey's HSD test was used for mean separation. Unless otherwise stated, the significance level was $p \leq 0.05$.

3. Results and Discussion

3.1. Effect of the Substrates on Physicochemical Characteristics

Table 1 shows the physicochemical characteristics of "Camarosa" and "Monterrey" strawberry cultivars that

may influence consumer preferences: fruit weight, firmness, SSC, TA and maturity index. While "Camarosa" fruit weight was affected by the type of growing substrate, "Monterrey" one was not affected at all. Plants from cultivar "Camarosa" grown under Pt treatment produced a significantly higher fruit weight (7.57 g/fruit) than the other two treatments studied (Pt-DRS and DRS, 5.38 and 4.53 g/fruit, respectively). These differences on fruit size may be due to the composition of the substrate. The sediment with a bulk density 3-4 times greater than peat caused aeration problems due to lower porosity and aeration, which caused a worse developed root system and therefore smaller plants and fruits. These fruit weights were higher that those obtained by Palencia et al. [27] for cultivar "Camarosa" grown under agrotextile, coir fibre, perlite and rock wool substrates, but lower than the reported by Liu et al. [28] for chinese cultivars cultivated in a soilless system with organic substrate; fruit weights were also lower than those obtained by Oliveira and Scivitarro [29], who reported values of up to 18.5 g/ fruit in different strawberry cultivars grown in the Pelotas region (Brasil).

On the other hand, firmness, titratable acidity and maturity index were not affected by the type of substrate used (Table 1). These results agreed with previous studies in strawberry cultivation in different substrates: cocopeat, perlite, sand, agrotextile, coir fibre, rock wool [27,30,31,32]. The two evaluated varieties showed good firmness (>2.97 Kg cm^{-2}), which may suggest that they have good storage capacity and are suitable for supermarket sales. Nevertheless, the soluble solid content (SSC) was affected by the type of substrate used in the cv. "Monterrey", but not for the cv. "Camarosa" (Table 1). "Monterrey" fruit had the greatest SSC (12.7 ºBrix) grown under DRS treatment, but not showed significant differences with Pt-DRS treatment (mixture). This was due to the peak of production of this variety in the months where the climatic demand begins to increase, besides, as mentioned above, the sediment bulk density, caused a stress in plant, thereby causing, as in crops under deficit irrigation, a greater accumulation of dry matter in fruit which, in this type of studies, gives rise to a compensatory growth later, growth that in this case did not occur due to the stress origin. Recamales et al. [30], Yildiz et al. [33] and Palencia et al. [27] reported lower values for "Camarosa" strawberry grown on different substrates than those obtained in this study (13.8ºBrix for DRS and 12.3ºBrix for Pt-DRS). In addition, Ceccato et al. [34] reported values of SSC of 6.9 and 5.7 ºBrix for cv. "Camarosa" and "Monterrey", respectively, being clearly lower than the values obtained in this study. Recamales et al. [30], Marinou et al. [32] and Palencia et al. [27] did not observed differences in SSC depending on the type of substrate used. However, other studies reported that the growing substrate can affect the content of SSC, for instance as that in tomato [35]. Thus, the SSC in fruits can be influenced by various factors such as genotype and origin of the substrates [36].

However, no significant differences were observed in titratable acidity. Fruit quality attributes such as SSC and TA are crucial because of their relevance for fruit taste [37]. The assessed, maturity index values were higher than 13.80 for both cultivars. These results agreed with those reported by Resende et al. [38] for the cultivar "Camp-Dover" (13.50). "Camarosa" and "Monterrey" would have a great consumer acceptance because this ratio affects the perception of taste (sweetness and acidity) by the consumer [39]. But these values did not agree with other studies [34,40] which reported lower values.

Table 1. Fresh weight (g), fruit firmness (Kg cm^{-2}), soluble solids content (SSC, ºBrix), titratable acidity (TA, g 100 mL^{-1}) and maturity index (SSC/TA) ratio from two cultivars grown on different substrates

	Fresh weight	Firmness	SSC	TA	SSC/TA
Camarosa					
Pt	7.57 ± 0.17 a	2.97 ± 0.39 a	11.47 ± 0.88 a	0.75 ± 0.04 a	15.41 ± 0.87 a
Pt-DRS	5.38 ± 0.29 b	3.30 ± 0.33 a	12.35 ± 1.13 a	0.81 ± 0.05 a	15.50 ± 1.38 a
DRS	4.53 ± 0.48 b	3.03 ± 0.18 a	13.88 ± 0.60 a	0.88 ± 0.06 a	16.28 ± 1.60 a
Monterrey					
Pt	7.29 ± 0.62 a	4.01 ± 0.06 a	9.19 ± 0.54 a	0.69 ± 0.04 a	13.80 ± 1.00 a
Pt-DRS	7.51 ± 0.99 a	3.95 ± 0.15 a	11.17 ± 0.52 ab	0.67 ± 0.03 a	16.81 ± 0.78 a
DRS	6.77 ± 0.42 a	3.28 ± 0.38 a	12.73 ± 0.58 b	0.83 ± 0.07 a	15.11 ± 0.94 a

Different letters next to a value in each column within cultivar indicate significant differences according to Tukey's HSD test ($p < 0.05$).

Table 2. Sucrose, glucose, fructose and total sugars concentration (mg g^{-1}), monosaccharide to disaccharide ratio and sweetness index (SI) in fresh weight of strawberry fruit from two cultivars grown on different substrates

	Sucrose	Glucose	Fructose	Total Sugar	(Fru+Glu) Suc^{-1}	SI
Camarosa						
Pt	12.73 ± 1.43 a	48.37 ± 3.85 a	57.39 ± 4.67 a	118.48 ± 9.80 a	8.58 ± 0.59 a	197.54 ± 16.31 a
Pt-DRS	9.80 ± 1.00 a	43.34 ± 1.92 a	52.28 ± 2.05 a	105.42 ± 3.61 a	10.46 ± 1.45 a	176.82 ± 6.11 a
DRS	9.48 ± 1.43 a	44.25 ± 3.57 a	53.97 ± 3.82 a	107.70 ± 7.49 a	12.19 ± 2.68 a	181.17 ± 12.50 a
Monterrey						
Pt	8.09 ± 1.46 a	26.90 ± 1.48 a	35.65 ± 1.54 a	70.64 ± 3.10 a	9.11 ± 1.74 ab	119.81 ± 5.01 a
Pt-DRS	8.63 ± 1.18 a	41.78 ± 4.17 b	51.31 ± 4.75 b	101.72 ± 8.54 b	12.07 ± 2.17 a	171.44 ± 14.54 b
DRS	13.78 ± 1.42 b	46.24 ± 2.04 b	59.10 ± 0.86 c	119.12 ± 3.95 c	8.04 ± 0.90 b	200.77 ± 5.75 c

Different letters next to a value in each column within cultivar indicate significant differences according to Tukey's HSD test ($p < 0.05$).

Table 3. Citric, malic, total organic acids concentration (mg g^{-1}), vitamin C concentration (mg 100 mL^{-1}) and total sugars/total acids ratio in fresh weight of strawberry fruit from two cultivars grown on different substrates

	Citric	Malic	Total acids	Vit C	Total sugars/Total acids
Camarosa					
Pt	9.35 ± 0.33 a	3.74 ± 0.28 a	13.09 ± 0.56 a	65.77 ± 2.22 a	8.97 ± 0.38 a
Pt-DRS	9.66 ± 0.25 a	2.79 ±0.50 a	12.66 ± 0.75 a	73.00 ± 1.54 ab	7.55 ± 1.00 a
DRS	8.70 ± 0.45 a	4.01 ± 0.19 a	12.71 ± 0.42 a	79.47 ± 4.35 b	8.48 ± 0.56 a
Monterrey					
Pt	7.59 ± 0.40 a	3.45 ± 0.25 a	11.04 ± 0.34 a	75.48 ± 1.02 a	6.42 ± 0.31 a
Pt-DRS	7.43 ± 1.24 a	4.21 ± 0.19 b	11.64 ± 1.30 ab	88.39 ± 3.15 c	9.44 ± 1.45 a
DRS	9.65 ± 0.89 a	4.91 ± 0.14 c	14.56 ± 0.95 b	82.52 ± 1.22 b	8.35 ± 0.66 a

Different letters next to a value in each column within cultivar indicate significant differences according to Tukey's HSD test ($p < 0.05$).

3.2. Effect of the Substrates on SUGARS and Organic Acids Content

The sugar and acid contents are related to fruit maturity and are considered the most important quality attribute of strawberry flavor [41]. Previous studies have shown that the concentrations of sugars may be altered by some agronomic practices (use of mulch, deficit irrigation) and nature of the substrates [26,27]. The three sugars (sucrose, glucose and fructose) and two organic acids (citric and malic acid) were identified and quantified in strawberry fruits (Table 2 and Table 3). In this study, fructose was the major sugar followed by glucose, significantly varying among cultivars and type of substrate. In cv. "Camarosa" sugar concentrations were not affected by the type of substrate, while "Monterrey" contents were sure influenced by the type of substrate. DRS showed the highest levels of sucrose (13.78 mg g^{-1}), glucose (46.24 mg g^{-1}) and fructose (59.10 mg g^{-1}). The total sugar contents for "Monterrey" ranged from 70.64 (Pt substrate) to 119.12 mg g^{-1} (DRS substrate), which are higher than those reported by other authors on different cultivars (Camarosa, Candonga, Festival, Benihoppe, Tochiotome, Sachinoka, and Guimeiren) [27,28]. These results suggest that the osmotic balance within the fruit was influenced by the composition of the growing media. The results also indicated that the physical properties of substrates, as well as slight differences in nutrient content may also alter the final fruit sugar content. However, Palencia et al. [27] did not find any influence of growing substrates on strawberry sugar concentrations. Likewise, Kim et al. [42] found that the proportion of sugar contents remain constant, regardless of the growing conditions and cultivars.

Organic acids are key components in strawberry flavor perception [43]. The accumulation of organic acids within the fruit is differently regulated among species and also between cultivars [44]. The organic acids profiles were significantly affected by the type of substrate (Table 3). The organic acids contents reported here slightly differed from those carried out by Palencia et al. [27]. Citric acid was the major organic acid and its contents were not influenced by the type of substrates in both cultivars. The malic acid content was influenced by the nature of the substrates, holding the strawberries grown under DRS the highest content (4.9 mg g^{-1}). Similarly, other researchers found that the major organic acid in strawberries was citric acid, followed by malic acid [27,28,40]. Liu et al. [28] also identified in strawberries others acids such as oxalic, succinic, tartaric, acetic and lactic. However, those organic acids were not identified in this study, which might be due to genotype, agro-climatic conditions and/or nature of the substrates. Part of those differences may be due to variability in sample preparation and analysis procedures.

Sweetness is one the major attributes appreciated by consumers. The good taste of strawberry is a balance among sweetness, due to sugars, and the sourness of organic acids [40]. The sweetness index (SI) was calculated based on the fact that fructose and sucrose are 2.3 and 1.35 times, respectively, sweeter than glucose. The nature of the substrates affected the sweetness index (Table 2). "Monterrey" was the sweetest cultivar grown under DRS (dredged remediated sediments). These values were higher than those reported in other strawberry studies grown worldwide [26,27,45].

Vitamin C plays a critical role in the nutritional evaluation of strawberry fruit. The strawberries grown under DRS and Pt-DRS substrates showed the highest contents of Vitamin C in both cultivars (Table 3). Vitamin C contents ranged from 65.77 mg $100g^{-1}$ ("Camarosa" grown under Pt substrate) to 88.39 mg 100 g-1 ("Monterrey" grown under Pt-DRS substrate). These contents agreed with previously reported vitamin C contents in fruits (31-85 mg per 100 g) [46,47]. The natural vitamin C content of several fruit depends on many factors, including variety, maturity status, growing conditions and harvest time.

3.3. Effect of the Substrates on Antioxidant Activity and Total Phenols

There are different methods for evaluating the antioxidant activity (AA) of foods. This variety of methods is due to the fact that none of them is able to exactly determine the total antioxidant capacity of a product. The measured AA of a sample depends on methodology and on free radical generator or oxidant in the measurement [48]. The antioxidant activity of strawberry fruits was evaluated using three different analytical methods: ABTS, DPPH, and FRAP (Figure 1). The antioxidant activity of strawberries was not affected by the type of substrate. Although the statistical test grouped the cultivars together, "Camarosa" and "Monterrey" showed the highest values of AA grown under dredged remediated sediment (DRS) for all methods assayed (19.6-18.3 mM Trolox for "Camarosa" and "Monterrey" by ABTS; 19.3-18.3 mM Trolox for "Camarosa" and "Monterrey" by DPPH; and 19.3-18.8 for "Camarosa" and "Monterrey" by FRAP) (Figure 1). These results are slightly higher than those reported by Yildiz et al. [33].

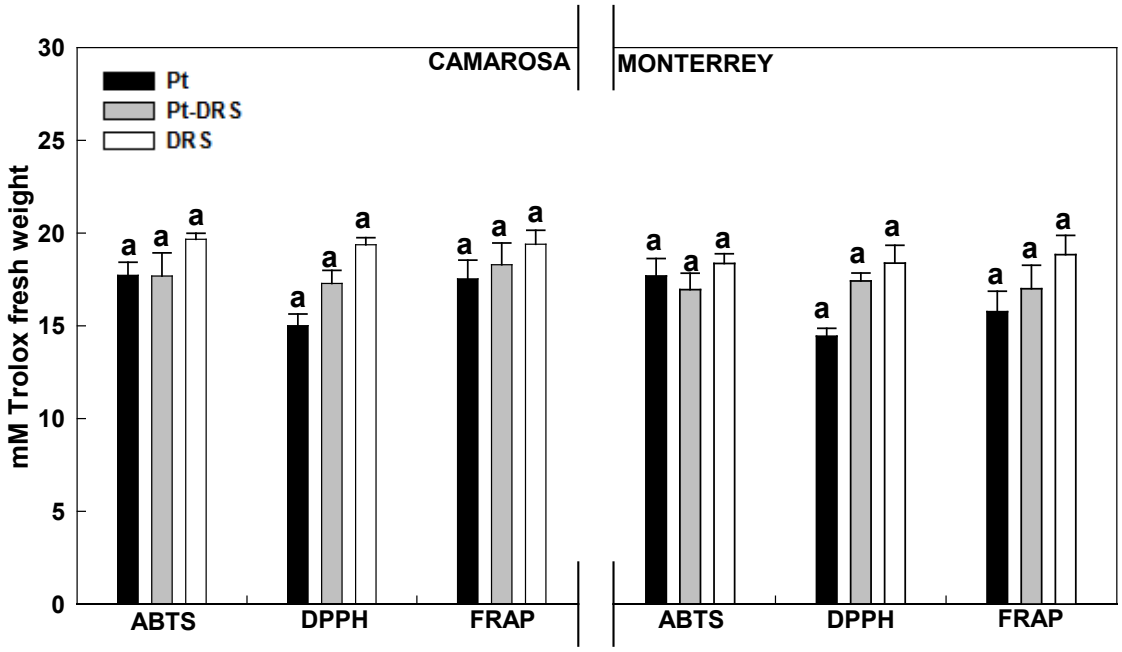

Figure 1. Antioxidant activity determined by the ABTS, DPPH and FRAP assays for each substrate, Pt (black bars), Pt-DRS (gray bars) and DRS (white bars) in both cultivars. Values are the mean of six measurements. Different letters on top of bars indicate significant differences according to Tukey's HSD test ($p < 0.05$)

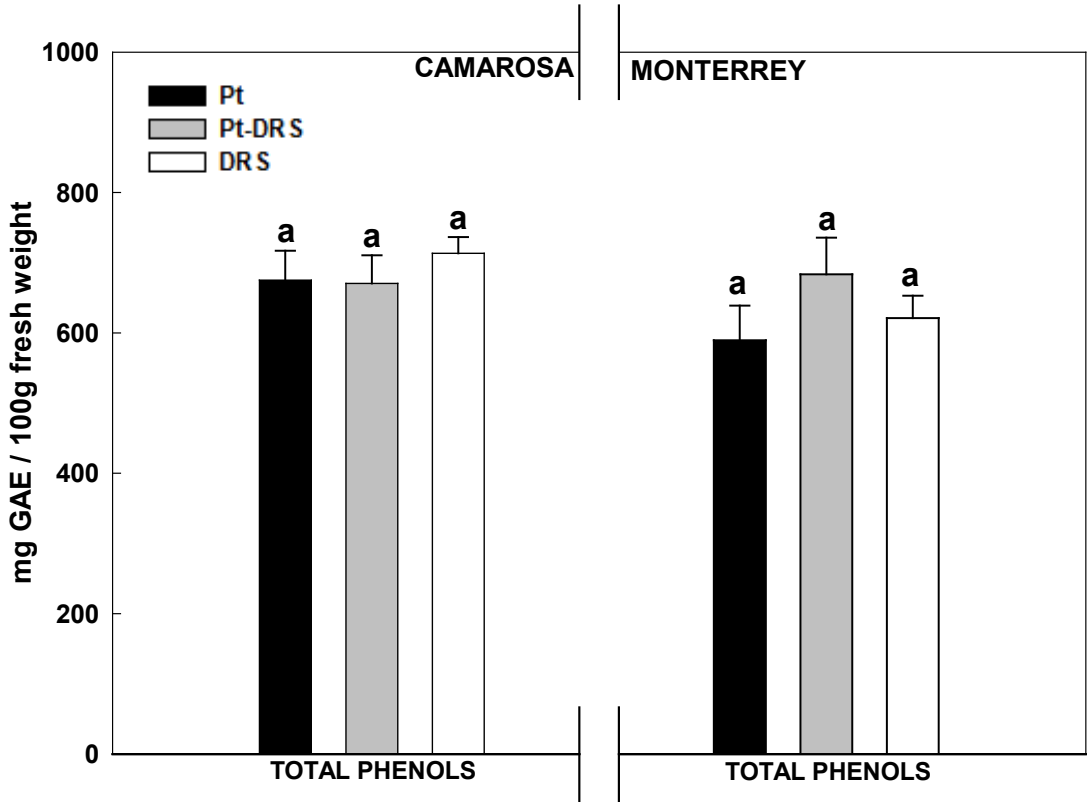

Figure 2. Total phenols for each substrate, Pt (black bars), Pt-DRS (gray bars) and DRS (white bars) in both cultivars. Values are the mean of six measurements. Different letters on top of bars indicate significant differences according to Tukey's HSD test ($p < 0.05$)

Total polyphenol contents (TPC) in strawberry fruits are presented in Figure 2. Likewise the results for antioxidant activity, the type of substrate did not affected the TPC. The total phenolic contents of strawberry were higher for both cultivars grown under Pt-DRS (>670 mg GAE 100 g^{-1}) and DRS (621 mg GAE 100 g^{-1}). These values are much higher than those previously reported by Voca et al. [49]; Torronen and Maatta [50]; Pineli et al. [51] and Yildiz et al. [3] reported values of TPC between 96 and 223 mg GAE per 100 g of fresh weight. The observed differences can be due to various factors such as genotype, agronomic practices, climatic, monthly observation, geographical locations and type of the substrate [52,53].

4. Conclusions

This is the first study carried out in Spain on the use of dredged remediated sediments for strawberry cultivation. The strawberries grown on this substrate or/and mixture were not affected the final fruit quality or composition. The strawberries grown under DRS and Pt-DRS substrates (mixture 50%) showed high contents in vitamin C, total phenols and antioxidant activity. These substrates had also the highest sweetness index and a good firmness. Therefore, the present study has shown that the used of dredged remediated sediments as a substrate for strawberry cultivation is a good and valid alternative to satisfy the progressive shortage of the traditional substrates. The results obtained in this study will be a useful reference for future studies on this new sediment applied to other horticultural, ornamental or fruit crops.

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