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Effects of Mulching on Early-Spring Green Asparagus Yield and Quality under Cultivation in Plastic Tunnels

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Abstract: Mulching significantly increases the crop yield and quality by positively affecting the physical features of the soil. The effect of multiple mulching treatments on soil temperature, yield, and nutrient composition of green asparagus grown in a plastic tunnel was assessed. Two mulch materials: transparent plastic film (PF) and rice husk (RH), were applied and compared with non-mulching treatment (CK). The soil temperatures at the soil surface and 10 cm below it were generally higher in the PF mulch than in the CK during the spring. PF mulch accelerated early spear emergence and growth, which led to harvesting 16 days earlier than in the CK. Under the PF mulch, the early yield of spears increased by 26.6% from January to the end of March, and the annual gross income by 14.8% because of the higher price resulting from the significantly higher marketable spear length and diameter; however, they were reduced in the RH mulch. Most nutrient compositions, such as soluble sugar, ascorbic acid, rutin, flavonoid content, and total antioxidant activity, were significantly increased in the PF mulch treatment. PF mulch might benefit green asparagus production during early spring because of its ability to promote early spear emergence and growth.

Keywords: *Asparagus officinalis*; mulch; soil temperature; yield; economic benefits; nutrient composition

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1. Introduction

Asparagus, one of the most popular vegetables grown worldwide, has been cultivated for over 2000 years [1,2]. There are at least 60 asparagus-producing countries worldwide, with a total harvested area of 1,623,741 hectares (ha) [3]. Over the past decades, green asparagus has started to dominate worldwide, mainly because of its greatest producers, China, Central and South America, and Europe, and its higher rutin content than white asparagus [4,5]. The production of green asparagus under cover has been extended using the mother stalk method [6]. Spears are usually harvested from April to June in North China, whereas the harvest season in the south extends from March to June in spring and from September to October in autumn in plastic tunnels. Late emergence and slow growth in the cool spring are the main limiting factors in early asparagus production because of low air and soil temperatures, even inside plastic tunnels. Thus, new cultivation methods must be developed to extend the harvest time and decrease production risks during the cool spring.

Environmental factors highly influence the cultivation method of asparagus. In most production areas with temperate and subtropical climates, the temperature is the primary factor determining the development and growth, as well as the spear yield and asparagus quality [7–10]. Our previous study indicated that asparagus spears harvested in early spring have higher contents of protein, carotenoids, and flavonoids than those harvested during other seasons [11].

Mulching is a simple and cost-effective technique for maintaining soil temperature and extending the growing season. This method can also effectively increase the output of different horticultural crops and enhance nutrient quality [12–16]. However, there have been limited studies on asparagus. Mulch cover positively affects soil physical characteristics, thereby significantly increasing the diameter and length of white asparagus stems [17–20]. There are very few reports on the effects of mulching on green asparagus [21,22]. Nie et al. [22] opined that only the plastic tunnel exhibited the greatest effect and not the treatment of plastic film (PF) mulch in a plastic tunnel, which was different from ours.

This study explored a new mulch method for green asparagus production to reduce the production risk associated with delayed emergence and poor asparagus marketable spear quality and extend the harvesting period during early spring. The effects of two different mulching methods on asparagus yield and quality during the cold season were assessed in a plastic tunnel. Transparent PF mulching, a suitable cover method that can accelerate early spear emergence and growth with better marketable spear quality for the subtropical regions, was proposed.

2. Materials and Methods

2.1. Plant Material and Growth Conditions

In East China, the experiment was conducted in a plastic tunnel in Fuyang County (lat.: 30.07° N, long.: 119.95° E, 107 m above sea level). The climate is subtropical, with sufficient rainfall and sunlight. The annual mean temperature is 16.2 °C. Temperatures are low during the winter months (December–February) with an average high of 7.6 °C and an average low of 0.9 °C in January. The soil in the experiment base was sandy loam with a pH of 6.5–7.2, which is suitable for asparagus growth. The soil pH was measured at a ratio of 1:2.5(m/v)(20 g air-dried soil/50 mL distilled water) using a pH meter (Delta 320, Shanghai, China) [23].

Asparagus cv. "Grande" seeds from California Asparagus Seed and Transplants, Inc. were sown in spring and transplanted into plastic tunnels (45 m long, 8.0 m wide, and 2.7 m high) in June 2015. The planting space was 1.5 m, with 0.3 m between and within rows, giving approximately 22,200 plants per ha. Fern vigor was encouraged without harvest until the spring of 2018. Standard fertilization and cultural practices were used during the experiment. Sheep manure (22,500 kg·ha^{-1}) and compound fertilizer (N:P_2O_5:K_2O = 14:16:15) at a dose of 1500 kg·ha^{-1} were applied at the end of December 2017 as a base fertilizer. During the harvest of the asparagus from January to April and July to October 2018 and 2019, the compound fertilizer was applied once a month, a total of six times, at a dose of 600 kg·ha^{-1}, so that the topdressing amount was 3600 kg·ha^{-1}. The weeds were controlled in a timely manner via manual weeding, and manual weeding was carried out approximately three times before the mother stalks were kept in summer.

2.2. Mulching Treatments

Mulching treatment was commenced in the middle of December 2018 and was repeated in 2019, when the ambient temperature outside the tunnel dropped below freezing. The average temperature inside the tunnel was approximately 5 °C. All data were obtained from the 2-year survey. Each shed contained two separate mulch treatments, 10 cm-thick rice husk (RH) and 0.015 mm-thick transparent PF, and a control treatment (CK) without mulching. Four replicates of each mulching treatment and CK were arranged in a randomized complete-block design, and the area of each plot was 60 m^2. The spears were harvested approximately 12 d after their emergence. During this period, ventilation was strictly regulated to keep the shed warm.

The soil temperature during covering, which lasted 3 months, was measured. The soil surface temperature and soil temperature at 10 cm below the surface were measured in each plot using a soil thermometer with copper-constantan thermocouples connected to a data logger (Model CR23X, Campbell Scientific Inc., Logan, UT, USA). The data logger was programmed to record readings every 20 min and stored each plot's hourly averages.

2.3. Harvest and Sample Analysis

The spears were harvested and sampled from the end of January (in winter) to April (in spring). The harvest ended in the middle of April to allow four–six spears per plant to develop into mother stalks. After 6 weeks of mother stalk culture, the harvesting started again in June and lasted for approximately 10 weeks. The spear traits, including the total number of spears and their mean weight and diameter, and the number and mean weight of marketable spears during spring and the whole year, were measured. Spears were considered nonmarketable if they were <0.8 cm in diameter at 2 cm from the base, were bent or damaged, or their tips were open. The gross income was calculated on a weekly basis according to the marketable yield and average price in the local market.

The spears were separated into four developmental stages (Stage 1: 4–5 cm, Stage 2: 9–10 cm, Stage 3: 14–15 cm, and Stage 4: 19–20 cm) according to their length and were evenly divided into three parts: top of the spear (T), middle part (M), and bottom of the spear(B). Three different asparagus organs (roots, stems, and cladophylls) and four stages of spears were sampled. The samples were taken at approximately 2 cm in length for the different parts of the spears from the four stages.

2.4. Determination of Nutritional Compositions

For dry matter content analysis, approximately 50 g of blended fresh samples for each treatment were dried in a thermostatically controlled oven at a uniform temperature of 75 °C until a constant weight was obtained [11,24]. Dry matter content was calculated as a percentage of the constant weight related to the fresh matter. The blended samples were prepared from three replicates of 18 spears (including the upper and bottom sections) harvested each month. Organic acid content was measured as described by Bhowmik et al. [25]. Measurement of the ascorbic acid content was performed via the method described previously [26]. Sugar content was determined as described by Lowell et al. [27]. Soluble sugars were evaluated using a Shimadzu LC-10A HPLC [25]. Reducing sugar content was measured using the 3, 5-salicylic acid technique, with glucose as the standard [7].

Total soluble protein was obtained from 0.1 g powdered, freeze-dried spears in 0.1 M NaOH and 1% (w/v) sodium dodecyl sulfate, and quantified using the technique described by King et al. [28]. Free amino acid content was determined using the ninhydrin color test [11]. To determine the rutin content, 2 g samples were accurately weighed and mixed with 35 mL of 70% ethanol aqueous solution. The flow rate was 1.0 mL·min^{-1}. The total injection volume was 10 mL. Rutin was quantified from the calibration curves obtained by the area measurement of standard rutin. The total flavonoid content was determined using ultraviolet spectrophotometry [29]. Flavonoid content was expressed as quercetin equivalents (mg quercetin·g $^{-1}$ dried extract).

The total saponin content was determined using the fennel aldehyde–sulfuric acid colorimetric method [30]. The total antioxidant activity was measured using a ferric reducing ability of plasma assay with three replicates [31].

2.5. Statistical Analysis

Statistical analyses were conducted using analysis of variance. Means for each parameter were compared using Tukey's test at an α = 0.05 level of significance and 0.01 level of high significance. Differences in yield- and quality-related variables were insignificant between the 2 years. Therefore, the data for 2018 have mainly been discussed in this article.

3. Results and Discussion

3.1. Soil Temperature

In most producing areas with temperate or subtropical climates, the temperature is the primary factor controlling asparagus development and growth. Mulching systems significantly affected the plants' surrounding temperature (Figure 1). Both the temperature of the soil surface and the soil at a depth of 10 cm under the PF mulch at 9 a.m. were generally higher than those in the CK (Figure 2). Because of the PF mulch, the soil surface temperature was increased by up to 5.4 °C compared with that under the CK, which ranged from 6.8–29.9 °C during the experimental season (Figure 2A). Similarly, the soil temperature at a 10 cm depth was increased by up to 3.4 °C compared with that under the CK (Figure 2B). This finding shows that the PF mulches capture more solar radiation or decrease the heat loss [32]. A similar increase in soil and air temperatures caused by PF mulches has been reported by many investigators [10,32,33]. For example, Wang et al. [18] reported that clear plastic mulches increased the soil temperature compared with no mulch control treatments during the early growing corn season.

Figure 1. Experiments on non-mulching treatment (CK), rice-husk mulch (RH), and plastic film mulch (PF) of green asparagus in the plastic tunnel.

However, in the RH mulch, the temperatures at the soil surface and 10 cm below it were relatively lower than those in the CK. In the RH mulches, the soil surface temperature and the temperature at 10 cm below the soil surface were approximately 9.0 °C and 3.0 °C lower than those in the CK plots during the late spring, respectively (Figure 2). Therefore, the effects of PF mulch and RH mulch on the soil temperature were inversely related.

3.2. Yield and Economic Benefits

Harvest of spears in the PF mulch started approximately 20 d after the cover treatment, which was 16 d earlier than those in the CK and the RH mulch plots (Table 1). Low soil temperature, even inside plastic tunnels in the cool spring, severely limited the early asparagus production. PF mulch is a simple and cost effective method for maintaining soil temperature and extending the harvest time, which is a new cultivation method for green asparagus.

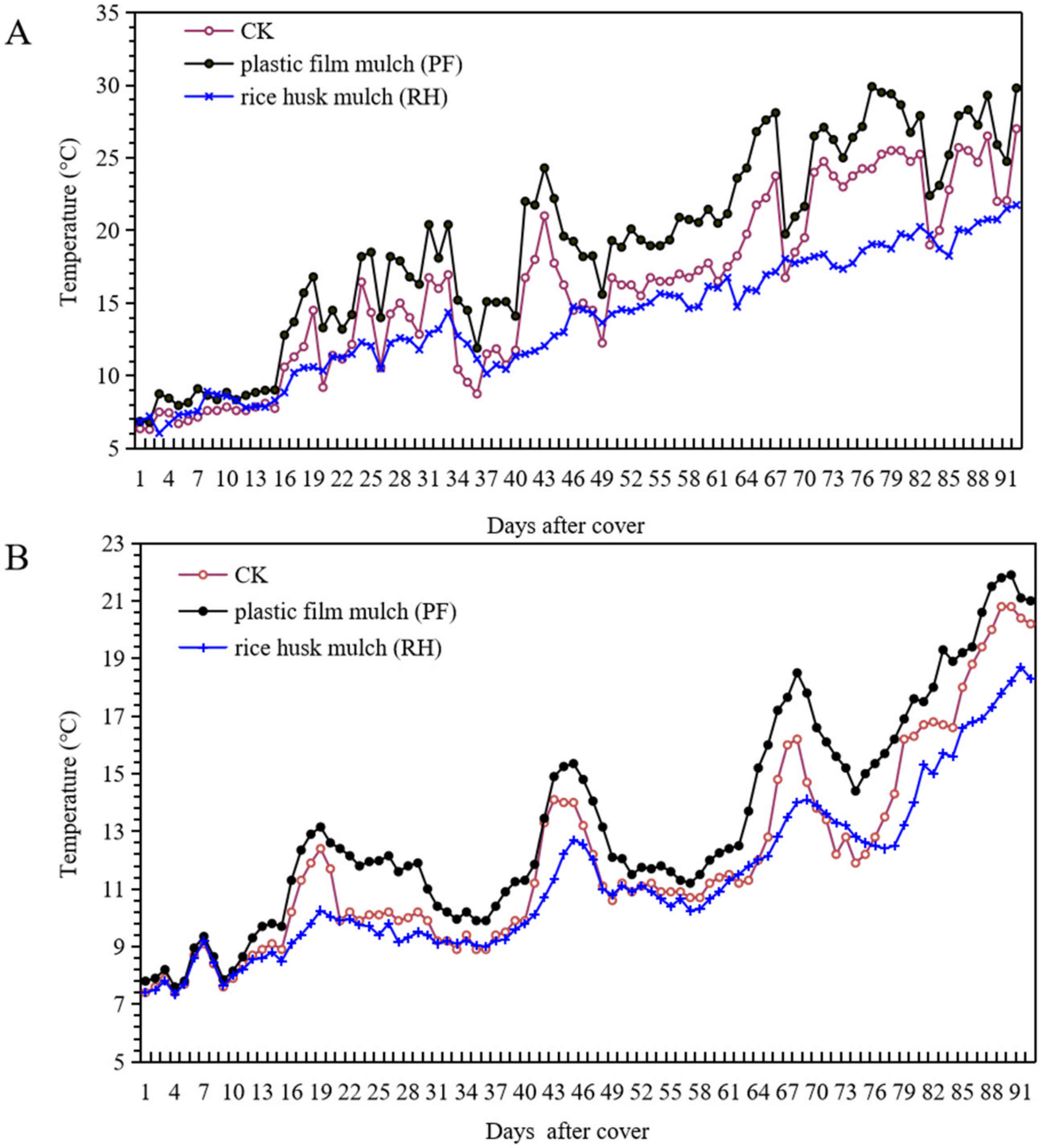

Figure 2. The effect of mulching on the soil surface temperature (**A**), and soil temperature at a depth of 10 cm (**B**), at 9 a.m. for asparagus grown in the plastic tunnel.

Table 1. The effects of mulching on asparagus mean yield and gross income in the plastic tunnel. Different lowercase superscript letters within the same column indicate significant differences at $p < 0.05$.

Treatment	Date of First Harvest	Yield (kg·ha^{-1})				Gross Income (USA $·ha^{-1})
		Early (1.20–3.10)	Middle (3.11–4.30)	Late (7.1–10.30)	Total	
CK	5 February	4575 ^{b}	8835 ^{ab}	15,065 ^{a}	28,475 ^{a}	51,157 ^{b}
RH	5 February	3840 ^{c}	8070 ^{b}	14,625 ^{a}	26,535 ^{a}	46,862 ^{c}
PF	20 January	5790 ^{a}	9015 ^{a}	13,725 ^{a}	28,530 ^{a}	62,324 ^{a}

The spear yield of the first 30 d during the harvest period is considered an early yield. The early yield in the PF mulch was significantly higher than those in the CK and RH mulch plots (Table 1). However, the differences in spear yield among the three treatments reduced with increased air temperature outside the tunnels. All three treatments resulted in similar yields during the late harvest period (after 1 June). Generally, no significant differences were observed between the treatments in terms of total annual yield, although the final yield of the RH mulch was slightly lower than those of the other treatments. Similarly, the yield and the number of white and green spears collected in the plastic tunnel were significantly higher than those in the open field [13]. Compared with non-mulching, PF mulching significantly increased wheat grain yield and corn yield [19,20]. Makus and Gonzalez [34] reported that white plastic row covers did not increase the spear yield of white asparagus. In contrast, black film covers increased the total harvest and marketable yield. In the study by Knaflewski and Krzesinski, low plastic tunnel covers were utilized to hasten the harvest beginning by approximately 10 d, but PF mulching in plastic tunnels was not conducted. Furthermore, the soil was covered with a layer of pine bark during winter to prolong the harvest season by delaying its onset, which is beneficial for practicing sustainable agriculture [21]. Nie et al. [22] reported that in plastic tunnels and in PF mulch in plastic tunnels, the harvest time was approximately 10 days earlier and that the early yield was more than two times that with no cover. However, the researchers were of the view that only the plastic tunnels exhibited the greatest effect because of the increase in bent spears while treated with PF mulches in the plastic tunnel, which was different from ours [22]. In our study, transparent PF mulch in plastic tunnels resulted in a higher yield and promoted early spear emergence, with better marketable spear quality. The type of PF used was unclear in the study by Nie [22], and the climatic variations in different districts might have caused the differences. Economic benefits and asparagus nutrient composition were rarely discussed in previous studies [13,21,22].

Our study obtained the highest gross income (62,324 $\$\cdot ha^{-1}$) from the PF mulch, which was 21.8% higher than that in the CK (51,157 $\$\cdot ha^{-1}$). In contrast, the gross income from the RH mulch (46,862 $\$\cdot ha^{-1}$) was 8.4% less than that in the CK (Table 1). Overall, although the total yield during the whole year under the PF mulch was similar to that under the CK, the gross income was higher in the PF mulch because of the much higher price of asparagus spears in the early spring. The average price per kilogram amounted to over 3.12 $ before early March, whereas the price dropped to 1.26 $ after the middle of March in both years.

3.3. Commodity-Related Traits of Asparagus Spears in Early Spring

The mean total number of spears obtained for the year was 81.75 per square meter for the plastic mulch plot, 76.38 per square meter for the RH mulch plot, and 83.02 per square meter for the CK, which suggests that mulching does not significantly affect the total number of year-round spears. However, the number of marketable spears significantly differed between the different cover treatments in the early spring, with the plastic mulch producing 19.8% and 48.4% more marketable spears than the CK and RH mulch treatments, respectively (Table 2).

Table 2. The effects of mulching on the number and some features of marketable asparagus spears in early spring. Different lowercase superscript letters within the same column indicate significant differences at $p < 0.05$.

Treatment	Marketable Spears (×1000/ha)	Spear Length (mm)	Mean Spear Weight (g)	Spear Diameter (mm)	Water Content (%)
CK	96.6^{b}	228.9 ± 34.4^{b}	38.1 ± 1.2^{ab}	13.1 ± 2.0^{b}	92.0 ± 0.4^{a}
RH	78.0^{c}	225.0 ± 24.0^{b}	36.7 ± 0.6^{b}	13.2 ± 1.5^{b}	92.4 ± 1.6^{a}
PF	115.8^{a}	244.8 ± 21.9^{a}	41.5 ± 1.0^{a}	15.0 ± 2.2^{a}	92.3 ± 0.3^{a}

The average spear diameter in the PF mulch (15.0 ± 2.2 mm) was 14.5% and 13.6% higher than that in the CK and RH treatments, respectively. Meanwhile, the weight of marketable spears under the PF mulch was significantly higher than that in the RH treatment and was approximately 8.19% higher than that in the CK, with no statistical significance.

The spear marketable length and individual weight also increased to a certain degree, and ultimately, the total yield and commodity value increased in early spring, although the difference in the individual weights between the plastic mulch and the CK was not statistically significant. Jakše and Maršić [35] reported that mulching influenced the average spear weight and yield, although the number of spears and the thickness did not increase. Furthermore, Ajibola et al. [36] reported that the plastic mulch significantly improved the number of fruits per plant, fruit diameter, and total cucumber yield. PF mulching also improved the yield and quality of tomatoes in spring [37].

3.4. Nutritional Quality of Asparagus Spears in Early Spring

Soluble sugars and reducing sugar content are essential quality attributes for fresh asparagus spears. The total soluble sugar content of the spears in the PF and RH mulch was significantly higher than that in the CK (Figure 3A).

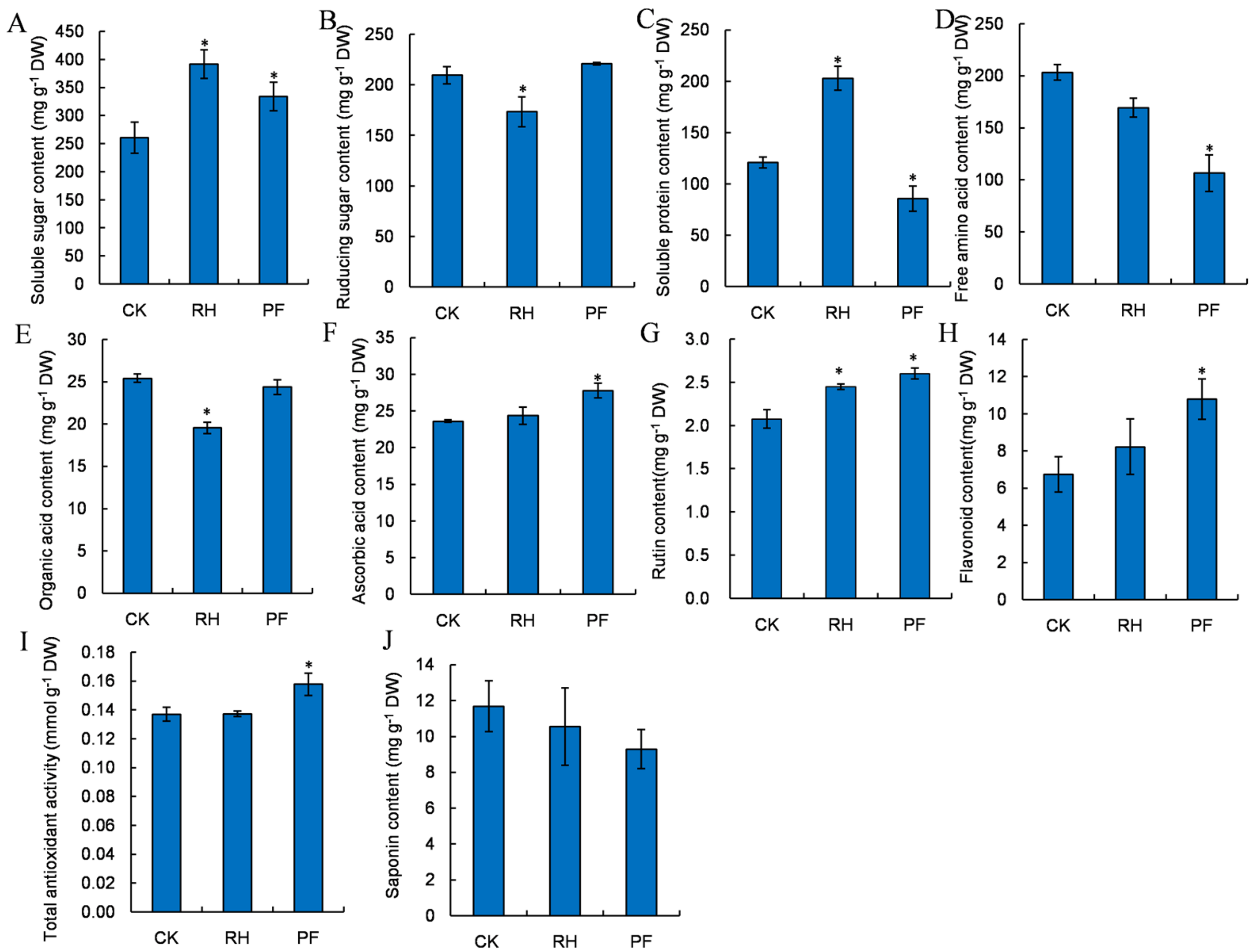

Figure 3. Comparison of the nutritional quality of spears under various mulching methods. Content of soluble sugar (**A**), reducing sugar (**B**), soluble protein (**C**), free amino acid (**D**), organic acid (**E**), ascorbic acid (**F**), rutin (**G**), and flavonoid (**H**). Total antioxidant activity (**I**) and saponin content (**J**) of spears. CK: non-mulching control treatment; RH: rice-husk mulch; PF: plastic film mulch. DW: dry weight. Asterisks indicate significant differences from the CK at $p < 0.05$ (student's t-test).

The reducing sugar content of the PF-covered spears was 22.7% higher than that of the RH mulch treatment (Figure 3B). The soluble sugar content of asparagus spears was highly related to environmental temperature. This correlation is due to increased sugar-metabolizing enzyme activity under higher temperatures [7].

Unexpectedly, the soluble protein content in the PF mulch decreased by 32.0% compared with CK, whereas it increased in the RH mulch (Figure 3C). Similarly, the total free amino acid content of the asparagus spears in the PF mulch was 50% lower than that in the CK plots (Figure 3D). As measured by the total titratable acidity in the RH mulch, the total organic acid components were lower by approximately 25.0% compared with the CK and the PF treatment (Figure 3E).

Asparagus contains various biologically active compounds, including flavonoids, steroidal saponins, and other phenol carboxylic acids [6,38,39]. The ascorbic acid content of the PF-covered spears was 16.7% higher than that of the CK, with significant differences (Figure 3F). The flavonoid content, rutin content, and antioxidant activity in harvested spears, were also significantly influenced by mulching. The rutin content of the spears in the PF and RH mulch was significantly higher than that in the CK (Figure 3G). Similarly, the highest flavonoid and antioxidant activities were found in the spears under the PF mulch, which were 59.9% and 15.1% higher than those of the CK, respectively (Figure 3H,I). Previous reports have shown that asparagus spears' lutein and phenolic content exhibits seasonal change [11]. These contents are also decreased by shading [40]. The high antioxidant activity of the spears under the PF mulch may be attributed to their higher flavonoid content when compared with those from the RH mulch and the CK, which supports previous studies proposing that flavonoids (mainly rutin) are primarily responsible for the antioxidant qualities of asparagus spears [41–43].

Other important biologically active constituents of asparagus are steroidal saponins, including sarsasapogenin, protodioscin, and a small amount of diosgenin [29,44]. Unlike the flavonoid content, the total saponin content was reduced in the PF-covered and the RH-covered spears, which was probably because of the higher relative growth rate of asparagus spears in the mulching plots; but the difference was not statistically significant (Figure 3J).

Therefore, this study has a practical importance to early asparagus production limited by the cool spring in regions of the world with temperate and subtropical climates.

3.5. Changes in Flavonoid Content, Antioxidant Activity, and Saponin Content in Asparagus Organs/Tissues

Asparagus is one of the best sources of antioxidants among the plant foods. Flavonoids belong to phenolics, which are the most abundant secondary plant metabolites, that are primarily responsible for the antioxidant qualities of asparagus [41,45]. The analysis of the flavonoid content of different tissues and at different developmental stages of the spears indicated that cladophylls contained the highest flavonoid concentration, followed by mother stalks and spears at various developmental stages (Figure 4A). At various developmental stages of the spears, the flavonoid content gradually decreased with the elongation of spears. From the top to the bottom of the spears too, the flavonoid content reduced significantly. Total flavonoid content in the top part of the spears was twice as much as that in the bottom section (Figure 4A). Total antioxidants did not vary significantly in various organs/tissues (Figure 4B). Total antioxidants slowly reduced with the elongation of spears and reduced significantly from the top to the bottom of the same spear (Figure 4B). The total saponins from the root, stem, and cladophyll, and from spears with different lengths, were extracted with the ultrasonic extraction method. The fennel aldehyde–sulfuric acid colorimetric method was used to detect the saponin content in various organs, which revealed that the cladophyll contained the highest saponin content (Figure 4C). During the development of the spears, the saponin content in the middle of the spears was lower than that in the top and bottom of the spears.

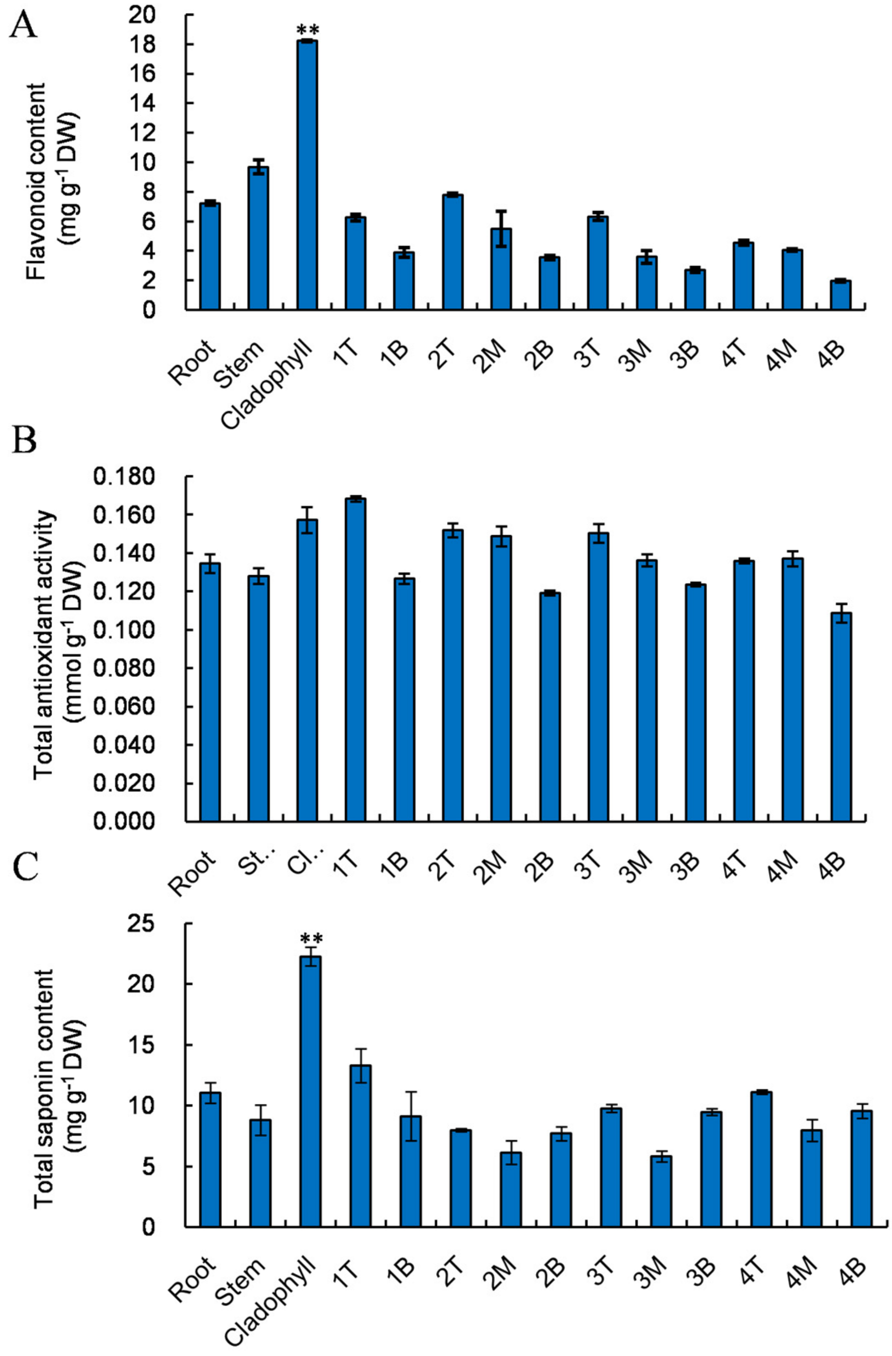

Figure 4. Total flavonoid content (**A**), antioxidant activity (**B**), and saponin content (**C**) in various asparagus organs and at different developmental stages according to the length of spears. Stage 1: 4–5 cm, Stage 2: 9–10 cm, Stage 3: 14–15 cm, and Stage 4: 19–20 cm. Parts of spears: T: top, M: middle part, B: bottom. The double asterisks indicate highly significant differences at level $p < 0.01$ (student's *t*-test).

4. Conclusions

PF mulch, a new mulch method for green asparagus production, can be a potential alternative to accelerate the harvest period of green asparagus grown under plastic tunnels and extend the harvesting period during early spring in China.

Moreover, compared with the RH and non-mulching treatment, the PF mulch method promoted early spear emergence, with better marketable spear quality. The PF mulch enhanced spear appearance, marketable spear length, and diameter. These effects could be attributed to its effect on significantly increasing soil and surface temperatures during the spring. Thus, the early yield was significantly increased. PF mulch treatment created an environment that was suitable for asparagus growth.

The PF mulch method might effectively improve the flavonoid content and antioxidant activity of asparagus. However, owing to the inconsistent responses of nutritional compositions to various treatments, further research is needed to investigate the effects of environmental factors on yield, quality and nutritional composition of green asparagus.

The transparent plastic mulch markedly decreases the production risk associated with delayed emergence and poor asparagus marketable spear quality and extends the harvesting period during early spring. Hence, the use of this method of cultivation can be popularized as an efficient and profitable system for asparagus production in Southern China and other regions of the world with temperate and subtropical climates. For sustainable agricultural development, more environmentally friendly materials for mulch treatment should be assessed.

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References

1. Pegiou, E.; Mumm, R.; Acharya, P.; de Vos, R.; Hall, R.D. Green and white asparagus (*Asparagus officinalis*): A source of developmental, chemical and urinary intrigue. *Metabolites* **2019**, *10*, 17. [CrossRef] [PubMed]
2. Li, S.F.; Lv, C.C.; Lan, L.N.; Jiang, K.L.; Zhang, Y.L.; Li, N.; Deng, C.-L.; Gao, W.J. DNA methylation is involved in sexual differentiation and sex chromosome evolution in the dioecious plant garden asparagus. *Hortic. Res.-Engl.* **2021**, *8*, 198. [CrossRef] [PubMed]
3. Faostat. Available online: http://www.fao.org/faostat/zh/#data/QC (accessed on 16 December 2021).
4. Yi, T.G.; Yeoung, Y.R.; Choi, I.Y.; Park, N.I. Transcriptome analysis of *Asparagus officinalis* reveals genes involved in the biosynthesis of rutin and protodioscin. *PLoS ONE* **2019**, *14*, e0219973. [CrossRef] [PubMed]
5. Hamdi, A.; Jaramillo-Carmona, S.; Rodríguez-Arcos, R.; Jiménez-Araujo, A.; Guillén-Bejarano, R. Chapter 8—Asparagus. In *Nutritional Composition and Antioxidant Properties of Fruits and Vegetables*; Jaiswal, A.K., Ed.; Phytochemicals and Food Quality Group, Instituto de la Grasa (CSIC): Seville, Spain, 2020; pp. 121–140.
6. Chin, C.K.; Garrison, S.A.; Shao, Y.; Wang, M.; Simon, J.; Ho, C.T.; Huang, M.T. Functional elements from asparagus for human health. *Acta Hort.* **2002**, *776*, 233–241. [CrossRef]
7. Alam, A.K.M.S.; Matsui, T.; Ikeuchi, T. Changes in acid invertase activity and sugar distribution in asparagus spears harvested in autumn. *Jpn. J. Trop. Agric.* **1998**, *42*, 257–262.
8. Srivastava, P.L.; Shukla, A.; Kalunke, R.M. Comprehensive metabolic and transcriptomic profiling of various tissues provide insights for saponin biosynthesis in the medicinally important *Asparagus racemosus*. *Sci. Rep.* **2018**, *8*, 9098. [CrossRef]
9. Hoberg, E.; Ulrich, D.; Gottwald, J.; Rosen, A. Environmental influences on the sensory quality of *Asparagus officinalis* L. *Acta Hort.* **2003**, *604*, 395–401. [CrossRef]
10. Heißner, A.; Schmidt, S.; Schonhof, I.; Feller, C.; Schreiner, M. Spear yield and quality of white asparagus as affected by soil temperature. *Eur. J. Agron.* **2006**, *25*, 336–344. [CrossRef]
11. Shou, S.; Lu, G.; Huang, X. Seasonal variations in nutritional components of green asparagus using the mother fern cultivation. *Sci. Hort.* **2007**, *112*, 251–257. [CrossRef]

12. Deng, B.; Li, W.; Lu, H.; Zhu, L. Film mulching reduces antibiotic resistance genes in the phyllosphere of lettuce. *J. Environ. Sci.-China* **2022**, *112*, 121–128. [CrossRef]
13. Dyduch, J.; Mysiak, B.; Rodkiewicz, T. Yielding of white and green asparagus in the open field and in the tunnel in the first two years of harvest. *Acta Sci. Pol. Hortorum Cultus* **2014**, *13*, 107–115.
14. Ramadhan, M.N. Yield and yield components of maize and soil physical properties as affected by tillage practices and organic mulching. *Saudi J. Biol. Sci.* **2021**, *28*, 7152–7159. [CrossRef]
15. Zhang, L.; Qin, R.; Wei, H.; Zhang, K.; Yu, C.; Li, F.M.; Zhang, F. Optimum plastic mulching application to reduce greenhouse gas emissions without compromising on crop yield and farmers' income. *Sci. Total Environ.* **2021**, *809*, 151998. [CrossRef] [PubMed]
16. Wang, L.; Li, X.G.; Guan, Z.H.; Jia, B.; Turner, N.C.; Li, F.M. The effects of plastic-film mulch on the grain yield and root biomass of maize vary with cultivar in a cold semiarid environment. *Field Crop. Res.* **2018**, *216*, 89–99. [CrossRef]
17. Dudaš, S. Effect of mulch in the cultivation of *Asparagus officinalis* L. *J. Glasnik Zaštite Bilja* **2009**, *32*, 22–32.
18. Wang, Z.; Li, M.; Flury, M.; Schaeffer, S.M.; Chang, Y.; Tao, Z.; Jia, Z.; Li, S.; Ding, F.; Wang, J. Agronomic performance of polyethylene and biodegradable plastic film mulches in a maize cropping system in a humid continental climate. *Sci. Total Environ.* **2021**, *786*, 147460. [CrossRef]
19. Luo, L.; Hui, X.; He, G.; Wang, S.; Wang, Z.; Siddique, K.H.M. Benefits and limitations to plastic mulching and nitrogen fertilization on grain yield and sulfur nutrition: Multi-site field trials in the semiarid area of china. *Front. Plant. Sci.* **2022**, *13*, 799093. [CrossRef]
20. Zhang, K.; Li, Y.; Wei, H.; Zhang, L.; Li, F.M.; Zhang, F. Conservation tillage or plastic film mulching? A comprehensive global meta-analysis based on maize yield and nitrogen use efficiency. *Sci. Total Environ.* **2022**, *831*, 154869. [CrossRef]
21. Knaflewski, M.; Krzesinski, W. Results of investigations on timing asparagus production in a temperate climate. *Acta Hort.* **2002**, *589*, 73–79. [CrossRef]
22. Nie, L.C.; Wang, M.; Liu, Y. Effects of different mulch methods on growth and early yield of green asparagus. *J. Inn. Mong. Agric. Univ.* **2007**, *28*, 59–61.
23. Chen, Z.; Han, Y.; Ning, K.; Luo, C.; Sheng, W.; Wang, S.; Fan, S.; Wang, Y.; Wang, Q. Assessing the performance of different irrigation systems on lettuce (*Lactuca sativa* L.) in the greenhouse. *PLoS ONE* **2019**, *14*, e0209329. [CrossRef] [PubMed]
24. Mastropasqua, L.; Tanzarella, P.; Paciolla, C. Effects of postharvest light spectra on quality and health-related parameters in green *Asparagus officinalis* L. *Postharvest Biol. Technol.* **2016**, *112*, 143–151. [CrossRef]
25. Bhowmik, P.K.; Matsui, T.; Ikeuchi, T.; Suzuki, H. Changes in storage quality and shelf life of green asparagus over an extended harvest season. *Postharvest Biol. Technol.* **2002**, *26*, 323–328. [CrossRef]
26. Li, S.; Wang, J.; Yu, Y.; Wang, F.; Dong, J.; Huang, R. D27E mutation of VTC1 impairs the interaction with CSN5B and enhances ascorbic acid biosynthesis and seedling growth in *Arabidopsis*. *Plant Mol. Biol.* **2016**, *92*, 473–482. [CrossRef]
27. Lowell, C.A.; Tomlinson, P.T.; Koch, K.E. Sucrose metabolizing enzymes in transport tissue and adjacent sink structures in developing citrus fruit. *Plant Physiol.* **1989**, *90*, 1394–1402. [CrossRef]
28. King, G.A.; Woollard, D.C.; Irving, D.E.; Borst, W.M. Physiological changes in asparagus spear tips after harvest. *Physiol. Plant* **1990**, *80*, 393–400. [CrossRef]
29. Wu, J.M.; Jiang, Z.S.; Tang, Y.S. Analysis of total flavonoid and rutin content in bamboo. *J. Zhejiang Univ.* **1998**, *24*, 425–428.
30. Shao, Y.; Poobrasert, O.; Kennelly, E.J.; Chin, C.K.; Ho, C.T.; Huang, M.T.; Garrison, S.A.; Cordell, G.A. Steroidal saponin from asparagus of ficinalis and their cytotoxic activity. *Planta Med.* **1997**, *63*, 256–262. [CrossRef]
31. Benzie, I.F.F.; Strain, J.J. Ferric reducing ability of plasma (FRAP) as a measure of antioxidant power: The FRAP assay. *Anal. Biochem.* **1996**, *239*, 70–76. [CrossRef]
32. Kwabiah, A.B. Growth and yield of sweet corn (*Zea mays* L.) cultivars in response to planting date and plastic mulch in a short-season environment. *Sci. Hort.* **2004**, *102*, 147–166. [CrossRef]
33. Frenz, F.W.; Munz, R. The influence of plastic covering of asparagus ridges on soil temperature and yield. *Acta Hort.* **1968**, *9*, 139–146. [CrossRef]
34. Makus, D.J.; Gonzalez, A.R. Production and quality of white asparagus grown under opaque row covers. *Hort. Sci.* **1991**, *26*, 374–377.
35. Jakše, M.; Maršić, N.K. Comparison of asparagus (*Asparagus officinalis* L.) cultivars and the effect of covering beds. *Acta Agric. Slov.* **2005**, *85*, 313–320.
36. Ajibola, O.V.; Amujoyegbe, B.J. Effect of seasons, mulching materials, and fruit quality on a Cucumber (*Cucumis sativus* L.) variety. *Asian J. Agric. Res.* **2019**, *3*, 1–11. [CrossRef]
37. Li, Y.; Zhang, Z.; Wang, J.; Zhang, M. Soil aeration and plastic film mulching increase the yield potential and quality of tomato (*Solanum lycopersicum*). *Agriculture* **2022**, *12*, 269. [CrossRef]
38. Huang, X.F.; Lin, Y.Y.; Kong, L.Y. Steroids from the roots of *Asparagus officinalis* and their cytotoxic activity. *J. Integra. Plant Biol.* **2008**, *50*, 717–722. [CrossRef]
39. Fuentes-Alventosa, J.M.; Jaramillo-Carmona, S.; Rodríguez-Gutiérrez, G.; Guillén-Bejarano, R.; Jiménez-Araujo, A.; Fernández-Bolaños, J.; Rodríguez-Arcos, R. Preparation of bioactive extracts from asparagus by-product. *Food Bioprod. Process.* **2013**, *91*, 74–82. [CrossRef]
40. Kohmura, H.; Watanabe, Y.; Muto, H. Polyphenol content, antioxidant activity and surface color of asparagus spears cultivated under different conditions of sunlight. *Acta Hort.* **2008**, *776*, 255–260. [CrossRef]

41. Makris, D.P.; Rossiter, J.T. Domestic processing of onion bulbs (*Allium cepa*) and asparagus spears (*Asparagus officinalis*): Effect of flavonol content and antioxidant status. *J. Agric. Food Chem.* **2001**, *49*, 3216–3222. [CrossRef]
42. Guillén, R.; Rodríguez, R.; Jaramillo, S.; Rodríguez, G.; Espejo, J.A.; Fernandez-Bolaños, J.; Heredia, A.; Jiménez, A. Antioxidant from asparagus spear: Phenolics. *Acta Hort.* **2008**, *776*, 247–254. [CrossRef]
43. Kulczyński, B.; Kobus-Cisowska, J.; Kmiecik, D.; Gramza-Michałowska, A.; Golczak, D.; Korczak, J. Antiradical capacity and polyphenol composition of asparagus spears varieties cultivated under different sunlight conditions. *Acta Sci. Pol. Technol. Aliment.* **2016**, *15*, 267. [CrossRef] [PubMed]
44. Fuentes-Alventosa, J.M.; Jaramillo-Carmona, S.; Rodríguez-Gutiérrez, G.; Rodríguez-Arcos, R.; Fernández-Bolaños, J.; Guillén-Bejarano, R.; Espejo-Calvo, J.A.; Jiménez-Araujo, A. Effect of the extraction method on phytochemical composition and antioxidant activity of high dietary fiber powders obtained from asparagus by-products. *Food Chem.* **2016**, *116*, 484–490. [CrossRef]
45. Dai, J.; Mumper, R.J. Plant phenolics: Extraction, analysis and their antioxidant and anticancer properties. *Molecules* **2010**, *15*, 7313. [CrossRef] [PubMed]