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Variation in Phenolic, Flavonoid, and Antioxidant Content of *Rosa × hybrida* Based on Flower Organs and Color: The Basis for Pruning Biomass Valorization

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ABSTRACT

Hybrid rose plants are not only valuable as floriculture commodities, but also have the potential to be a source of bioactive compounds. In cultivation activities, leaves and stems from pruning are often not fully utilized, so a scientific basis is needed to select the most promising biomass and to develop a simple extraction process. This study analyzed total flavonoids, total phenolics, and antioxidant capacity in red, pink, white, and purple flowers, stems, and leaves of *Rosa × hybrida* Schleich. We extracted fresh samples by infusion in distilled water at 90 °C for 15 minutes. Total flavonoids were determined by AlCl₃ complexation and expressed as mg QE/g FW; total phenolics were determined with Folin-Ciocalteu as mg GAE/g FW; while antioxidant capacity was measured by DPPH and the Modified Phenanthroline Method (MPM) as mg AAE/g FW. The highest flavonoids were found in purple stems (37.046 ± 17.557 mg QE/g FW), the highest phenolics in pink flowers (20.286 ± 1.704 mg GAE/g FW), the highest DPPH in purple leaves (10.928 ± 1.227 mg AAE/g FW), and the highest MPM in purple stems (7.762 ± 3.111 mg AAE/g FW). DPPH and MPM were highly correlated in flowers, stems, and leaves ($r = 0.997-0.999$). These findings suggest that vegetative biomass, especially purple rose stems and leaves, should be prioritized for the development of aqueous extracts and the valorization of pruning biomass. This study is a laboratory proof of concept; economic impact, community adoption, safety, and product performance still require further pilot testing.

Potential contribution to the Sustainable Development Goals (SDGs):

SDG 3: Good Health and Well-Being

SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Reactive oxygen species (ROS) are formed as byproducts of aerobic metabolism and play a role in cellular signaling. However, excessive ROS production or decreased antioxidant defense capacity can disrupt redox homeostasis and trigger oxidative stress. This condition can cause membrane lipid

oxidation, changes in protein structure, nucleic acid damage, and impaired cellular function, all associated with various degenerative processes [1], [2]. Antioxidants can suppress these reactions by donating electrons or hydrogen atoms, stopping radical chain reactions, chelating prooxidant metal ions, and regenerating other antioxidant components. Therefore, the search for natural antioxidant sources from plants remains crucial for developing functional foods, pharmaceutical and cosmetic raw materials, and more sustainable use of biological resources [2]–[5].



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Roses are an important floricultural commodity used as cut flowers, landscape plants, fragrances, rose water, herbal tea, and food and cosmetic ingredients. Beyond their aesthetic and economic value, roses can provide bioactive compounds, particularly phenolics and flavonoids, associated with antioxidant activity. However, research on rose phytochemistry has largely focused on flower petals, whole flowers, fruits, or essential oil distillates. The leaves and stems routinely produced during cultivation and pruning are relatively underutilized, creating a gap between the production of pruning biomass and its utilization as a value-added material.

This gap is relevant to developing simple technologies applicable to the rose cultivation chain. Simultaneous evaluation of flowers, leaves, and stems is necessary to identify plant parts with the greatest phytochemical and antioxidant potential. Flower color can also be related to phytochemical composition, so that different color types may indicate different phenolic, flavonoid, and antioxidant profiles. This organ- and color-based information can inform raw material selection before pruning biomass utilization technology is tested on a farmer group or small-scale enterprise.

Aquadest was chosen as the extraction solvent because it is safe, readily available, inexpensive, and reduces dependence on organic solvents. Hot water extraction is also more readily applicable at the application level because it does not require complex equipment and aligns with green extraction approaches. Thus, the technology tested in this study aims to bridge the gap in the utilization of vegetative biomass through a simple initial process. However, extraction conditions and reaction mechanisms influence the antioxidant response, so the water extract needs to be evaluated using multiple analytical methods [5], [6]. This study is a laboratory proof of concept; it has not directly measured technology adoption, cost savings, or socioeconomic impacts on the community.

1.2. Literature review

Various species of *Rosa* are known to contain a complex group of phenolic compounds, including quercetin and kaempferol-derived flavonols, anthocyanins, gallic acid, ellagic acid, catechins, proanthocyanidins, and hydrolyzable tannins [3], [7]–[15]. Studies on various rose cultivars have shown that the composition and concentration of these phytochemicals are influenced by genotype, flower color, developmental stage, growing environment, and post-harvest treatment [9]–[11], [16]–[18]. Phenolic compounds can act as hydrogen or electron donors and, depending on their molecular structure, can also complex with metal ions, thus contributing to the antioxidant capacity of rose extracts [19]–[21].

Phytochemical composition also varies between organs. Chromatographic analysis of six *Rosa hybrida* organs showed that each tissue had a distinct polyphenol fingerprint. Woody tissue was reported to be relatively rich in catechins and proanthocyanidin derivatives, while buds and flowers contained higher levels of kaempferol derivatives [12]. These findings suggest that assessments focused solely on flowers do not fully reflect the plant's overall phytochemical potential.

The potential value of rose vegetative tissue is further supported by research on *Rosa damascena* biomass. Pruned

leaves and stems still contain phenolic compounds, flavonoids, and various phytochemicals identified by HPLC [22]. This means that pruning residues should not be viewed solely as agricultural waste but rather as secondary raw materials for valorization processes, provided the quality, safety, and feasibility of the process are further studied.

Water-based extraction has also been used to obtain bioactive compounds from roses. Rose petal infusion can produce a beverage with significant phenolic content and antioxidant capacity [23]. *Rosa rugosa* water extract has been reported to contain gallic acid derivatives, polysaccharides, phenolic glycosides, flavonoids, and tannins [24], [25]. Newer green extraction techniques, including boiling, microwave-assisted extraction, ultrasonics, and other environmentally friendly approaches, can also extract bioactive compounds from plant materials [26].

However, temperature, time, solid-to-solvent ratio, and extraction technique strongly influence the amount and composition of extracted compounds. Furthermore, each antioxidant assay is based on a different reaction mechanism. Therefore, using multiple antioxidant methods on aqueous extracts or infusions provides a more comprehensive interpretation than a single assay [5], [6].

1.3. Research purposes

This study aims to analyze the variation in total phenolic content, total flavonoids, and antioxidant capacity of flower, leaf, and stem water extracts of four *Rosa × hybrida* color types, and to identify the most promising organ and color combinations as a basis for utilizing pruning biomass. These laboratory results are intended to inform the selection of materials and processes for further testing at a pilot or community scale, not as direct evidence of the success of empowerment interventions.

2. MATERIALS AND METHODS

2.1 Place, Design, Samples, and Materials

The study was conducted in September–November 2023 at the Applied Analytical Chemistry Laboratory, Measurement Laboratory, and Organic Chemistry Laboratory of Natural Products, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Andalas University. The study used a laboratory experimental design; there were no human participants, training sessions, or community interventions. Therefore, this study design did not include participant sampling criteria, demographic composition, training duration, or community impact validation instruments. The units of analysis were fresh red, pink, white, and purple rose flowers, stems, and leaves obtained from West Sumatra. All plant parts were selected in fresh condition and showed no obvious physical damage. The Andalas University Herbarium (ANDA) confirmed the botanical identity as *Rosa × hybrida* Schleich based on identification letter Number 822/K-ID/ANDA/XI/2023. Four color variations were used to capture potential differences in secondary metabolite accumulation associated with genetic characteristics and pigmentation.

The chemicals used included quercetin, gallic acid, ascorbic acid, aluminum chloride (AlCl₃), sodium nitrite (NaNO₂), sodium

hydroxide (NaOH), Folin–Ciocalteu reagent, sodium carbonate (Na_2CO_3), 2,2-diphenyl-1-picrylhydrazyl (DPPH), iron(III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), ortho-phenanthroline, methanol pro analysis, and distilled water. All absorbance measurements were performed using a Genesys 20 UV–Vis spectrophotometer (Thermo Scientific), while materials and standards were weighed using an analytical balance. Standard solutions and reagents were prepared according to working concentrations and used under appropriate conditions to minimize changes during analysis.

2.2 Sample Preparation and Extraction

Fresh samples were washed with distilled water to remove surface dirt, drained, and then separated into flowers, stems, and leaves. We added approximately 2 g of each sample to 100 mL of distilled water and extracted it by infusion at 90 °C for 15 minutes. After heating, we filtered the mixture and brought the volume to 100 mL with distilled water. The liquid extract was used on the same day to minimize compositional changes due to oxidation, contamination, or degradation during storage. The choice of infusion was based on the simplicity of the process, the use of safe solvents, and its proximity to traditional forms of utilization such as infusions or decoctions. Previous studies have shown that hot-water extraction can dissolve phenolics and confer good antioxidant capacity. However, compound amounts and profiles are still influenced by cultivar, temperature, time, and extraction technique [23]–[27].

2.3 Determination of Total Flavonoids and Total Phenolics

Total flavonoid content was determined using the AlCl_3 complexation colorimetric method with quercetin as a standard [20], [28]. Add 0.3 mL of 5% NaNO_2 to 1 mL of the standard solution or diluted extract, and let the mixture stand for 5 minutes. Next, add 0.3 mL of 10% AlCl_3 and incubate for 6 minutes. Then, add 2 mL of 1 M NaOH and distilled water to a final volume of 10 mL. Absorbance was measured at 400 nm, and the results were calculated using the quercetin calibration curve equation, then expressed as mg quercetin equivalents per gram fresh weight (mg QE/g FW). Since the aluminum complexation response varies across flavonoid classes, the obtained values are treated as equivalent parameters based on the method rather than the absolute number of flavonoid molecules in the extract [20], [29].

Total phenolic content was determined using the Folin–Ciocalteu method with gallic acid as a standard [30]. A 1 mL standard solution or diluted extract was reacted with 0.4 mL of Folin–Ciocalteu reagent and allowed to stand for 5 minutes. Then, 4 mL of 7% Na_2CO_3 was added, the volume was made up to 10 mL with distilled water, and the mixture was incubated for 2 hours before measuring absorbance at 731 nm. Results were expressed as mg equivalents of gallic acid per gram fresh weight (mg GAE/g FW). The Folin–Ciocalteu reagent measures the reducing capacity of the sample towards the phosphomolybdate–phosphotungstate complex; therefore, the results represent the content of reducing compounds in gallic acid equivalents and may include contributions from certain nonphenolic components [30].

2.4 Determination of Antioxidant Capacity

Antioxidant capacity was determined using two spectrophotometric approaches with ascorbic acid as a standard. In the DPPH method, 1 mL of standard solution or diluted extract was mixed with 2.5 mL of 0.1 mM DPPH, incubated in the dark for 30 minutes, and then the absorbance was measured at 517 nm [31]. The decrease in absorbance reflects the extract components' ability to reduce DPPH radicals by transferring hydrogen atoms or electrons. In the Modified Phenanthroline Method (MPM), 1 mL of standard or extract was added with 2 mL of distilled water, 1 mL of 0.1% $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, and 1 mL of 0.1% ortho-phenanthroline. We left the mixture for 20 minutes and measured it at 410 nm [6], [32]. MPM is based on the reduction of Fe^{3+} to Fe^{2+} by antioxidants and the formation of Fe(II) –phenanthroline complexes. We expressed results from both methods as mg ascorbic acid equivalents per gram fresh weight (mg AAE/g FW). Using two methods provides a more robust picture because a single antioxidant assay does not always capture the entire reaction mechanism in a complex plant matrix [5], [6].

2.5 Data Analysis

Each sample combination was analyzed in triplicate ($n = 3$), and results are presented as means $\pm$ standard deviations. The effects of color variation and plant part were analyzed using a two-factor ANOVA with replication to evaluate the main effects of color, plant part, and their interaction separately. If significant differences were found at the 5% level, analysis was continued with Duncan's Multiple Range Test. Relationships between total flavonoids, total phenolics, DPPH, and MPM were determined using Pearson's correlation coefficient (r). Correlations assessed the strength of relationships, not causality or the percentage contribution of individual compounds. As a descriptive summary, we calculated the relative difference between the highest and lowest values as a percentage of the lowest value; this percentage does not indicate baseline–post-intervention or community impact.

3. RESULTS AND DISCUSSION

3.1 Total Flavonoid and Total Phenolic Content

Total flavonoid content differed significantly between color variations ($p < 0.001$), while the effect of plant part ($p = 0.102$) and the color $\times$ part interaction ($p = 0.079$) were not significant at the 5% level. Purple rose stems gave the highest value, namely 37.046 ± 17.557 mg QE/g FW, while white rose stems gave the lowest value, namely 5.686 ± 3.291 mg QE/g FW. Descriptively, the highest value is approximately 551.5% higher than the lowest value. Purple rose flowers and leaves also showed relatively high flavonoids compared to most other color samples. This pattern suggests that factors related to color variation or genotype are stronger than general organ grouping. However, the large standard deviation in purple rose stems indicates heterogeneity between replicates, so this high average still needs confirmation through broader biological replication. The distribution of total flavonoids based on color variation and plant part is shown in Figure 1.

Differences in flavonoid content among cultivars have been widely reported in *Rosa $\times$ hybrida*. Cultivars with intense flower color often exhibit higher flavonoid, anthocyanin, and antioxidant capacity. However, the relationship between visual color and

flavonoids is not simple because color is also influenced by anthocyanins, carotenoids, copigment composition, vacuolar pH, and other genetic factors [9]–[11], [14], [17], [18], [33]. In the intensely colored garden genotype, quercetin and kaempferol glycosides were reported as dominant components [11], while the red petals of *Rosa hybrida* cv. Noblered contained cyanidin 3,5-di-O-glucoside and pelargonidin 3,5-di-O-glucoside as the major anthocyanins [14]. Thus, the high values of purple roses in this study likely reflect a combination of genotype, pigmentation, and metabolite distribution. The identity of the dominant compounds cannot be confirmed by colorimetric assays alone.

Differences among organs also help explain the study's results—the polyphenol profile of *Rosa hybrida* cv. Jardín de Granville showed that woody tissues, leaves, buds, and flowers exhibited distinct chromatographic profiles [12]. In Taif rose pruning waste, some stem samples showed high flavonoids, while leaves tended to have higher phenolics [22]. These findings suggest that the purple rose stems in this study contain compounds that strongly respond to the AlCl₃ test. However, differences in equivalent standards and reporting bases make values across publications not directly comparable without normalization.

The highest total phenolic content was found in pink rose flowers at 20.286 ± 1.704 mg GAE/g FW, while the lowest value was found in pink rose stems at 5.400 ± 0.442 mg GAE/g FW. The highest value was approximately 275.7% greater than the lowest value. ANOVA results showed that plant part ($p < 0.001$) and the color $\times$ part interaction ($p = 0.004$) had a significant effect, while color variation as a single factor had no significant effect ($p = 0.983$). These findings indicate that the accumulation of reducing compounds detected by the Folin–Ciocalteu assay cannot be explained by flower color alone but depends on a combination of tissue characteristics and plant variation. Rose phenolic compounds include phenolic acids, flavonols, anthocyanins, catechins, proanthocyanidins, and ellagitannins, which are distributed differently in flowers, leaves, stems, and woody tissues [7], [12], [13], [15], [34]. The total phenolic pattern of all sample groups is shown in Figure 2.

In Indian rose cultivars, phenolic content and antioxidant capacity vary widely, with some dark-red cultivars exhibiting among the highest values [9]. Similar patterns of variation have been reported in Argentinean and European garden rose cultivars, but color is not always the sole predictor of chemical composition [17], [18]. In this study, pink flowers produced the highest phenolics, while purple leaves did not always have higher phenolics than other colors. This suggests that the high antioxidant capacity of purple roses may be determined not only by the total phenolic content, but also by the type, structure, and reactivity of the extracted compounds. Extracts with similar total content may exhibit different antioxidant responses if the proportion of aglycones, glycosides, tannins, or non-phenolic components differs.

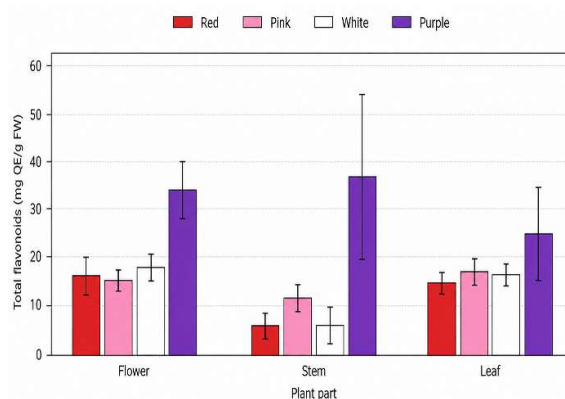


Figure 1. *Rosa × hybrida* Schleich water extract. Bars indicate the mean, and error bars indicate the standard deviation ($n = 3$).

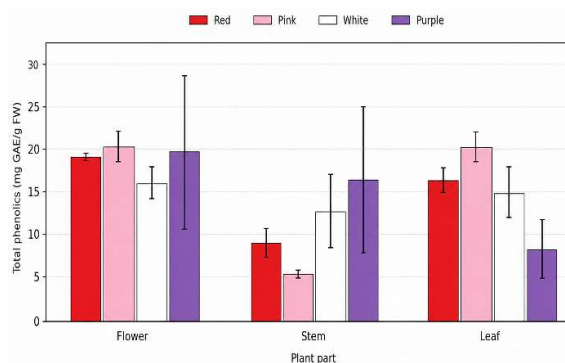


Figure 2. Total phenolic content of aqueous extract of *Rosa × hybrida* Schleich. Bars indicate the mean, and error bars indicate the standard deviation ($n = 3$).

Figure 1 shows the dominance of the purple rose group in flavonoid content, particularly in the stems. Conversely, Figure 2 shows that phenolic content does not consistently follow the same color pattern. Pink flowers and leaves have the highest phenolic content, while stems from the same color group have the lowest. This difference in pattern reinforces the hypothesis that interactions between genotype or cultivar color and the physiological function of each organ influence the distribution of secondary metabolites.

3.2 Antioxidant Capacity of MPM and DPPH Methods

Antioxidant measurements using DPPH and MPM showed a consistent trend: purple rose samples had higher values than most red, pink, and white samples. In the DPPH method, purple rose leaves had the highest value (10.928 ± 1.227 mg AAE/g FW), while red rose leaves had the lowest (1.218 ± 0.090 mg AAE/g FW); descriptively, the difference was approximately 797.2%. In MPM, purple rose stems had the highest value (7.762 ± 3.111 mg AAE/g FW), while red rose leaves had the lowest (0.590 ± 0.269 mg AAE/g FW); the relative difference was approximately 1,215.6%. The high values in purple leaves and stems indicate that non-flowering organs cannot always be assumed to have lower antioxidant potential. Figures 3 and 4 show comparisons of MPM and DPPH results, respectively.

Color variation significantly affected the MPM and DPPH results (both $p < 0.001$), while the plant part and its interaction

showed no significant effect. DPPH assesses the extract's ability to neutralize stable radicals by transferring hydrogen atoms or electrons. At the same time, MPM mainly describes the reducing power towards Fe^{3+} and the formation of Fe(II) -phenanthroline complexes [6], [31]. Since both methods use different reactive species, media, wavelengths, and kinetics, their absolute values are not expected to be the same [5], [6]. However, the similar order of responses among samples suggests that the dominant components in purple roses may participate in both reaction mechanisms.

Various garden and edible rose cultivars have also been reported to have high antioxidant capacity [9]–[11], [16]–[18]. Kalisz et al. [18] found significant variations in phenolic and flavonoid content among 23 cultivars, while Baibuch et al. [16] showed that solvent type is an important factor affecting phenolic yield and antioxidant capacity of petals. Direct numerical comparisons should be made with caution due to differences in species or cultivars, fresh or dry weight basis, solvent type, material to solvent ratio, drying treatment, and method of expressing results. Water extraction is closer to infusions or decoctions, but it can extract semipolar compounds with different efficiencies than ethanol or methanol.

Water-based extraction data from other studies provide relevant context. Hot infusions of 12 rose cultivars yielded significantly different radical-scavenging capacities and phenolic contents between cultivars [23]. *Rosa rugosa* flower aqueous extracts were found to contain antioxidant components, including gallic acid derivatives and polysaccharides [24]. In contrast, bud aqueous extracts yielded phenolic glycosides, flavonoids, and tannins that chromatography could isolate [25]. *Rosa rugosa* petal aqueous extracts also showed a positive correlation between total phenolics and several biological activities in a comparison of edible flowers [27]. These findings support the conclusion that infusions not only produce aqueous extracts but also solubilize a group of chemically and biologically relevant polar compounds.

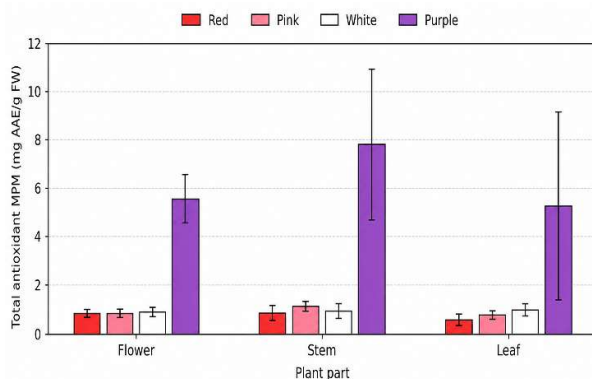


Figure 3. Total antioxidant capacity of *Rosa × hybrida* Schleich water extract based on the Modified Phenanthroline Method (MPM). Bars indicate the mean, and error bars indicate the standard deviation (n = 3).

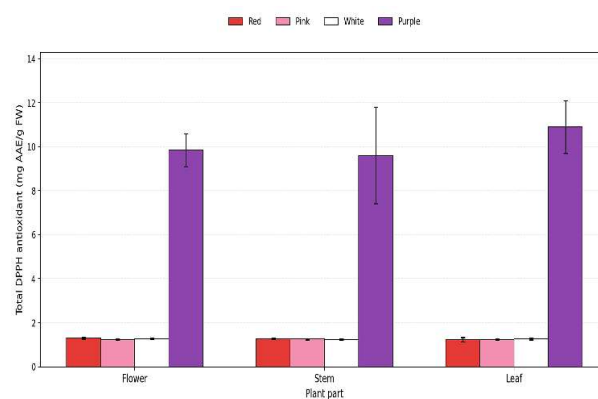


Figure 4. Total antioxidant capacity of *Rosa × hybrida* Schleich water extract based on the DPPH method. Bars indicate the mean, and error bars indicate the standard deviation (n = 3).

Figures 3 and 4 show a clear contrast between purple roses and the other three color groups. Although the absolute DPPH values are higher than those for MPM, both methods yield very similar relative rankings. This visual pattern is consistent with the DPPH–MPM correlations approaching unity in flowers, stems, and leaves, supporting the consistency of measuring the antioxidant capacity of aqueous extracts using two different reaction mechanisms.

3.3 Correlation between parameters

The correlation between DPPH and MPM results was very strong across all plant parts, with $r = 0.999$ in flowers and stems and $r = 0.997$ in leaves. This closeness indicates that both methods provide nearly identical tendencies in distinguishing samples with low and high antioxidant capacity. These results support using MPM as a comparison method for water-based herbal extracts, as previous validation showed good agreement among MPM, DPPH, FRAP, and other iron-reduction methods [6], [32]. However, a high correlation does not mean that both methods respond to each compound in the same proportion, as each remains influenced by the reaction mechanism and matrix composition.

In flowers, antioxidant capacity correlated strongly with flavonoids ($r = 0.993$ for DPPH and $r = 0.994$ for MPM), but the correlation with total phenolics was low ($r = 0.302$ and 0.293). In stems, the antioxidant–flavonoid correlation was very strong ($r = 0.984$ – 0.989), while the antioxidant–phenolic correlation was relatively strong ($r = 0.762$ – 0.774). In leaves, flavonoids and phenolics both showed strong to very strong correlations with antioxidants ($r = 0.889$ – 0.986). This pattern suggests that flavonoid responses more consistently track variations in antioxidant capacity across organs. In contrast, the contribution of phenolic components, as measured by the Folin–Ciocalteu assay, varies by tissue. These findings align with reports that quercetin and kaempferol glycosides are important components of various rose extracts and may contribute to both reducing and radical-scavenging activities [7], [11]–[13], [35].

Phenolic–flavonoid correlations also differed between parts, being very low in flowers ($r = 0.185$), strong in stems ($r = 0.665$), and very strong in leaves ($r = 0.832$). These differences may reflect variations in the proportion of flavonoids to other phenolic groups, differences in the analytical response of the two methods, and the presence of non-flavonoid reducing compounds. The AIC13 test does not provide a uniform response to all flavonoid

subclasses, while the Folin–Ciocalteu test can also react with reducing compounds other than polyphenols [29], [30]. Therefore, the correlation coefficient cannot be used to express the percentage of antioxidant sources or to prove a causal relationship. LC–MS/MS or HPLC–DAD analysis is needed to identify the dominant compounds and to link the chemical profiles more precisely to the activity of each organ.

Table 1. Pearson correlation coefficients between antioxidant capacity, phenolics, and flavonoids

Organ	Fen.- DPPH	Fen.- MPM	Flav.- DPPH	Flav.- MPM	DPPH- MPM	Fen.- Flav.
Flower	0.302	0.293	0.993	0.994	0.999	0.185
Stem	0.774	0.762	0.984	0.989	0.999	0.665
Leaf	0.889	0.896	0.977	0.986	0.997	0.832

The extreme range of values may also influence the very high correlation between antioxidants and flavonoids in flowers. Purple flower samples had significantly higher flavonoid and antioxidant levels than the other three colors, so a single cluster of high values can increase the correlation coefficient when the number of observation points is limited. With only four color variations for each organ, these coefficients should be treated as exploratory indications, not definitive proof of mechanism. Increasing the number of cultivars, biological replicates, and multivariate analyses is needed to improve the power of inference and separate the effects of color, genotype, organ, and individual compound composition.

3.4 Implications of Implementation and Limitations

The results of this study broaden the focus of rose utilization from flowers to vegetative biomass. Stems and leaves, especially from purple roses, show high flavonoid and antioxidant capacity, making them promising raw materials for aqueous extracts. This approach aligns with the concept of plant byproduct valorization, which converts previously underutilized pruning biomass into value-added materials. Previous studies on *Rosa hybrida* organs and *Rosa damascena* pruning waste have shown organ-specific polyphenol compositions [12], [22]. At the same time, hydrodistillation byproducts can still contain quercetin- and kaempferol-rich fractions with biological activity [35], [36]. Thus, this study provides a laboratory basis for biomass selection and a simple infusion process prior to validation at production or community scale.

Recent primary literature reinforces the relevance of rose waste valorization within a circular economy framework. Rose flower waste has been used as a filler in biopolymer films [37]; rose cultivation waste can be composted into valuable organic fertilizer [38] and has even been tested at a commercial scale in rose plantations in Kenya to close the resource cycle [39]. Pruned *Rosa damascena* leaves have also been evaluated for cosmetic applications using environmentally friendly extraction techniques [40]. In contrast, the use of natural deep eutectic solvents can enhance phenolic recovery from distillation residues [41]. Rose distillation wastewater has been reported to have potential as a

circular biostimulant [42], and a recent comprehensive characterisation confirmed that branches, leaves, flowers, and industrial residues still possess phytochemical profiles and biological activities that can be valorised [43]. Compared with these studies, this study's contribution lies in the simple mapping of organ $\times$ color in *Rosa $\times$ hybrida* using water infusion and two antioxidant methods, thereby providing an inexpensive initial screening step before further processing.

Interpretation of the results still requires caution. This study did not measure baseline and post-intervention performance, operational costs, community adoption rates, or participant skill enhancement because the study design included no human intervention. Therefore, the current data cannot support claims of long-term socioeconomic benefits. Samples included only four color varieties from a single region and have not been characterized to the cultivar or molecular genotype level. The assay was performed on a fresh-weight basis, so differences in water content among organs may affect comparisons. The spectrophotometric method provides total equivalents but does not identify individual compounds, and high standard deviations in some samples suggest the need for additional biological replications. The in vitro antioxidant results also do not directly demonstrate biological efficacy, safety for consumption, bioaccessibility, or product stability. Further research should include LC–MS/MS, water content and extraction yield, optimization of infusion conditions, stability and toxicity testing, comparison of green extraction techniques, and pilot testing with potential users to assess costs, process efficiency, acceptability, and sustainability of adoption [16], [26].

4. CONCLUSION

Aqueous extracts of flowers, stems, and leaves from four color varieties of *Rosa $\times$ hybrida* Schleich contained flavonoids and phenolics and exhibited antioxidant capacity with different patterns according to color and organ. The highest total flavonoids were found in purple rose stems, the highest total phenolics in pink flowers, the highest DPPH values in purple rose leaves, and the highest MPM values in purple rose stems. Color variation significantly affected flavonoids and the results of both antioxidant methods, while phenolics were more influenced by plant part and the color $\times$ part interaction. DPPH and MPM results were highly correlated across all organs. In flowers, antioxidant capacity was primarily associated with flavonoids, whereas in stems and leaves, there was a strong to very strong relationship with flavonoids and phenolics. Overall, purple rose stems and leaves are promising biomass candidates to prioritize for the development of water extraction and biomass valorization through pruning. However, application at a community or product scale requires compound identification, process standardization, safety, and biological activity evaluation, and pilot testing to assess technical and socioeconomic aspects.

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