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ARTICLE

Comprehensive Analysis of Decortication Effects on Faba Bean Bioactive Compounds and Antioxidant Activities

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ABSTRACT

This study investigated the impact of seed coat removal (decortication) on the phenolic composition and antioxidant activities of two Tunisian faba bean (*Vicia faba* L.) cultivars (Local Nabeul and Local Beja). The total phenolic, flavonoid, and tannin contents, alongside three antioxidant activity assays (1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging, β-carotene bleaching inhibition, and total antioxidant ability), were measured in whole and decorticated seeds. The results indicated that decortication did not significantly alter total phenolic and flavonoid content but variably influenced specific antioxidant activities depending on the cultivar. Notably, DPPH radical scavenging activity improved by 25–35% following decortication, suggesting that removal of the seed coat eliminated interfering compounds such as tannins, thereby enhancing the extract's free radical neutralizing efficiency. Conversely, total antioxidant ability slightly decreased, indicating the loss of some pro-oxidant or metal-reducing compounds concentrated in the hull. Tannin content was identified as the primary discriminating variable between cultivars and was significantly reduced by the process. Multivariate analyses, including Principal Component Analysis (PCA) and hierarchical clustering, demonstrated distinct discrimination among samples.

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Local Beja Whole Seeds (LBWS) clustered distinctly due to its high tannin content, while decorticated samples from both cultivars grouped together. This reveals that processing can dominate cultivar-based differences in functional properties. This study demonstrates that decortication's effect is not uniform but rather dependent on both the specific cultivar and the antioxidant mechanism evaluated, providing crucial insights for optimising faba bean processing to balance nutritional retention with sensory improvement.

Keywords: Decortication; Phenol Composition; Antioxidant Activities; Principal Component Analysis; Faba Bean

1. Introduction

Legume seeds, commonly referred to as pulses, represent one of the most diverse and significant plant families globally[1]. Their consumption has seen a marked increase in recent years, driven by their nutritional benefits and role in sustainable food systems[2]. Faba bean (*Vicia faba* L.) is a key pulse crop, cultivated extensively in regions including China, the Mediterranean, Europe, and the Americas, with growing production in Australia and North Africa[3,4]. Nutritionally, faba beans contain high levels of dietary fibre, protein, essential minerals such as iron, zinc, and potassium, and complex carbohydrates[5,6]. They are abundant in secondary metabolites such as polyphenols, notably flavonoids and phenolic acids, as well as carotenoids and vitamins, which contribute to their high antioxidant capacity[7,8]. Research indicates that these natural antioxidants help mitigate oxidative stress by counteracting lipid peroxidation, protein denaturation, and DNA damage mediated by reactive oxygen species (ROS)[9]. Persistent cellular oxidation, arising from a discrepancy between ROS generation and protective scavenging systems, is linked to several ongoing health disorders, for instance, vascular troubles, brain disorders, and tumours[10].

Processing methods such as germination, fermentation, dehulling, and milling are commonly employed to modify the nutritional composition, bioactive and volatile compound profile, and organoleptic properties of legume seeds[11,12]. Decortication (dehulling) is a critical processing step for faba beans (*Vicia faba* L.), significantly influencing their nutritional profile, sensory attributes, and volatile compound composition[13]. The process removes the seed coat, which contains higher concentrations of phenolic compounds, tannins, and certain bitter-tasting volatiles, thereby altering the overall flavor and aroma profile of the resulting flour or product[14].

The present research aimed to characterize the impact of decortication on total phenolic, flavonoid and tannin contents, as well as on total antioxidant ability, DPPH (1,1-diphenyl-2-picrylhydrazyl) scavenging activity, and carotene bleaching inhibition activity of faba bean cultivars. The novelty of this study lies in the application of multivariate analysis to identify discriminating factors among the evaluated parameters for both raw and decorticated seeds, and to elucidate the relationships among all parameters under both conditions.

2. Materials and Methods

2.1. Plant Material

For this investigation, two cultivars of small-sized faba beans from two different governorates (Nabeul and Beja) were employed. Intact kernels of comparable dimensions, free from visible defects, were selected. The samples were kept at 4 ℃ within light-proof aluminium packaging prior to processing. Hulled and unhulled grains of different cultivars were designated with the following abbreviations: Local Nabeul Whole Seeds (LNWS), Local Beja Whole Seeds (LBWS), Local Nabeul Decorticated Seeds (LNDS), and Local Beja Decorticated Seeds (LBDS).

For flour production, 50 g of each seed type was milled with a household grinder under ambient conditions. The resultant powder was subsequently sifted through a 100-mesh screen to achieve consistent particle size.

For each cultivar, multiple batches of seeds were used to ensure biological replication, accounting for natural variability between individual seeds and ensuring reliable and reproducible results.

2.2. Extraction

Extraction was performed on 20 g of dry powder using 200 mL of 80% methanol. The mixture was kept at room temperature for 24 h and then passed through Whatman No. 4 filter paper. The collected liquid phase was concentrated under reduced pressure using a vacuum (40–50 ℃), and the obtained residue was maintained at 4 ℃ pending testing[15].

Extraction yield was not determined in this study, as the primary focus was the comparative analysis of phenolic composition and antioxidant activities expressed per gram of dry weight of seed material. All extracts were prepared under identical conditions to ensure consistency across samples.

2.3. Total Phenol Content (TPC)

TPC was quantified using the Folin-Ciocalteu reagent[16]. Results were calculated as milligrams of gallic acid equivalent per gram of dry weight (mg GAE/g DW). The calibration curve exhibited excellent linearity over the concentration range of 0–500 μg/mL ($R^2 > 0.997$). All analyses were performed in triplicate.

2.4. Total Flavonoid Content (TFC)

Total flavonoid content was determined using a previously described method[16]. Data were reported in milligrams of catechin equivalent per gram of dried mass (mg CE/g DW) using a standard reference line derived from (+)-catechin concentrations spanning 0 to 500 μg/mL. The calibration curve showed good linearity ($R^2 > 0.998$). All analyses were performed in triplicate.

2.5. Total Tannin Content (TTC)

Concentrations of condensed tannins were assessed following a method reported earlier[16]. The data were expressed as mg catechin equivalent per gram of dry weight (mg CE/g DW). The calibration curve exhibited excellent linearity ($R^2 > 0.998$). All analyses were performed in triplicate.

2.6. Total Antioxidant Ability (TAA)

TAA was determined as mg GAE/g DW[16]. In detail, 100 μL of faba bean extract was mixed with 1 mL of reagent solution (4 mM ammonium molybdate, 28 mM sodium phosphate, 0.6 M H_2SO_4). The mixture was incubated at 95 ℃ for 90 min, then cooled. Absorbance was read at 695 nm. Results were expressed as mg GAE/g DW using a calibration curve (0–500 μg/mL). The calibration curve showed good linearity ($R^2 > 0.997$). Analyses were performed in triplicate.

2.7. DPPH Radical Scavenging Assay

The DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging activity of faba bean extracts was determined according to an established protocol[17]. Briefly, 250 μL of a 2 mmol/L DPPH methanolic solution was added to 1 mL of extract at various concentrations. The mixture was thoroughly agitated and incubated in the dark for 30 min at room temperature. Absorbance was read at 517 nm. The percentage of inhibition was calculated as $[(A_0 - A_1)/A_0] \times 100$, where A_0 and A_1 are the absorbances of the control and sample, respectively. The IC_{50} value was determined by linear regression analysis of the concentration–inhibition curve ($R^2 = 0.994$). The IC_{50} value (μg/mL) represents the concentration required to scavenge 50% of the DPPH radical. All tests were performed in triplicate.

2.8. β-Carotene Bleaching Inhibition Assay

The procedure for assessing β-carotene bleaching was originally described elsewhere[18]. A 4 mL aliquot of 10% β-carotene in chloroform was mixed with 40 mg linoleic acid and 400 mg Tween 40. After evaporating chloroform under reduced pressure at 40 ℃, the emulsion was vigorously mixed with 100 mL aerated ultrapure water. Subsequently, 150 μL of the emulsion was transferred to a 96-well plate, and 10 μL of faba bean methanolic extract was added. The plate was incubated at 50 ℃ for 120 min. Absorbance was read at 470 nm using an EAR 400 microplate reader. Antioxidant activity (AA, %) was calculated as $[(A_0 - A_1)/A_0] \times 100$, and results were expressed as IC_{50} (μ/mL). The IC_{50} value was determined by linear regression analysis of the concentration–inhibition curve ($R^2 = 0.9355$). All analyses were performed in triplicate.

2.9. Statistical Analysis

Multivariate analysis and heatmaps (XLSTAT software) were considered in the interpretation of the results. PCA was applied to information collected from hulled and unhulled faba bean grains. All experiments were conducted in triplicate. A one-way analysis of variance (ANOVA) was conducted, followed by post hoc evaluation using Duncan's test to determine significant differences at $p < 0.05$. Data are presented as mean ± standard deviation (SD). For quantitative analysis, calibration curves were prepared using standard solutions of gallic acid (for total phenolic content and total antioxidant ability) and (+)-catechin (for total flavonoid and total tannin contents). All standard solutions were prepared

in 80% methanol at concentrations ranging from 0 to 500 µg/mL. A high value of R^2 (coefficient of determination) indicates that the prediction relationship is good.

3. Results

3.1. Effect of Decortication on Phenolic Composition

3.1.1. Total Phenolic Content

Figure 1 demonstrates the changes in phenolic content extracted from whole and decorticated seeds of both cultivars. Dehulling significantly reduced total phenolic content by 6.2% (LN) to 8.3% (LB), confirming that phenolic compounds, including condensed tannins, are predominantly localised in the seed coat. The varietal difference observed in whole seeds disappeared after dehulling, indicating that the cotyledons of both varieties possess similar phenolic profiles.

3.1.2. Total Flavonoid Content

Figure 1 shows the variation in TFC among the different seeds. We observed no significant differences between whole and decorticated seeds, either within the same cultivar or between cultivars. Different samples (LNWS, LNDS, LBWS, and LBDS) presented similar amounts (around 0.5 mg catechin/g DW).

3.1.3. Total Tannin Content

The analysis of **Figure 1** indicated that the decortication slightly affected the tannin content in different faba bean seeds. In addition, a difference in TTC between cultivars was detected. LNWS displayed 0.22 mg CE/g DW, whereas LBWS contained approximately 0.33 mg CE/g DW. Although TTC decreased following decortication (18–24% reduction, depending on cultivar), this represented only a 0.04–0.08 mg CE/g DW decrease in absolute terms. Given that tannins constituted only 18.4–26.9% of total phenolics in whole seeds, this modest reduction was insufficient to cause a statistically detectable decrease in TPC ($p > 0.05$).

3.2. Effect of Decortication on Antioxidant Activities

3.2.1. DPPH Radical Scavenging Activity

The neutralizing ability of methanolic faba bean extracts toward the DPPH free radical was expressed as the half-maximal inhibitory concentration (IC_{50}). Samples demonstrating the strongest radical-neutralising capacity showed the smallest optical density readings. The seed coat removal was accompanied by an improvement in the scavenging activities for Local Beja and Local Nabeul seeds by 35% and 25%, respectively (**Figure 2**). Among all samples, LNDS exhibited the strongest DPPH radical scavenging activity, as indicated by its lowest IC_{50} value (13.75 µg/mL). Conversely, LBWS showed the weakest activity, with the highest IC_{50} value (108.0 µg/mL). The concentration inhibition curve for the DPPH assay showed good linearity ($R^2 = 0.9944$) over the tested concentration range.

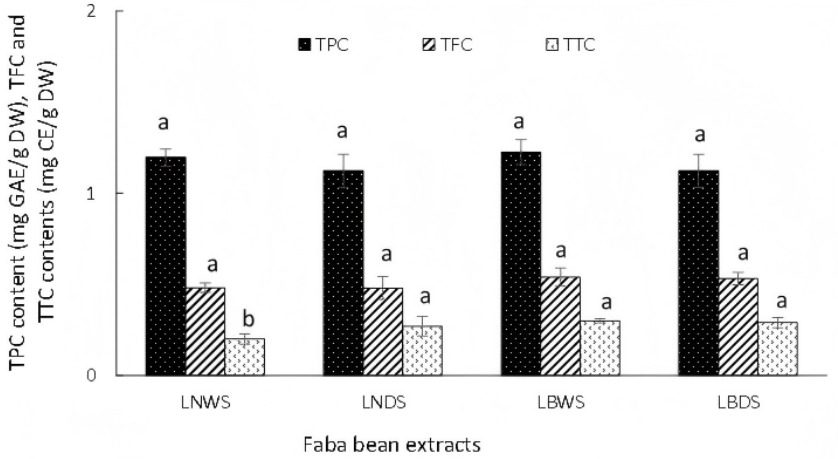


Figure 1. Total phenolic content (TPC; mg GAE/g DW), total flavonoid content (TFC; mg CE/g DW), and total tannin content (TTC; mg CE/g DW) of faba bean seed extracts from Local Nabeul Whole Seeds (LNWS), Local Beja Whole Seeds (LBWS), Local Nabeul Decorticated Seeds (LNDS), and Local Beja Decorticated Seeds (LBDS).

Note: Values are expressed as mean ± standard deviation (SD) of three independent replicates (n = 3). Different lowercase letters (a, b, c) above the bars indicate statistically significant differences between samples for each parameter, as determined by one-way ANOVA followed by Duncan's multiple range test ($p < 0.05$).

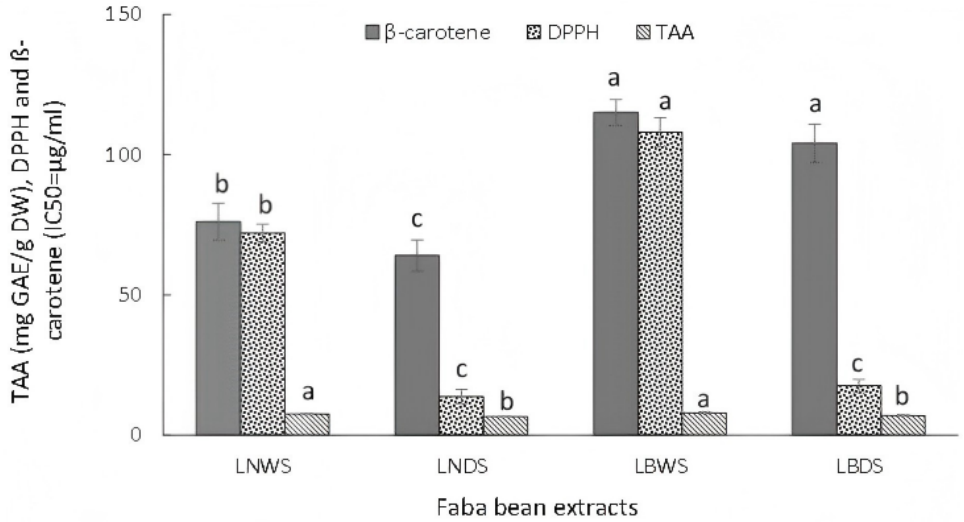


Figure 2. Total antioxidant ability (TAA; mg GAE/g DW), DPPH radical scavenging activity (IC_{50}; µg/mL), and β-carotene bleaching inhibition activity (IC_{50}; µg/mL) of faba bean seed extracts from Local Nabeul Whole Seeds (LNWS), Local Beja Whole Seeds (LBWS), Local Nabeul Decorticated Seeds (LNDS), and Local Beja Decorticated Seeds (LBDS).

Note: Values are expressed as mean ± standard deviation (SD) of three independent replicates (n = 3). Different lowercase letters (a, b, c) above the bars indicate statistically significant differences between samples for each parameter, as determined by one-way ANOVA followed by Duncan's multiple range test ($p < 0.05$). Bars sharing the same letter are not significantly different ($p > 0.05$). For IC_{50} values, lower values indicate higher antioxidant activity.

3.2.2. β-Carotene Bleaching Inhibition Activity

The β-carotene bleaching inhibition activities of the different methanolic extracts are presented in **Figure 2**. The whole seed LNWS extract (IC_{50} = 76 µg/mL) exhibited stronger β-carotene bleaching inhibition activity compared to LBWS (IC_{50} = 114 µg/mL), indicating that the Nabeul cultivar possesses greater lipophilic antioxidant capacity in its hulls. Additionally, decorticated seeds of the Nabeul cultivar (LNDS) displayed notable activity (IC_{50} = 60 µg/mL), whereas LBDS showed lower antioxidant activity (IC_{50} = 105 µg/mL).

3.2.3. Total Antioxidant Ability

The TAA values of whole and decorticated faba bean seeds are summarized in **Figure 2**. The TAA of LNWS and LBWS were 7.61 and 7.94 mg GAE/g DW, respectively. Decortication resulted in a slight decrease compared with the whole seed samples (6.55 and 7.01 mg GAE/g DW, respectively).

3.3. Multivariate Analysis of Phenolic Compounds and Antioxidant Activities

3.3.1. Identification of Discriminating Compounds of Faba Bean Extracts

PCA was conducted to compare the two legume cultivars, uncover relationships between compound families and variety types, visualize sample clustering and divergence, and detect specific metabolites in each cultivar under both treatment conditions (**Figure 3**).

Figure 3 displays the principal component biplot for *Vicia faba* samples. The initial two principal axes accounted for 94.73% of the overall variance, with PC1 and PC2 explaining 60.95% and 33.78% of the dataset variability, in that order. PC1 was strongly associated with TAA and DPPH radical scavenging activity, and PC2 was primarily determined by TTC (**Figure 3a**). According to **Table 1**, TAA, DPPH, and TTC were the key factors defining PC1 and PC2 with their loading values of 22.96, 21.15, and 38.38, respectively. As shown in **Figure 3b**, the four extracts were classified into three groups. Group 1 was formed by LBWS, occupying the top-right portion of the principal component space and varying proportionally with both axes. This group exhibited high TTC. Group 2 included LNDS and LBDS, located in the upper-left quadrant of the principal component space, showing negative loading on PC1 and positive loading on PC2. This group presented low antioxidant activity. Finally, LNWS was placed within the negative half-space of both axes and was characterized by low TTC.

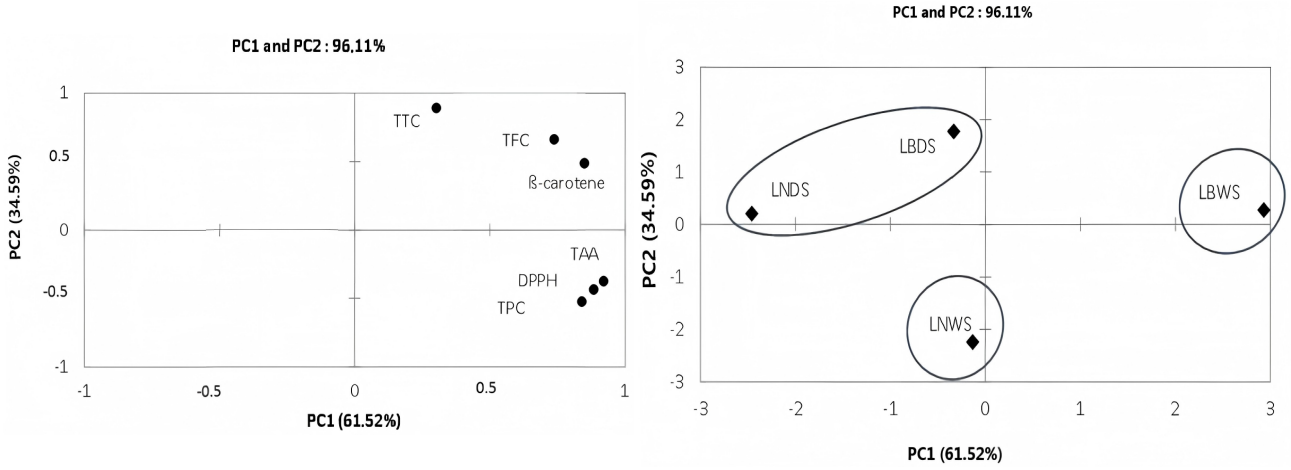
3.3.2. Correlations among the Phenolic Constituents and Antioxidant Activities

Table 2 summarizes the Pearson's correlation coefficients among all evaluated parameters. We observed strong

positive correlations between DPPH scavenging activity and TPC (r = 0.995), β-carotene bleaching inhibition and TFC (r = 0.977), and TAA and DPPH scavenging activity (r = 0.959). Further strong correlations were detected between TTC and TFC (r = 0.765), TAA and TFC (r = 0.446), and TTC and β-carotene inhibition (r = 0.624). Nevertheless, weak inverse correlations were observed between TAA and TTC (r = −0.093) and between DPPH scavenging activity and TTC (r = −0.06).

3.3.3. Hierarchical Cluster Analysis (HCA)

Hierarchical cluster analysis was performed on all acquired data to evaluate the impact of seed coat removal on the discrimination of whole and decorticated seeds from different faba bean cultivars (**Figure 4**). The generated heatmap reveals three main clusters: C1 includes LBDS and LNDS; C2 comprises LBWS; and C3 contains only LNWS. The colour matrix displays data through colour coding: red indicates the lowest values, black indicates intermediate values, and green indicates the highest values.



(a) **(b)**

Figure 3. Principal component analysis (PCA) biplots showing (**a**) the contribution of phenolic compounds and antioxidant activities to the variation (loading plot) and (**b**) the grouping of whole and decorticated faba bean samples according to PC1 and PC2 axes (score plot). PC1 and PC2 explained 60.95% and 33.78% of the total variance, respectively (cumulative variance: 94.73%).
Note: Abbreviations: TPC = total phenolic content; TFC = total flavonoid content; TTC = total tannin content; TAA = total antioxidant ability; DPPH = DPPH radical scavenging activity; β-carotene = β-carotene bleaching inhibition activity; LNWS = Local Nabeul Whole Seeds; LBWS = Local Beja Whole Seeds; LNDS = Local Nabeul Decorticated Seeds; LBDS = Local Beja Decorticated Seeds.

Table 1. Contribution (%) of phenolic compounds and antioxidant activities to the definition of principal components PC1 and PC2.

	PC1	PC2
TPC	19.097	13.251
TFC	14.749	21.012
TTC	2.468	38.382*
DPPH	21.154	9.130
TAA	22.962*	6.793
β-carotene	19.570	11.432

Note: Abbreviations: TPC = total phenolic content; TFC = total flavonoid content; TTC = total tannin content; DPPH = DPPH radical scavenging activity; TAA = total antioxidant ability; β-carotene = β-carotene bleaching inhibition activity. * Values marked with asterisks indicate the highest contributing variables for each principal component.

Table 2. Pearson's correlation coefficients (r) among the chemical classes of whole and decorticated faba bean seeds.

Variables	TPC	TFC	TTC	DPPH	TAA	β-Carotene
TPC	1					
TFC	0.253	1				
TTC	−0.167	0.765	1			
DPPH	0.995	0.340	−0.064	1		
TAA	0.955	0.446	−0.093	0.959	1	
β-carotene	0.430	0.977	0.624	0.504	0.621	1

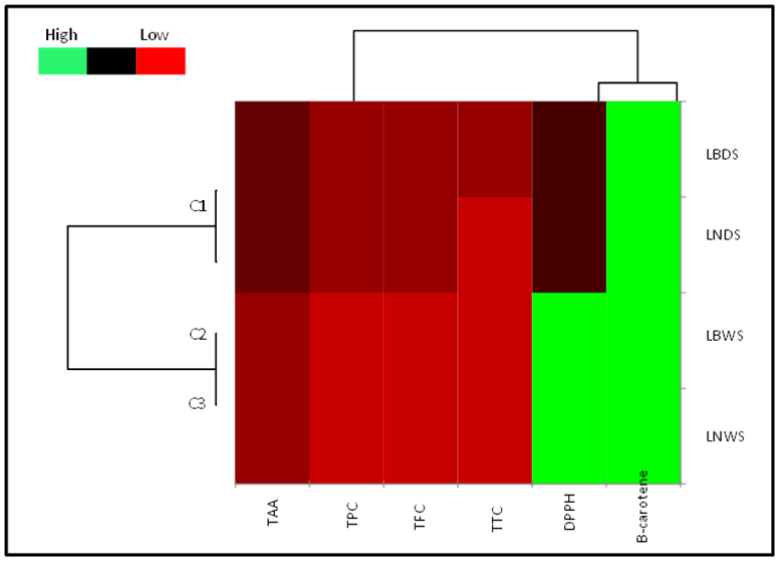


Figure 4. Hierarchical cluster analysis (HCA) heatmap based on Euclidean distances and Ward's linkage method, showing the distribution of phenolic compounds and antioxidant activities across faba bean samples.
Note: The colour scale represents the normalized values of each parameter: red indicates the lowest values, black indicates intermediate values, and green indicates the highest values. Three distinct clusters (C1, C2, and C3) were identified based on the similarity of their bioactive profiles.

4. Discussion

The present study elucidates the effects of decortication on the phenolic profile and antioxidant activities of two Tunisian faba bean (*Vicia faba* L.) cultivars. The findings align with the broader understanding that processing significantly modulates the bioactive compound composition and resultant health-promoting properties of pulses [13]. Contrary to initial expectations, the removal of the seed coat did not lead to a severe reduction in TPC or TFC. This suggests that a substantial proportion of these compounds in the studied local cultivars may be distributed within the cotyledons, not only concentrated in the hulls. Similar retention of phenolic compounds post-dehulling has been observed in other legume studies, where the distribution varies by species and genotype [5].

The decrease in TTC following decortication confirms that condensed tannins are predominantly located in the seed coat, consistent with reports showing tannin levels of 5.8–7.6% in hulls versus 0.56–0.65% in cotyledons [19,20]. The cultivar-dependent variation observed (18–24% reduction) aligns with findings that dehulling reduced tannin content by 1.70–66.99% across 22 cultivars [21]. This reduction is nutritionally significant, as tannins complex with dietary proteins, reducing their digestibility.

The relationship between TPC and TTC in this study reflects the quantitative contribution of tannins to the overall phenolic pool. In the studied cultivars, tannins represented a minority fraction (18–27%) of total phenolics, consistent with findings that condensed tannins account for 15–35% of total phenolics in faba beans depending on cultivar and growing conditions [22]. Therefore, decortication-induced removal of hull tannins did not substantially alter TPC.

Recent research evaluating 68 faba bean accessions demonstrated substantial genetic diversity in phenolic and tannin contents, with total tannin showing particularly high variation (CV > 37%). This supports our finding that cultivar origin (Nabeul vs. Beja) significantly influences TTC profiles and reinforces the importance of genotype selection when evaluating the effects of decortication [23]. A study on dry fractionation of Canadian faba bean genotypes demonstrated that tannin content varied considerably among genotypes (0.01–0.66%) and influenced processing outcomes [24]. This underscores the importance of genotype-specific approaches to processing and validates our observation that cultivar selection is critical when evaluating decortication effects on bioactive profiles.

The most remarkable finding was the significant improvement in DPPH radical-scavenging activity (25–35% lower IC_{50}) after decortication. This phenomenon, where phenolic content remains stable but antioxidant capacity increases, can be explained by the nature of the seed coat matrix. The hull contains high levels of tannins and other polymeric phenolics that may act as pro-oxidants or form

complexes with other antioxidant molecules, thereby masking or inhibiting their free radical scavenging potential in raw extracts[7]. Removing the hull likely eliminates this interference, allowing for a more efficient expression of the antioxidant activity from the cotyledon-derived phenolics. This highlights that total phenolic content alone is an insufficient predictor of bioactivity, and the specific composition and matrix interactions are critical[9]. Conversely, the β-carotene bleaching assay and total antioxidant ability (TAA) yielded different trends. The varietal difference was pronounced in the β-carotene test, and decortication did not yield a uniform improvement. This assay measures the inhibition of lipid peroxidation, a mechanism in which lipophilic antioxidants like carotenoids and tocopherols play a major role. The results suggest that decortication may have a limited or variable effect on the profile of these specific antioxidants, which could be differentially concentrated between the hull and cotyledon. Previous research confirmed that faba bean hulls exhibit higher antioxidant activity than cotyledons[25], while other studies demonstrated that dehulling effects are highly cultivar-dependent, with some genotypes showing increased bioactivity and others showing significant losses[21]. Therefore, the decision to decorticate faba beans must consider both the specific antioxidant compounds under investigation and the genetic background of the cultivar[23].

The application of multivariate analysis powerfully clarified these relationships. The Principal Component Analysis (PCA) successfully discriminated the samples, identifying TTC as the primary variable separating the Local Beja Whole Seeds (LBWS) from others. This aligns with the concept that tannin content is a key chemotaxonomic marker distinguishing faba bean cultivars[19,20]. The strong positive correlation between DPPH radical scavenging activity and TPC ($r = 0.995$) confirms that phenolics are the principal contributors to this radical scavenging mechanism in faba beans. The hierarchical clustering visually confirmed that decorticated samples (LNDS, LBDS) clustered together, distinct from their whole-seed counterparts, demonstrating that processing can dominate cultivar-based similarities in functional property profiles[2,14].

These findings have direct implications for food processing. Decortication is aimed at improving sensory attributes by reducing bitterness and volatile off-flavors of certain legumes[26]. For the studied cultivars, it may even enhance specific radical-scavenging activities beneficial for oxidative stability in food products. Furthermore, the retained antimicrobial potential of phenolic compounds, even after decortication[11,12], suggests that processed faba bean flour could serve as a dual-functional ingredient, contributing to both preservation and health benefits[27]. Future research should investigate the specific phenolic profiles (e.g., using HPLC) of hulls versus cotyledons for these cultivars and correlate them with *in vitro* and *in vivo* bioactivities to fully unlock their potential in nutraceutical and food applications.

5. Conclusions

In conclusion, the decortication of faba bean seeds influenced their bioactive profile and functional properties. While the process did not reduce total phenolic or flavonoid content, it significantly altered antioxidant activities. The improvement of DPPH radical scavenging capacity post-dehulling suggests that the removal of seed coat components may improve the extract's efficiency in neutralizing specific free radicals, possibly by reducing interference from compounds like tannins. Conversely, the slight reduction in total antioxidant ability (TAA) suggests the loss of some pro-oxidant or metal-reducing compounds concentrated in the hull. The study showed the strong influence of genetic origin, as evidenced by the distinct phenolic, particularly tannin, profiles of the Nabeul and Beja cultivars, which dictated their clustering in multivariate analyses. The significant correlations, especially between DPPH activity and total phenolics, affirm that phenolic compounds are key contributors to the antioxidant mechanisms in these seeds. Therefore, the decision to decorticate faba beans should be cultivar-specific and application-driven, balancing the reduction of antinutritional condensed tannins and bitter volatiles against the preservation of health-promoting cotyledon-derived phenolics (flavonoids and phenolic acids) and lipophilic antioxidants (carotenoids, tocopherols). Notably, decortication paradoxically enhanced DPPH scavenging activity by 25–35% through the removal of interfering tannins. These findings provide a valuable framework for the food industry to select and process faba bean cultivars for specific nutritional or functional ingredient applications.

Author Contributions

I.R. conceived and designed the experiment, analyzed the data, and wrote the paper. M.B. performed the experiment. R.N.O. reviewed the draft. H.M. supervised the research. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

All data generated were presented in the article.

Conflicts of Interest

The authors declare no conflict of interest.

AI Use Statement

During the preparation of this work, the authors used DeepSeek to improve the grammar and language clarity of the manuscript. No original text, data, or scientific insights were generated by the AI tool. After using this service, the authors reviewed and edited all suggestions manually and take full responsibility for the final content of the publication.

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