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From Fresh to Dried Lavender Flower: Changes in Phytochemical Profile According to Drying Method

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Abstract: *Lavandula angustifolia* Mill. is a part of the Lamiaceae family, which includes aromatic plants used in perfumery, manufactory, food, ornamental, and medicinal sectors. Both fresh and dried lavender flowers can be exploited in different ways; however, post-harvest treatments such as drying processes can help maintain the flowers' properties for a longer period. This study analyzed fresh (F) and dried lavender flower ultrasound-assisted extracts, comparing two different drying methods, i.e., heat-pump drying (HP) and hot-air drying (HA), to assess potential differences in their effect on the phytochemical composition (total phenolic content, total anthocyanin content, and phenolic profile) and antioxidant activity (FRAP, DPPH, and ABTS assays) of flowers, focusing on three lavender selections from north-western Alps (i.e., Susa, Stura, and Tanaro). Results showed that HP-dried flowers are to be preferred over HA-dried flowers, as they contain +66.73% of phenolics and +62.2% of anthocyanins, and they have higher antioxidant activity (from 60.32% to 284.3% more according to the assay). HP-dried flowers, particularly those from the Tanaro selection, showed also higher values in the relative antioxidant capacity index (RACI) and the global antioxidant score (GAS), ranking together with the fresh flowers. Nine bioactive compounds out of thirteen were detected by means of HPLC, seven in F (caffeic acid, hyperoside, quercetin, ellagic acid, catechin, epicatechin, and dehydroascorbic acid), four in HA (ferulic acid, hyperoside, quercitrin, and epicatechin), and two in HP (caffeic acid and hyperoside). The higher temperatures used in HA probably promoted oxidative and biochemical reactions that led to the presence and increase in these compounds. However, many other phenolic compounds may contribute to the antioxidant power of lavender extracts. Overall, HP resulted in an effective and sustainable method for drying lavender flowers and may have interesting applications to obtain final products richer in bioactive compounds and antioxidant activity to be used in the functional food industry.

Keywords: lavender; ultrasound-assisted extraction; hot-air drying; heat-pump drying; phenolics; antioxidant activity



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1. Introduction

In recent years, knowledge of the beneficial properties of plants, and especially edible flowers, has increased, leading to a rise in their consumption, especially as natural food colorants or additives [1–3]. Recent studies highlighted their health benefits [4–9] due to their composition rich in vitamins and phytochemicals (carotenoids or phenolics) with antioxidant properties [10–17].

Within the genus *Lavandula*, which includes about 50 species of aromatic evergreen shrubs [17], lavender (*Lavandula angustifolia* Mill.) can be found. Lavender is used in perfumery, cosmetic, and food manufacturing [18–21], in addition to ornamental purposes [17–21]. Actually, fresh and dried lavender flowers are employed in culinary preparations to decorate or flavor bakery products, jellies, candies, infusions, and sauces [18,22–25].

Lavender flowers can be freshly used; however, post-harvest processing can prolong their shelf life, preserving their nutraceutical characteristics [7,25]. Actually, when stored

at 4 °C, *L. angustifolia* showed marketable conditions up to day 7, increasing its total phenolic content and, therefore, antioxidant activity [16]. More specifically, drying is an essential process to reduce moisture content and inhibit enzymatic degradation, thus preventing the growth of microorganisms and reducing weight, enabling easier processing and storage [7,26]. Many different drying methods are applied to foodstuff, i.e., natural drying (i.e., air drying, shade drying, sun drying) or artificial drying (i.e., freeze drying, vacuum–microwave drying, hot-air drying, etc.) [7,23,27]. However, excessively long drying periods or heat application to edible flowers may damage their quality due to some bioactive compounds with antioxidant activity (i.e., phenolic molecules) that could degrade [7,23,25,27–30]. To overcome this issue, the heat-pump method has been adopted to dry products at lower temperatures maintaining their color, aroma, and phytochemical qualities for a longer time than naturally or hot-air-dried products [27,31,32]. Moreover, it is an energy-efficient technology since it reduces the time of the drying process, thus consuming lower amounts of energy than hot-air-drying methods. In a previous study, we assessed this drying technology to obtain dried lavender flowers for decoction production, obtaining higher results than hot-air-dried flowers' decoctions [33].

Among the various extraction methods (maceration, decoction, infusion, etc.), ultrasound-assisted extraction (UAE) is an alternative green technique suitable for edible flowers since it promotes the disruption of cell walls, reduces the thermal degeneration of secondary metabolites, and reduces the extraction time, thus releasing the phytochemicals without damaging them [34–36]. UAE has already been used to obtain phytoextracts from edible flowers, i.e., pansies, begonias, lavender, rosa, and saffron [13,15,16,33,37]. Actually, this extraction method operates at room temperature, thus not damaging the phytochemicals [38]. Based on the literature, ultrasound extracts of *L. angustifolia* flowers obtained from different drying methods have not been compared to fresh flower extracts. Thus, this work aimed to analyze the ultrasound extracts of three local selections of lavender flowers, both fresh and dried (hot-air dried and heat-pump dried), in order to compare their amount of bioactive compounds and to establish a more effective drying method. This could be useful for the food industry, for the extraction of natural additives, or to create functional preparations using new green technologies to sustainably extract bioactive molecules.

2. Materials and Methods

2.1. Plant Material

Three genotypic selections of *L. angustifolia* flowers originating from different latitudinal ranges of distribution in the wild (Northwestern Italian Alps [22]) were cultivated since 2017 in the DISAFA's catalog field, in Grugliasco (TO) (System WGS84 latitude: 45.067176; longitude: 7.591896). Two hundred g of fresh flowers (F) were harvested per selection in spring 2019, in full bloom; one part was directly ground in liquid nitrogen and stored at –80 °C, while the other was dried; analysis followed.

2.2. Drying Method

Two different techniques, i.e., hot-air drying and heat-pump drying, were used on dry lavender flowers.

Concerning hot-air drying (HA), aluminum trays were used to contain lavender flowers and dry them for 24 h at 50 °C in a laboratory stove (VWR Stoves, DRY-Line natural convection, DL 53 DL). Dried flowers were then stored in glass jars at room temperature.

Regarding heat-pump drying (HP), refrigeration equipment cooling and dehydrating the air (NWT-5, North West Technology, Boves—CN, Italy, 0.45 kW, 50 Hz) was used to dry lavender flowers on perforated trays, put on top of each other. A constant humidity rate was set at 5–6%. Flowers were dried for 24 h at 22 ± 2 °C, ground with mortar and pestle using liquid nitrogen, and stored at –80 °C until ultrasound-assisted extraction.

The duration of the entire process was defined for both drying methods by assessing the flowers' weight at regular intervals until it remained constant (i.e., about 40% of the initial weight).

2.3. Ultrasound-Assisted Extraction (UAE)

One gram of lavender powder obtained from fresh and both drying methods was extracted with 50 mL of ultrapure water using an ultrasound extractor (Sarl Reus, Drap, France) at 23 kHz for 15 min [13,14]. The obtained solution was filtered at first with one-layered filter paper (Whatman No. 1, Maidstone, UK), then with a 0.45 µm PVDF syringe filter (CPS Analytica, Milano, Italy). The extracts were stored at −20 °C until further analysis.

2.4. Bioactive Compounds

2.4.1. Total Phenolic Content, Total Anthocyanin Content, and Antioxidant Activity

Total phenolic content (TPC), total anthocyanin content (TAC), and antioxidant activity (AOA) of fresh and dried lavender flowers' extracts were evaluated via colorimetric methods, using a Cary 60 UV-Vis spectrophotometer (Agilent, Santa Clara, CA, USA), as reported in previous studies [13,14,16,39–45].

Fresh flower values were converted into dry matter (DM) to allow comparisons with dry flower results and with the literature.

TPC was analyzed following the Folin–Ciocalteu method [13,14,39,40], and the results were expressed as milligrams of gallic acid equivalents per 100 g of dry matter (mg GAE/100 g DM).

TAC was estimated by the pH differential method, as described in the literature [13,16,41]. The results were presented in milligrams of cyanidin-3-O-glucoside per 100 g (mg C3G/100 g DM).

AOA was analyzed using three assays: the ferric reducing antioxidant power (FRAP) method [13,14,42], the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay [14,43], and the 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulfonic acid (ABTS) assay [14,44,45]. The FRAP test values were expressed as millimoles of ferrous iron equivalents per kilogram of dry matter (mmol Fe²⁺/kg DM). The DPPH and ABTS values were expressed as micro moles of Trolox Equivalents per 1 g of dry matter (µmol TE/g DM).

2.4.2. Phenolic Profile

The chromatographic analysis on the fresh and dried lavender flowers' extracts was conducted using high-performance liquid chromatography (HPLC) with Diode Array Detection (DAD) (Agilent 1200, Agilent Technologies, Santa Clara, CA, USA), and a Kinetex C18 column (4.6 × 150 mm, 5 mm, Phenomenex, Torrance, CA, USA) for compound separation, with different mobile phases, according to previously validated protocols (Table 1) [14,46–48]. Compounds were identified by comparing their retention times and UV spectra with those of the analytical standards with the same chromatographic conditions. The determined compounds were phenolic acids (cinnamic acids: caffeic, chlorogenic, coumaric, and ferulic acids; benzoic acids: ellagic and gallic acids); flavonols (hyperoside, isoquercitrin, quercetin, and rutin); and flavanols (catechin and epicatechin). Results were expressed as mg/100 g DM.

2.5. Statistical Analysis

Data from TPC, TAC, and AOA (FRAP, DPPH, and ABTS assays) were first tested for the homogeneity of variances (Levene test, $p \geq 0.05$). Raw data from FRAP, DPPH, and ABTS were transformed into standard scores and averaged to obtain the Relative Antioxidant Capacity Index (RACI) [49] and the Global Antioxidant Score (GAS) [50]. The RACI standard score was calculated by using the following equation:

$$(x - \mu) / \sigma$$

where x is the single raw data, μ is the average value of all data, and σ is the standard deviation of all data. The GAS T-score was calculated using the following equation:

$$\text{T-score} = (X - \text{min}) / (\text{max} - \text{min})$$

where min and max represent the smallest and the largest values of variable X among the investigated extracts.

A two-way ANOVA was then performed to examine the influence of the three lavender selections, the two drying methods, and their reciprocal interactions on the bioactive compounds content. Means were separated according to the Ryan–Einot–Gabriel–Welsch F post hoc test (REGW-F, $p \leq 0.05$). Moreover, a one-way ANOVA test was performed to note differences between the selections and the processing methods. When the ANOVA assumptions were not expected, data were analyzed with the Kruskal–Wallis ($p < 0.05$) via stepwise comparison. Ryan–Einot–Gabriel–Welsch Studentized Range Q (REGW-Q) post hoc test ($p \leq 0.05$) was performed on HPLC values. These statistical analyses were computed by SPSS software (version 26.0, SPSS Inc., Chicago, IL, USA).

Table 1. Main characteristics of the chromatographic protocols adopted. (LOD = Limit of Detection; LOQ = Limit of Quantification).

Classes of Compounds	Standard	Retention Time (t _R) (min)	Mobile Phase	Elution Conditions	Wavelength (nm)	LOD (mg L ⁻¹)	LOQ (mg L ⁻¹)
Cinnamic acids	Caffeic acid	4.54	A: 10 mM KH ₂ PO ₄ /H ₃ PO ₄ pH = 2.8 B: CH ₃ CN	5% B to 21% B in 17 min + 21% B in 3 min (2 min conditioning time); flow: 1.5 mL min ⁻¹	330	0.305	1.016
	Chlorogenic acid	3.89				0.940	3.134
	Coumaric acid	6.74				2.907	9.690
	Ferulic acid	7.99				1.245	4.150
Flavonols	Hyperoside	10.89	A: H ₂ O/CH ₃ OH/HCOOH (5:95:0.1 v/v/v), pH = 2.5 B: CH ₃ OH/HCOOH (100:0.1 v/v)	3% B to 85% B in 22 min + 85% B in 1 min (2 min conditioning time); flow: 0.6 mL min ⁻¹	280	3.372	11.241
	Isoquercitrin	11.24				0.252	0.840
	Quercetin	17.67				4.055	13.518
	Quercitrin	13.28				5.456	18.187
Benzoic acids	Rutin	12.95	A: H ₂ O/CH ₃ OH/HCOOH (5:95:0.1 v/v/v), pH = 2.5 B: CH ₃ OH/HCOOH (100:0.1 v/v)	3% B to 85% B in 22 min + 85% B in 1 min (2 min conditioning time); flow: 0.6 mL min ⁻¹	280	2.937	9.790
	Ellagic acid	18.65				0.611	2.035
	Gallic acid	4.26				0.435	1.451
Catechins	Catechin	10.31	A: H ₂ O/CH ₃ OH/HCOOH (5:95:0.1 v/v/v), pH = 2.5 B: CH ₃ OH/HCOOH (100:0.1 v/v)	3% B to 85% B in 22 min + 85% B in 1 min (2 min conditioning time); flow: 0.6 mL min ⁻¹	280	2.343	7.809
	Epicatechin	14.3				0.763	2.543

3. Results and Discussion

3.1. Total Phenolic Content, Total Anthocyanin Content, and Antioxidant Activity

Three different lavender selections were examined before and after drying in order to analyze their bioactive compound content and compare two different drying methods, to understand modification dynamics in bioactive compounds during the drying process, and to select the most efficient drying method.

TPC, TAC, and AOA (FRAP, DPPH, and ABTS assays) of fresh and dried *L. angustifolia* flowers' extracts are reported in Table 2.

Regardless of the processing method, lavender flowers from the three selections did not show differences in TPC (from 662.29 to 781.01 mg GAE/100 g DM), DPPH (from 26.82 to 34.95 μ mol TE/g DM), and ABTS (from 29.08 to 33.00 μ mol TE/g DM), while they differed in TAC and FRAP assay (Table 2). Tanaro always showed the highest values (95.75 mg C3G/100 g DM and 262.06 mmol Fe²⁺/kg DM, respectively), confirming the results reported by Demasi and colleagues [22] for the lavender selection from Mediterranean ecological conditions on volatile organic compounds and essential oils. It was followed by Stura for TAC (66.99 mg C3G/100 g DM) and by both Susa and Stura for FRAP (210.41 and 198.44 mmol Fe²⁺/kg DM, respectively).

Regarding the processing methods (whether flowers were analyzed fresh, hot-air dried, or heat-pump dried), significant differences were found in all the analyzed parameters. UAE extracts obtained from fresh flowers outperformed those obtained from dried flowers in all the studied parameters, with the exception of TAC and FRAP where HP showed the highest values, similar to what was observed on decoctions of HP dried flowers [33]. Extracts obtained from HP processing showed higher values than those obtained from HA.

Table 2. Total phenolic content (TPC), total anthocyanin content (TAC), and antioxidant activity (FRAP, DPPH, and ABTS assays) in fresh and dried *L. angustifolia* flowers ultrasound extracts. Two-way ANOVA was used to compare the three selections (values averaged by the three processing methods) and the three processing methods (values averaged by the three selections). Data are presented as mean values. F = Fresh; HA = Hot-Air drying; HP = Heat-Pump drying.

SELECTION (A)	TPC (mg GAE/100 g DM)	TAC (mg C3G/100 g DM)	FRAP (mmol Fe ²⁺ /kg DM)	DPPH (μmol TE/g DM)	ABTS (μmol TE/g DM)
Susa	662.29	44.70	210.41	34.95	29.08
Stura	777.56	66.99	198.44	26.82	29.30
Tanaro	781.01	95.75	262.06	27.49	33.00
<i>p</i>	ns	***	*	ns	ns
PROCESSING METHOD (B)	TPC (mg GAE/100 g DM)	TAC (mg C3G/100 g DM)	FRAP (mmol Fe ²⁺ /kg DM)	DPPH (μmol TE/g DM)	ABTS (μmol TE/g DM)
F	1268.43	12.51	286.63	47.36	44.81
HA	357.08	74.34	79.35	16.06	17.89
HP	595.35	120.59	304.93	25.84	28.68
<i>p</i>	***	***	***	***	***
INTERACTION	TPC	TAC	FRAP	DPPH	ABTS
A × B	***	***	<i>p</i> **	***	***

Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the REGWF post hoc test. The statistical relevance is provided (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = not significant).

TPC values varied from 1268.43 mg GAE/100 g DM in fresh flowers to 595.35 mg GAE/100 g DM in HP flowers and 357.08 mg GAE/100 g DM in HA flowers. TPC values of our HP-dried lavender extracts were higher also than those found by Radu and colleagues [51] in air-dried (40 °C) lavender extracts (329 mg GAE/100 g DM). These findings support data on the potential negative effect on the phenolic content caused by temperature already assessed in edible flowers [7]. A similar hypothesis is also advanced by Calín-Sánchez and colleagues [52], who analyzed some fruits, vegetables, and aromatic herbs, assessing different drying methods, among which are convective and microwave drying using hot air, and freeze drying and heat-pump drying using lower temperatures. Their results showed that TPC was reduced in *Aronia melanocarpa* (Michx.) Elliot with the use of hot-air-drying methods; conversely, TPC was preserved using lower temperatures [52]. In other studies on lavender [23,53], using different drying methods (freeze drying, hot-air drying, microwave drying) TPC values were higher than ours (from two to five times more); however, the authors used different extraction solutions (50% ethanol, ethanol/acetone/water (7/7/6 v/v/v)), probably more efficient in extracting the phenolic compounds.

Total anthocyanin content (TAC) showed a significantly neat separation among the processing methods, with HP having significantly higher values (120.59 mg C3G/100 g DM), followed by HA (74.34 mg C3G/100 g DM), and lastly by F (12.51 mg C3G/100 g DM).

Concerning antioxidant activity, fresh flowers showed the highest values in two assays (DPPH: 47.36 μmol TE/g DM; ABTS: 44.81 μmol TE/g DM), and a similarly high value as HP in the FRAP assay (286.63 mmol Fe²⁺/kg DM). Conversely, HA showed the lowest values in the three assays (FRAP: 79.35 mmol Fe²⁺/kg DM; DPPH: 16.06 μmol TE/g DM; ABTS: 17.89 μmol TE/g DM). Duda and colleagues [54], analyzing *L. angustifolia* flowers air dried at 22–27 °C, found similar FRAP values (from 65.2 to 73.3 mmol Fe²⁺/kg DM) than our HA processed flowers but lower than our HP processed flowers, even using for extraction the maceration technique in ethanol 70%, for a time of 96 h [54]. A similar pattern to TPC was highlighted for antioxidant activity. Both Calín-Sánchez and colleagues [52] and Kamiloglu and colleagues [55] found a general decrease in antioxidant activity in hot-air-drying methods, probably due to thermal degradation of bioactive compounds, while freeze drying and heat-pump drying allowed to maintain the antioxidant compounds in fruits, vegetables, and aromatic herbs.

Significant interactions among the lavender selections and the processing methods were found for all the studied parameters (Table 3).

Table 3. Differences in total phenolic content (TPC), total anthocyanin content (TAC), and antioxidant activity (FRAP, DPPH, and ABTS) in *L. angustifolia* according to the processing method (fresh, hot-air dried, and heat-pump dried). One-way ANOVA. Results are presented as the mean values. F = Fresh; HA = Hot-Air drying; HP = Heat-Pump drying.

SELECTION (A)	TPC (mg GAE/100 g DM)		TAC (mg C3G/100 g DM)		FRAP (mmol Fe ²⁺ /kg DM)		DPPH (μmol TE/g DM)		ABTS (μmol TE/g DM)	
F Susa	1133.36	abc	13.65	cd	260.55	ab	66.98	a	45.02	a
F Stura	1427.94	a	13.65	d	326.19	ab	39.30	ab	43.68	ab
F Tanaro	1244.00	ab	10.24	d	273.15	ab	35.81	ab	45.73	ab
HA Susa	597.53	cde	69.56	bc	77.10	cd	32.82	ab	29.68	bcd
HA Stura	220.74	f	32.08	cd	61.59	d	6.58	c	11.06	e
HA Tanaro	252.95	ef	121.40	ab	99.35	bcd	8.77	bc	12.93	cde
HP Susa	255.98	def	50.89	bcd	293.58	ab	5.06	c	12.54	de
HP Stura	684.00	bcd	155.25	a	207.54	abc	34.57	ab	33.16	abc
HP Tanaro	846.07	a–d	155.62	a	413.68	a	37.89	ab	40.34	abc
<i>p</i>	**		**		**		**		**	

Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the REGWF post hoc test. The statistical relevance is provided (** $p < 0.01$).

In general, F extracts showed the highest values or values as high as the highest in all the studied parameters, with the exception of TAC, where it obtained the lowest results. HP Stura and HP Tanaro also obtained similarly high values in all the analyzed parameters. HA Stura generally obtained the lowest results in all the analyzed parameters.

Relative Antioxidant Capacity Index (RACI) and Global Antioxidant Score (GAS) were calculated in an integrated approach to rank the antioxidant capacity of samples (Figure 1). As shown in Figure 1A, higher values of RACI have been ascribed to F Susa, HP Tanaro, F Stura, and F Tanaro. The same ranking was obtained with GAS (Figure 1B). GAS values were in the range between 0.0354 (HA Stura) and 0.7761 (F Susa). In the literature, data on RACI and GAS values are available only for vegetables [49] and a few medicinal and aromatic plants such as *Salvia rosmarinus* Spenn. [56,57]. Van Leeuw and colleagues [50] used GAS values to compare the antioxidant capacity of red wines. Both RACI and GAS values could represent a ranking tool of high-quality plant material useful for the food industry. Therefore, in the case of lavender drying materials, the Tanaro selection processed by heat-pump drying may be the best choice to obtain extracts rich in bioactive compounds.

3.2. Phenolic Profile

Processing altered the phenolic profile of lavender flowers (Figure 2). Cinnamic acids were present in F (50.93 mg/100 g DM), HA (187.11 mg/100 g DM), and HP (28.81 mg/100 g DM) dried flowers, as well as flavonols (F: 979.51 mg/100 g DM; HA: 142.20 mg/100 g DM; 67.96 mg/100 g DM). Catechins were present in F (2975 mg/100 g DM) and HA (1162.46 mg/100 g DM) dried flowers, while benzoic acids and vitamin C were present only in the fresh flowers (Figure 2).

Moreover, in *L. angustifolia* fresh flowers' extracts 7 out of 13 compounds were found, namely caffeic acid, hyperoside, quercetin, ellagic acid, catechin, epicatechin, and dehydroascorbic acid (Table 4). Hyperoside, quercetin, catechin, and epicatechin were previously detected in *L. angustifolia* fresh flowers by Demasi and colleagues [14] with similar or slightly lower values than those found in this study.

Conversely, regarding dried flowers' extracts, 4 out of 13 compounds were found for HA (ferulic acid, hyperoside, quercitrin, and epicatechin) and 2 out of 13 for HP (caffeic acid and hyperoside) (Table 4).

According to the processing method, different amounts of bioactive compounds were detected in the lavender UAE extracts (Table 4). Bioactive compounds indeed include unstable molecules, which can be affected by temperature, pH, or oxygen availability [58].

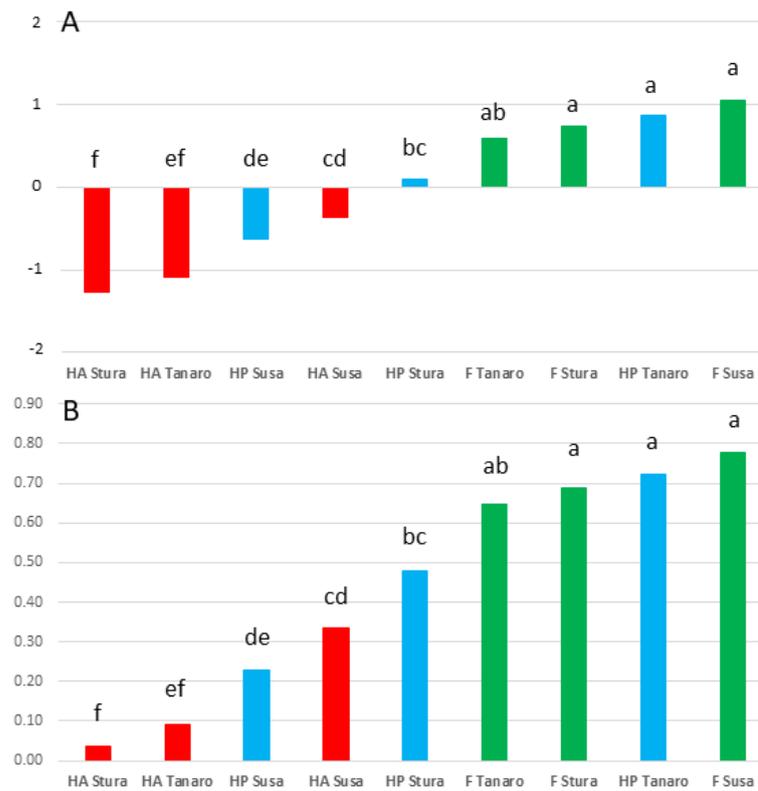


Figure 1. (A) Relative antioxidant capacity index (RACI) and (B) global antioxidant score (GAS) in different *L. angustifolia* selections (Susa, Stura, and Tanaro) according to the processing method (fresh, hot-air dried, and heat-pump dried). F = Fresh, green bars; HA = Hot-Air drying, red bars; HP = Heat-Pump drying, blue bars. Small case letters indicate significant differences between species, according to the REGWF post hoc test ($p < 0.05$).

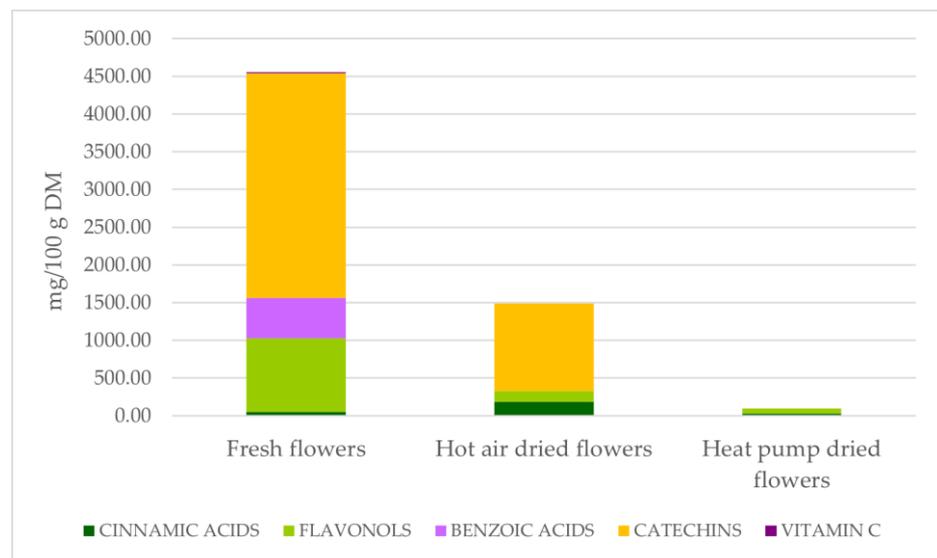


Figure 2. Phenolic classes (cinnamic acids, flavonols, benzoic acids, catechins, and vitamin C) content (mg/100 g DM) in the fresh, hot-air dried, and heat-pump dried lavender flowers' extracts.

Table 4. Differences in the total amount of bioactive compounds between the processing methods (hot-air dried, heat-pump dried, and fresh). One-way ANOVA. Data are presented as means of the three selections. F = Fresh; HA = Hot-Air dried; HP = Heat-Pump dried. Values are expressed in milligrams (mg) per 100 g DM.

Processing Method	Cinnamic Acids			Flavonols					
	Caffeic Acid		Ferulic Acid		Hyperoside	Quercetin		Quercitrin	
F	37.40	a	0.00	b	55.26	664.06	a	0.00	b
HA	0.00	c	62.37	a	36.71	0.00	b	10.69	a
HP	9.60	b	0.00	b	22.65	0.00	b	0.00	b
<i>p</i>		***		**	ns		**		**
Processing Method	Benzoic Acids		CATECHINS				Vitamin C		
	Ellagic Acid		Catechin		Epicatechin		Dehydroascorbic Acid		
F	393.39	a	1203.21	a	982.09	a	8.94	a	
HA	0.00	b	0.00	b	387.49	b	0.00	b	
HP	0.00	b	0.00	b	0.00	c	0.00	b	
<i>p</i>		**		**	**		***		

Mean values showing the same letter are not statistically different at $p \leq 0.05$, according to the REGWQ post hoc test. The statistical relevance is provided (** $p < 0.001$; * $p < 0.01$; ns = not significant).

Quercetin (664.06 mg/100 g DM), ellagic acid (393.39 mg/100 g DM), catechin (1203.21 mg/100 g DM), and dehydroascorbic acid (8.94 mg/100 g DM) were detected only in fresh flowers. Ferulic acid (62.37 mg/100 g DM) and quercitrin (10.69 mg/100 g DM), conversely, were found only in HA flowers. Regarding other compounds, caffeic acid ranged from 9.60 (HP) to 37.40 (F) mg/100 g DM; epicatechin ranged from 387.49 (HA) to 982.09 (F) mg/100 g DM. For hyperoside, no differences were detected.

In *L. angustifolia* air-dried (22–27 °C) flowers, Duda and colleagues [54] found lower values of caffeic acid (3.04–6.17 mg/100 g DM) and ferulic acid (2.40–4.20 mg/100 g DM) than our results. Furthermore, the authors did not detect the presence of hyperoside and quercitrin [54]. Conversely, Dobros and colleagues [53] found higher values of caffeic acid (170–247 mg/100 g DM) and ferulic acid (379–764 mg/100 g DM). These higher results may be due to the different extraction solvents used (1:1 ethanol:water solution).

Heat-pump-dried extracts showed fewer bioactive compounds than hot-air-dried ones, although they showed higher TPC and antioxidant activity (FRAP, DPPH, and ABTS). This inconsistency may be explained by the presence of phenolic compounds in HA lavender extracts (ferulic acid, quercitrin, and epicatechin), possibly deriving from oxidative degradation or biochemical reactions, thus resulting higher than in HP extracts [59,60].

Typically, catechins are unstable compounds, and the decrease in their content (HA), or even their absence (HP), may be due to structural changes caused by different factors: degradation, oxidation, or epimerization caused by temperature, pH, or oxygen availability [58]. Epimerization, and therefore degradation, can happen at high temperatures, changing catechins in their corresponding isomers; oxidation can happen when there are high oxygen levels [58], as may be the case of a heat-pump drying system, where air flows continually through samples.

Moreover, HP extracts may have a higher content of bioactive molecules, which were not assessed in this study.

For example, rosmarinic acid was seen to be the main phenolic acid (549 mg/100 g DM) in *L. angustifolia* sun-dried flowers' macerates [61]; similarly, rosmarinic acid (331–1082 mg/100 g DM) and morin (342–1270 mg/100 g DM) resulted to be among the most abundant compounds in ethanolic UAE extracts of different lavenders [53]. Some works also identified ellagic acid, coumarin, isoquercitrin (which were investigated in our study, but not detected), vanillin, and sinapic acid, but in smaller amounts, while chlorogenic acid and ferulic acid (also investigated but not detected in our study) were identified in trace amounts [53,54] in dried lavender flowers.

Therefore, the TPC, TAC, and antioxidant activity assays and the calculation of RACI and GAS may give a better general overview of the effects of the different drying methods. The analysis of extracts by HPLC gives information about the effect of drying methods

on specific molecules. Thus, the larger number of molecules assessed, the more complete information is obtained.

4. Conclusions

Fresh lavender flowers have interesting phytochemical characteristics and antioxidant properties for obtaining functional foods and beverages. Processing techniques are needed to prolong their utilization without compromising their characteristics. Hot-air drying and heat-pump drying showed to affect the content of bioactive compounds differently. Overall, HP extracts were characterized by higher values of TPC, TAC, and antioxidant activity. Optimization of the drying procedure may be useful to further improve the preservation of lavender bioactive compounds. In addition, heat-pump drying could be preferable, being more energy-efficient than hot-air drying because it reduces the drying time, thus considerably lowering energy costs.

Ultrasound-assisted extraction in water was found to be effective in extracting bioactive compounds with health benefits, thus it may be interesting to increase its use to develop lavender-based products with healthy beneficial effects. Moreover, the UAE technique could fasten the extraction time of bioactive compounds because it has a rapid running time with high efficiency, thus it could be more exploited in commercial applications.

Therefore, the combination of the heat-pump-drying method and the UAE technique may have interesting and sustainable applications to obtain both dried lavender flowers and extracts rich in bioactive compounds to be used in the food industry as natural additives or in new preparations.

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