Article

Heat Pump Drying of Lavender Flowers Leads to Decoctions Richer in Bioactive Compounds

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Abstract: *Lavandula angustifolia* Mill. (Lamiaceae family) is commonly exploited in different sectors, such as cosmetics, perfumery, and medicine because of its phytochemicals. More recently it has gained attention as an edible flower in the food and beverage industry. Post-harvest technologies can help producers to increase the functional beverages market, where there is a growing demand for new products rich in bioactive molecules with beneficial health effects. To maintain lavender flower properties, bioactive compounds have to be effectively preserved after harvesting and processing. This study compared an emerging technology, heat pump drying, with a classical drying approach, i.e., hot air drying, focusing on differences in the total phenolic content, the anthocyanin content, the phenolic profile, and in antioxidant activity of the dried lavender flowers. Three different Italian local lavender flower selections (i.e., Susa, Stura, and Tanaro) were analyzed by means of decoction extraction. Results showed that each one was better preserved in its phytochemical composition by heat-pump drying. Among the lavender selections, Stura and Tanaro showed the highest values for phenolics (2200.99 and 2176.35 mg GAE/100 g DW, respectively), anthocyanins (59.30 and 60.74 mg C3G/100 g DW respectively) and antioxidant activity, assessed through three assays (FRAP, DPPH, ABTS). Four bioactive compounds were detected by means of HPLC, three in the heat pump dried flowers' decoction (quercitrin, ellagic acid, gallic acid), and one in the hot air-dried flowers' decoction (epicatechin). Overall, heat pump drying allowed to obtain decoctions richer in bioactive compounds.

Keywords: lavender; decoction; hot air drying; cold drying; phenolics; anthocyanins; antioxidant activity

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1. Introduction

Nowadays the interest in edible flowers is growing, due to the recent studies on their nutraceutical properties, and thus to the major awareness of consumers [1–6]. Marigold flowers (*Calendula officinalis* L.), rose flowers (*Rosa* L. spp.), violets (*Viola odorata* L.), saffron (*Crocus sativus* L.), carnation (*Dianthus caryophillus* L.), dandelion (*Taraxacum officinale* Weber), and elder (*Sambucus nigra* L.) are a few examples of flowers which were consumed in ancient times and now they are reemerging in culinary preparations [2,7–11]. Flowers can be rich in phytochemicals, such as vitamins, carotenoids, or phenolics, with antioxidant properties beneficial to human health [11–15], which can be exploited in functional products, such as functional beverages [16]. Functional beverages, i.e., energy drinks, sports beverages, functional water, or herbal infusions (these latter have been widely used in popular medicine) are becoming popular in recent years. The demand for foods and beverages with beneficial properties is increasing, especially after the COVID-19 pandemic since consumers want to strengthen their body's defenses, thus functional beverages are growing in production [16]. Consequently, this has a positive impact on the market, which is looking for innovative plant-based beverage products [17]. Data from the Report on the Functional Beverage Market showed how the annual growth rate of this sector increased

by 4.6% in 2015, and four years later it was estimated at about USD 128,660 million. In addition, the market is estimated to increase to 6.96% by 2025 [16,17].

Many edible flowers can be found in the Lamiaceae family, i.e., lavender, sage, and rosemary are among the most popular [16,18].

Lavandula angustifolia Mill. (Lamiaceae family), commonly known as lavender or true lavender, is a small evergreen shrub [15,19], with aromatic compounds which lead to leaves and flowers being used for food, as well as for cosmetic, perfumery, and medicinal purposes [19–23].

Lavender flowers can be used in culinary preparations through different conservation methods, i.e., fresh, dried, or candied, to flavor and decorate bakery products, jellies, candies, and ice cream, but also as infusions with sedative and analgesic effects to relieve depression, headaches or anxiety problems [13,20,24,25].

The beneficial health effects of lavender are due to its chemical composition, rich in phytochemicals with bioactive properties, such as polyphenols, a group of secondary metabolites which have antioxidant activity, scavenging reactive oxygen species [12,26,27], thus lowering the risk of cardiovascular and chronic diseases. However, the phenolic composition of the true lavender flowers as well as the presence and concentration of other botanicals may vary widely among different genotypes and according to growing conditions and environment [19,22,27].

Lavender plants bloom for a few months a year. Drying can allow to extend shelf life and easily pack and transport the processed product [24,28], as it inhibits enzymatic degradation and avoids the growth of microorganisms, and reduces the weight and volume [3,28]. Some drying methods are already applied to edible flowers, such as hot-air drying, freeze drying, microwave drying, sun drying, etc. [3,24,29]. A recent approach proposed for water removal is a cold drying method, namely heat pump drying, that performs at low temperatures (about 22 °C) [30]. This technology could better preserve dried flowers' color, appearance, and aroma, and it can be used as an industrial drying system because of the possibility to control the drying conditions [29,31] and dry large amounts of plant material. Moreover, the heat pump drying system is considered more efficient in terms of energy consumption than hot air drying, since the drying time is considerably reduced [29]. This method is considered suitable for flowering plants due to the excellent maintenance of the quality properties of the dried flowers (color, smell, flavor, appearance), i.e., the *Rosa damascena* Mill. [29].

This work aimed to select the more effective drying method, between hot air drying and heat pump drying, for lavender flowers. To highlight differences in phytochemical composition and antioxidant activity, lavender decoctions from three Italian local selections of dried flowers were analyzed.

2. Materials and Methods

2.1. Plant Material

Flowered spikes from three selections of *Lavandula angustifolia* were harvested in the catalog field of the Department of Agricultural, Forest and Food Sciences, in Grugliasco (TO) (latitude: 45.06653008866393; longitude: 7.588967392687288), each selection having a different origin from the wild (latitude WGS84/32N. Susa: 4994234; Stura: 4914856; Tanaro: 4882887), from the highest to the lowest latitudinal range of distribution respectively [19]. About 200 g of fresh flowers were collected per selection in spring 2019, at full flowering, dried in the laboratory, and then analyzed.

2.2. Drying Methods

The drying of lavender flowered spikes was performed through two different drying methods, i.e., hot and heat pump drying.

For hot air drying, flowers were placed in aluminum trays and left for 24 h in a laboratory stove (VWR Stoves, DRY-Line natural convection, DL 53. Leuven, Belgium) which was heated to 50 °C. Dried flowers were then stored in glass pots at room temperature.

For heat pump drying, flowers were arranged in a single layer on perforated trays which were then placed on top of each other in refrigeration equipment that cools and dehydrates the air (NWT-5, North West Technology, Boves–CN, Italy, 0.45 kW, 50 Hz). The humidity inside the refrigeration system was maintained at 5–6%. Flowers were dried for 24 h at 22 ± 2 °C, and then stored in glass pots at room temperature.

For both drying methods, the duration of the whole process was defined by evaluating the weight of the flowers at regular intervals, until it remained constant.

2.3. Decoction

For each lavender selection, three biological replicates of dried flowers were finely ground with liquid nitrogen. Water extracts were prepared to simulate a homemade cup of hot beverage. The dried lavender powder (1 g) was extracted with 200 mL of water [32], heated to boiling, and allowed to boil for 5 min, as reported by Pereira and colleagues [33]. The resulting decoction was allowed to cool at room temperature for 20 min. The obtained solution was then filtered through a layer of filter paper (Whatman No. 1, Maidstone, UK), and afterwards with a 0.45 µm PVDF syringe filter (CPS Analitica, Milano, Italy). The extracts were maintained at −20 °C until further analysis.

2.4. Total Phenolic Content (TPC), Total Anthocyanin Content (TAC) and Antioxidant Activity

A Cary 60 UV–vis spectrophotometer (Agilent, Santa Clara, CA, USA) was used to evaluate the total phenolic content (TPC), the total anthocyanins content (TAC), and the antioxidant activity of dried lavender flowers' decoctions by colorimetric methods.

TPC was determined through the Folin–Ciocalteu colorimetric method [11,15,34,35]: a total of 200 µL of lavender flower decoction was mixed with 1000 µL of diluted (1:10) Folin–Ciocalteu's reagent. Samples were then left in the dark at room temperature for 10 min, then 800 µL of Na_2CO_3 (7.5%) were added. After 30 min in the dark at room temperature, absorbance was read at 765 nm, expressing results as mg gallic acid equivalents (GAE) per 100 g of dry weight (mg GAE/100 g DW).

The total anthocyanin content (TAC) was determined through the pH differential method using two buffer systems: hydrochloric acid/potassium chloride buffer at pH 1.0 (25 mM) and sodium acetate buffer at pH 4.5 (0.4 M), as described in the literature [8,11,36]. This method is based on the structural transformation of anthocyanins due to a change in pH (colored at pH 1.0 and colorless at pH 4.5). Briefly, 0.2 mL of each decoction was added in a 5 mL volumetric flask and made up to volume with the aqueous buffer at pH 1; the same was performed in a second 5 mL flask with the aqueous buffer at pH 4.5. After 20 min in the dark at room temperature, the solution was read against Milli-Q water as a blank at 510 and 700 nm. Absorbance (A) was calculated as follows: A = (A510 nm–A700 nm) pH 1.0−(A510 nm–A700 nm) pH 4.5. Then, the total anthocyanin content of each decoction was calculated by the following equation: $TA = [A \times MW \times DF \times 1000] \times 1/\varepsilon \times 1$, where A is the absorbance; MW is the molecular weight of cyanidin-3-O- glucoside (449.2 D); DF is the dilution factor (25); ε is the molar extinction coefficient of cyanidin-3-glucoside (26.900) and results were expressed on a dry weight basis in milligrams of cyanidin-3-O-glucoside per 100 g (mg C3G/100 g DW).

The antioxidant activity was evaluated by means of three different procedures: the ferric reducing antioxidant power (FRAP) method [11,15,37], the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay [15,38], and the 2,2′-azino-bis-3-ethylbenzthiazoline-6-sulfonic acid (ABTS) assay [15,39,40].

The FRAP assay was performed as follows: to obtain the FRAP solution, a buffer solution at pH 3.6 ($C_2H_3NaO_2 \cdot 3H_2O$ + $C_2H_4O_2$ in water), 2,4,6-tripyridyltriazine (TPTZ, 10 mM in HCl 40 mM) and $FeCl_3 \cdot 6H_2O$ (20 mM) were mixed. Afterwards, 30 µL of lavender flower decoction was mixed with 90 µL of deionized water and 900 µL of FRAP reagent. After 30 min at 37 °C, the absorbance was read at 595 nm. The results were expressed as millimoles of ferrous iron equivalents per kilogram of DW (mmol Fe^{2+} kg^{-1} DW).

The DPPH assay was performed as follows: the working solution of DPPH radical cations (DPPH, 100 μM) was obtained by dissolving 2 mg of DPPH in 50 mL of MeOH. The samples were prepared by mixing 40 μL of lavender flower decoction with 3 μL of DPPH radical solution. After 30 min in the dark at room temperature, the absorbance was read at 515 nm. Results were expressed as micromoles of Trolox equivalents per 1 g of DW (μmol TE/g DW).

The ABTS assay was performed as follows: to obtain the working solution of ABTS radical cation (ABTS), a 7.0 mM ABTS stock solution reacted with a 2.45 mM potassium persulfate ($K_2S_2O_8$) solution. The samples were obtained by mixing 30 μL of lavender flower decoction with 2 mL of ABTS$^{\cdot}$ radical solution. After 10 min in the dark at room temperature, the absorbance was read at 734 nm. Results were expressed as micromoles of Trolox equivalents per 1 g of DW (μmol TE/g DW).

2.5. Phenolic Profile

A High-performance liquid chromatography (HPLC) with diode array detection (DAD) (Agilent 1200, Agilent Technologies, Santa Clara, CA, USA) was used to determine the presence of bioactive compounds in dried lavender flowers' decoctions (volume of 20 μL). Compounds were separated using a Kinetex C18 column (4.6 × 150 mm, 5 mm, Phenomenex, Torrance, CA, USA) and different mobile phases, based on the previously tested methodology (Table 1) [15,41,42]. The compounds were identified by comparing retention times and UV spectra of analytical standards, and they were quantified using calibration curves at the same chromatographic conditions. The external standard method was used for quantitative determinations. Different data points were used to generate the external standard calibration curves. For HPLC analysis, 20 μL of each standard solution was used and for each concentration level, manual injections were conducted in triplicate. Calibration curves were obtained by plotting the peak area (y) of the compound at each level against the sample concentration (x). The limit of detection (LOD) and the limit of quantification (LOQ) for the reference compounds were experimentally determined by HPLC analysis of serial dilutions of a standard solution to achieve a signal-to-noise (S/N) ratio of 3 and 10, respectively. Validation was performed in accordance with international guidelines for analytical techniques for quality control of biopharmaceuticals (ICH guidelines) [43].

Table 1. Main validation characteristics of the chromatographic methods used.

Classes of Compounds	Standard	Retention Time (*t* R) (min)	Mobile Phase	Elution Conditions	Wavelenght (nm)
Cinnamic acids	Caffeic acid	4.54	A: 10 mM KH_2PO_4/H_3PO_4 pH = 2.8 B: CH_3CN	5%B to 21%B in 17 min + 21%B in 3 min (2 min conditioning time); flow: 1.5 mL min^{-1}	330
	Chlorogenic acid	3.89			
	Coumaric acid	6.74			
	Ferulic acid	7.99			
Flavonols	Hyperoside	10.89			
	Isoquercitrin	11.24			
	Quercetin	17.67			
	Quercitrin	13.28			
	Rutin	12.95			
Benzoic acids	Ellagic acid	18.65	A: $H_2O/CH_3OH/HCOOH$ (5:95:0.1 *v*/*v*/*v*), pH = 2.5 B: $CH_3OH/HCOOH$ (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
	Gallic acid	4.26			
Catechins	Catechin	10.31			
	Epicatechin	14.3			

The following bioactive compounds were investigated: phenolic acids (cinnamic acids: caffeic, chlorogenic, coumaric, and ferulic acids; benzoic acids: ellagic, and gallic

acids); flavonols (hyperoside, isoquercitrin, quercetin, and rutin); flavanols (catechin and epicatechin). Results are expressed as mg/100 g of dry flowers.

2.6. Statistical Analysis

Data of total phenolic content, anthocyanins, and antioxidant activity (FRAP, DPPH, ABTS assays) were first tested for the homogeneity of variances (Levene test), then a two-way ANOVA was performed to analyze potential differences between the three lavender selections and the two drying methods, and their reciprocal interaction. Moreover, mean comparisons were computed using a one-way ANOVA test to analyze potential differences between the drying methods. Means were separated according to the Ryan–Einot–Gabriel–Welsch F post hoc test (REGWF). The value for statistical significance was $p < 0.05$. All statistical analyses were performed by SPSS software (version 26.0, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Total Phenolic Content (TPC), Total Anthocyanin Content (TAC) and Antioxidant Activity

Lavandula angustifolia flowers from the three different selections were analyzed after drying in order to compare two different drying methods and select the more efficient to obtain decoctions rich in polyphenols, anthocyanins, and antioxidant activity (Table 2).

Table 2. Comparison of total phenolic content (TPC), total anthocyanin content (TAC), and antioxidant activity (FRAP, DPPH, and ABTS assays) of *L. angustifolia* decoction according to the three selections (A), the drying method (B), and their interaction. HA = hot air dried; HP = heat pump dried. Data are based on dry weight (DW).

Lavender Selection (A)	**TPC mg GAE/100 g DW**		**TAC mg C3G/100 g DW**		**FRAP mmol Fe^{2+}/kg DW**		**DPPH μmol TE/g DW**		**ABTS μmol TE/g DW**	
Susa	1877.18 ± 449.02	b	40.14 ± 8.19	b	988.08 ± 348.43	b	76.10 ± 50.83	b	85.49 ± 49.42	c
Stura	2200.99 ± 461.35	a	59.30 ± 19.40	a	1265.16 ± 570.28	a	104.88 ± 38.75	a	112.59 ± 23.86	a
Tanaro	2176.35 ± 525.81	a	60.74 ± 6.52	a	946.48 ± 342.51	b	102.08 ± 20.74	a	99.99 ± 20.36	b
p	***		*		**		***		***	
Drying Method (B)	**TPC mg GAE/100 g DW**		**TAC mg C3G/100 g DW**		**FRAP mmol Fe2+/kg DW**		**DPPH μmol TE/g DW**		**ABTS μmol TE/g DW**	
HA	1648.88		55.57 ± 19.60		708.41 ± 102.86		61.29 ± 23.75		71.10 ± 23.50	
HP	2520.79		51.22 10.37		1424.73 ± 313.48		127.42 ± 13.27		127.61 ± 8.30	
p	***		ns		***		***		***	
Interaction	**TPC**		**TAC**		**FRAP**		**DPPH**		**ABTS**	
					p					
A × B	*		ns		*		***		***	

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).

At first, results showed differences among the three lavender selections. TPC was significantly higher in the Tanaro (2176.35 mg GAE/100 g DW) and Stura (2200.99 mg GAE/100 g DW) selections and lower in the Susa (1877.18 mg GAE/100 g DW) selection.

TAC showed the same pattern, i.e., significantly higher values in the Tanaro (60.74 mg C3G/100 g DW) and Stura selections (59.30 mg C3G/100 g DW), and lower in the Susa (40.14 mg C3G/100 g DW) one. These results confirmed previous studies which highlighted how lavender plants at lower latitudes contained higher levels of bioactive compounds than lavender plants at higher latitudes [19].

The antioxidant activity, assessed through three different assays, resulted significantly higher in the Tanaro and Stura selections, as already highlighted with TPC and TAC, in the DPPH assay (102.08 and 104.88 μmol TE/g DW, respectively), while in the ABTS and FRAP assays only the Stura selection resulted significantly higher (112.59 μmol TE/g DW and 1265.16 mmol Fe^{2+}/kg DW, respectively).

Stating below the differences due to the drying method, heat pump drying showed significantly higher results in TPC than hot air drying (2520.79 and 1648.88 mg GAE/100 g DW, respectively), thus suggesting that the selection of flowers from lower latitudes and dried with lower temperatures give a final product richer in bioactive compounds. In literature, lavender decoctions have been poorly investigated thus the obtained results were compared with other lavender extracts and other medicinal plants used for infusions or decoctions. In general, for both drying methods, our results on TPC are higher than those found in other studies on dried lavender flowers, such as Dorozko and colleagues [24], who investigated *L. agustifolia* flowers' ultrasound extracts and found values of TPC ranging from 1046 to 1183 mg GAE/100 g DW, depending on the drying method used. They assessed three different drying methods, namely hot air drying (40 °C for 6 h), freeze drying (−18 °C for 24 h), and microwave drying (800 W for 6–7 min), finding the highest TPC values in microwave-dried flowers and a lower TPC value in freeze-dried flowers [24]. Duda and colleagues [44] found a value TPC in *L. angustifolia* macerates higher (from 1244 to 1816 mg GAE/100 g DW) than in the previous study but anyway lower than our results, drying the plant material in the shadow at 22–27 °C. Dobros and colleagues [45] found a more similar TPC in *L. angustifolia* freeze-dried flowers' decoctions, from 1489 to 2067 mg GAE/100 g DW.

Regarding TAC, data showed no significant differences between heat pump drying and hot air drying, probably because the high temperatures reached during decoction may have damaged the quality of the processed product [3,28].

Concerning the antioxidant activity, we found significant differences between the two drying methods in all three antioxidant activity assays, confirming that heat pump drying preserves a higher content of bioactive compounds and a better final product.

However, although Dobros and colleagues [45] found a similar TPC content, they showed higher DPPH values for lavender dried flowers' decoction than those obtained in this study, ranging from 113.20 to 174.93 µmol TE/g DW. This is probably due to their different drying method, which could have preserved more bioactive compounds with antioxidant properties. Demasi and colleagues too (personal communication) confirmed higher antioxidant activity in decoctions of several species dried with lower temperatures than our results (i.e., ABTS: 34.9 to 865.7 µmol TE/g DW). Sentkowska and colleagues [46] compared infusion and decoction as extraction processes for *Melissa officinalis* L., highlighting how decoction had a higher antioxidant activity because it was more effective in extracting compounds with reductive activity, obtaining higher values than this study (TPC: 1408 mg GAE/g DW). This result is confirmed by Dias and colleagues [47] who investigated the antioxidant activity of *Achillea millefolium* L. infusions and decoctions, finding higher values of DPPH assay for this latter.

A significant interaction between the lavender selections and the drying method was also found, thus showing how intraspecific differences and drying temperature can interact in affecting the TPC and the antioxidant activity; no significant interaction was found for the anthocyanin content. More in detail, results reported in Table 3 showed that heat pump-dried selections allowed to obtain significantly higher values than hot air-dried ones in all the examined parameters, with the exception of the DPPH assay, where the hot air-dried Tanaro selection showed a similar value to the heat pump Susa and Tanaro selections. Looking within the flowers dried by means of a heat pump, the Stura and Tanaro selections showed higher values for TPC (2620.52 and 2655.83 mg GAE/100 g DW respectively) than Susa (2286.02 mg GAE/100 g DW) while no significant differences were found for anthocyanins from 34.70 to 66.06 mg C3G/100 g DW). The antioxidant activity was overall higher in Stura (FRAP: 1779.50 mmol Fe^{2+}/kg DW; DPPH: 140.03 µmol TE/g DW; ABTS: 134.09 µmol TE/g DW).

Table 3. Differences in total phenolic content (TPC), total anthocyanin content (TAC), and antioxidant activity (FRAP, DPPH, and ABTS assays) of *L. angustifolia* decoction according to the drying method. HA = hot air dried; HP = heat pump dried. Data are based on dry weight (DW).

Lavender Selection	TPC mg GAE/100 g DW		TAC mg C3G/100 g DW	FRAP mmol Fe^{2+}/kg DW		DPPH µmol TE/g DW		ABTS µmol TE/g DW	
HA Susa	1468.33	e	34.70	670.45	c	30.79	d	40.42	e
HA Stura	1781.46	c	66.06	750.81	c	69.73	c	91.09	c
HA Tanaro	1696.86	d	65.93	703.98	c	83.35	b	81.78	d
HP Susa	2286.02	b	45.57	1305.70	b	121.41	ab	130.55	a
HP Stura	2620.52	a	52.55	1779.50	a	140.03	a	134.09	a
HP Tanaro	2655.83	a	55.54	1188.98	b	120.82	ab	118.20	b
p	***		ns	***		**		***	

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 (** $p < 0.01$; *** $p < 0.001$; ns = not significant).

Within hot air-dried selections, the Stura one showed the highest values in all the parameters (TPC: 1781.46 mg GAE/100 g DW; DPPH: 69.73 µmol TE/g DW; ABTS: 91.09 µmol TE/g DW), followed by the Tanaro (TPC: 1696.86 mg GAE/100 g DW; DPPH: 83.35 µmol TE/g DW; ABTS: 81.78 µmol TE/g DW) and Susa ones (TPC: 1468.33 mg GAE/100 g DW; DPPH: 30.79 µmol TE/g DW; ABTS: 40.42 µmol TE/g DW), except for the FRAP assay where no significant differences were found among hot air dried selections (from 670.45 to 750.81 mmol Fe^{2+}/kg DW).

3.2. Phenolic Profile

In *L. angustifolia* dried flowers' decoction, 4 compounds out of 13 were found (quercitrin, ellagic acid, gallic acid, and epicatechin; Figure 1). Heat pump drying allowed to obtain more compounds than hot air drying, 3 out of 4, namely quercitrin, ellagic acid, and gallic acid, while hot air drying only extracted epicatechin, in all three lavender selections (Table 4; Figure 1).

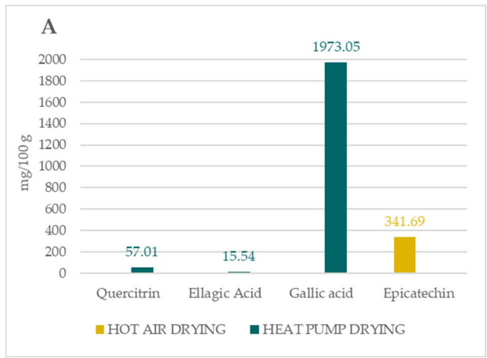
Regarding heat pump drying, quercitrin showed similar values among the three selections (from 56.695 to 57.319 mg/100 g) (Table 4). Conversely, ellagic acid showed a higher value in the Stura selection (18.963 mg/100 g), followed by Susa (15.541 mg/100 g), and lastly by the Tanaro selection (6.608 mg/100 g). Gallic acid showed a different distribution: higher values were found in the Susa selection (1973.051 mg/100 g), followed by Tanaro (1784.697 mg/100 g), and by Stura selections (1596.342 mg/100 g).

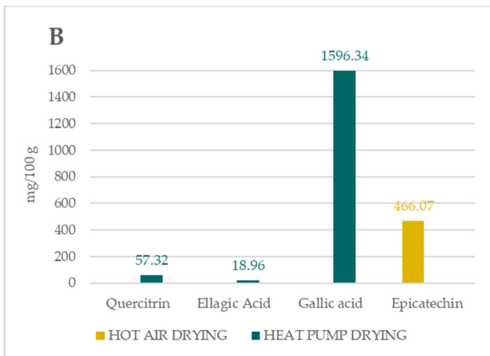
Concerning hot air drying, epicatechin showed higher values in the Stura selection (466.068 mg/100 g), followed by the Tanaro (403.880 mg/100 g) and the Susa selections (341.692 mg/100 g) (Table 4).

Therefore, each population has its own peculiar amount of bioactive compounds, thus explaining how different origins of selections, even of the same species, can show variations in the phenolic profile.

Quercitrin has antibacterial properties and can inhibit the oxidation of low-density lipoproteins [48]. Ellagic acid has anti-inflammatory and antioxidant activities [49]. Gallic acid shows antioxidant properties, antiallergic, anti-inflammatory, antimutagenic, and anticarcinogenic activities [50]. Epicatechin has antidiabetic, anticancer, antilipidemic, cardioprotective, anti-inflammatory, and antioxidant properties [51].

Our results for quercitrin were higher than those found by Duda and colleagues [44], who analyzed dry lavender flowers with the maceration technique, but did not detect this compound. Moreover, they did not report the presence of ellagic acid, gallic acid, and epicatechin, which were highlighted in our analysis. It has to be noted that Sentkowska [52] and colleagues stated that phenolics can be affected by thermal processing, and they found that chlorogenic acid, coumaric acid, and caffeic acid decreased during the decoction and infusion processes.





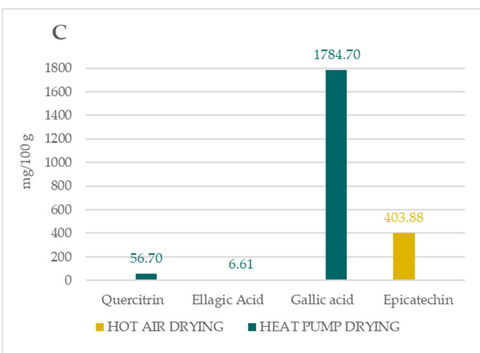


Figure 1. Total bioactive compounds detected by means of HPLC analysis in *L. angustifolia* hot air-dried and heat pump-dried flowers extracted by decoction in Susa (**A**), Stura (**B**), and Tanaro (**C**) selections. The colored number above the columns indicates the detected value of each bioactive compound (yellow for hot air drying, blue for heat pump drying). Values are expressed in mg/100 g of dry flowers.

Table 4. Differences in the total detected bioactive compounds between the two drying methods. Values are expressed as means of the three selections values. HA = hot air dried; HP = heat pump dried. Data are based on dry weight (DW).

Drying Method	Quercitrin mg/100 g DW	Ellagic Acid mg/100 g DW	Gallic Acid mg/100 g DW	Epicatechin mg/100 g DW
HA	0	0	0	403.88
HP	57.007	13.704	1784.697	0
p	***	***	***	***

The statistical relevance is provided (*** $p < 0.001$).

4. Conclusions

Heat pump drying is an emerging technology adopted to better preserve the color, appearance, and aroma of dried vegetal produce. In this study, it better preserved polyphenols and antioxidant activities of lavender flowers using decoction as an extraction method, compared to hot air drying. Moreover, heat pump drying allowed to maintain different molecules such as quercitrin, ellagic acid, and gallic acid, conversely to hot air drying. The use of three lavender selections made it possible to demonstrate this in different plant samples. At the same time, the differences detected between the three selections of local lavender, i.e., polyphenols and antioxidant activity, can offer interesting indications for developing new products for the functional food and beverage industry rich in phytochemicals, with antioxidant activity, and naturally flavored and colored. Moreover, new technologies could be applied to produce flower extracts containing bioactive compounds, i.e., ultrasound-assisted extraction, an efficient method with commercial applications. Therefore, it is important to improve the bioactive and sensory qualities of these new products, developing new aroma and taste combinations, but also different associations of

bioactive compounds, to create functional food and beverages suited for the specific needs of consumers.

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