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Evaluation of drying techniques for postharvest residue utilization in 'Nufar' Basil (*Ocimum basilicum* L.) production

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Abstract
In this study, drying techniques including lyophilization, forced convection, marquee with polyshade, and refractive window were evaluated in the post-harvest residue of Nufar variety basil (*Ocimum basilicum* L.) in the department of Tolima, Colombia. The physicochemical and bromatological analysis showed that lyophilization and forced convection better maintained the organoleptic properties of dry basil, while the marquee with polyshade technique did not affect the phenolic content and antioxidant capacity. The refractive window technique showed higher rehydration capacity but lower essential oil content. In the sensory evaluation, the infusions of dried leaves in the marquee with polyshade method were highly accepted. The results suggest that drying by forced convection and marquee with polyshade are effective methods to preserve the quality of dried basil, presenting a viable alternative for the use of post-harvest residue and improving the useful life of the product, benefitting local producers by increased employability and added value.

Keywords: *Ocimum basilicum*; agroindustry; drying systems; residues use.

Evaluación de técnicas de secado para el aprovechamiento del residuo poscosecha en la producción de albahaca 'Nufar' (*Ocimum basilicum* L.)

Resumen
En este estudio se evaluaron las técnicas de secado por liofilización, convección forzada, marquesina y ventana refractiva en los residuos postcosecha de albahaca (*Ocimum basilicum* L.) variedad Nufar en el departamento del Tolima, Colombia. El análisis fisicoquímico y bromatológico mostró que la liofilización y la convección forzada mantuvieron mejor las propiedades organolépticas de la albahaca seca, mientras que la técnica de marquesina no afectó el contenido de fenoles y su capacidad antioxidante. La técnica de ventana refractiva mostró mayor capacidad de rehidratación, pero menor contenido de aceite esencial. En la evaluación sensorial, las infusiones de hojas secadas en marquesina fueron altamente aceptadas. Los resultados sugieren que el secado por convección forzada y marquesina son métodos efectivos para preservar la calidad de la albahaca seca, siendo una alternativa viable para el aprovechamiento de residuos postcosecha y mejora de la vida útil del producto, beneficiando a los productores locales al aumentar su empleabilidad y valor agregado.

Palabras clave: *Ocimum basilicum*; agroindustria; sistemas de secado; aprovechamiento de residuos.

1 Introduction

Basil (*Ocimum basilicum* L.) belongs to the Lamiaceae family and is an herbaceous plant with a height of 20 to 60 cm and purplish-white flowers. It is grown in Mediterranean countries and regions with temperate and warm climates. Basil is an agricultural and agroindustrial alternative for Colombia; it is an aromatic species that is characterized by its condiment and pharmaceutical use, given its diuretic and stimulant properties, as well as its essential oil content, based

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on cineole, methyl chavicol, linalool, estragole, eugenol and thymol, used in the cosmetics, food and pharmaceutical industries [1] .Aromatic species, such as basil, are promising crops in Colombia with great economic potential, which increasingly attract more producers due to their recent and growing commercialization in international markets [2]. In many regions worldwide, dehydrated basil is used as an alternative to impart aroma and highlight the flavor of foods such as pasta-based preparations and salads.

Basil cultivation in the department of Tolima was, by 2017, one of the most promising crops with a growth of 21%, and it was the main aromatic plant exported [3]. However, there are still gaps in the harvest and postharvest stages identified in the municipalities of Espinal, Honda, and Mariquita, such as the amount of residue generated that becomes a phytosanitary reservoir for pests and diseases, which limits the reduction in export material. The non-exportable remainder is estimated at 30 to 50%, which could be used in different agro-industrial processing processes.

This article presents alternatives and treatments using various drying systems, including freeze-drying, forced convection, marquee with polyshade, and refractive window. The sun drying technique is the most used. However, it has many problems, such as prolonged exposure during drying, environmental pollution, climate uncertainty, and labor requirements. There is often a decrease in the quality of dried products because most conventional techniques use high temperatures during the drying process. Processing can introduce undesirable changes in appearance and cause texture, flavor, and color changes. Furthermore, drying is one of the conservation methods that guarantee microbial safety and, in turn, prolong the shelf life of food.

Consequently, the objective of the work was to evaluate different drying techniques for post-harvest basil residue in terms of physicochemical and sensory characteristics. It is sought which of the drying techniques such as freeze-drying, forced convection, refractive window and canopy with polyshading allow to increase the useful life and preserve the quality of dried basil.

2 Materials and methods

Plant residues (leaves and stems) of basil (*Ocimum basilicum* L.) of the Nufar variety were collected from the postharvest process on producer farms in the municipality of Espinal, Tolima Department, Colombia, following the guidelines indicated in Resolution 1466 of December 3, 2014, of Autoridad Nacional de Licencias Ambientales (ANLA) [National Environmental Licensing Authority]. The leaves were removed from the stem, and only healthy leaves were selected.

2.1 Drying techniques for postharvest basil residues

The drying of basil leaves was carried out using the following four different techniques that allowed the dehydration of the plant material until a moisture percentage of less than 10% was obtained. 1) Marquee with polyshade: Basil leaves were dehydrated in a marquee-type dryer with a 65% polyshade cover (20.4–52.5°C, 24.5–95% moisture); 2) Refractance window: this technique utilized basil leaves mixed with water in a 1:3 w/w ratio and subjected to sonication in a Hielscher UP 200s sonicator for 1 h at an amplitude of 100% and 0.5 cycles. After this period, the water was removed, and the leaves were macerated until obtaining a paste that was dehydrated in a refractance window pilot equipment at 80°C; 3) Forced air convection drying system: the basil leaves were taken to a Memmert reference UF55 dehydrating oven coupled to a forced convection system that allows the recirculation and homogenization of hot air; the process was carried out at a temperature of 50°C with a ventilation setting of 50% and a hatch opening of 100% that allows the generated water vapor to escape; and 4) Lyophilization: Freeze-drying of the classified leaves was carried out in a Christ Alpha model 1-4 LO Plus laboratory pilot-scale freeze-dryer. The plant material was previously frozen at -22°C ± 2 in a conventional freezer for 3–4 h. Once this first stage was completed, it was taken to the lyophilizer with the condenser freezing setting of -51°C ± 2 for 16 h as the main drying stage and then the final drying stage of 2 h; the vacuum level, i.e., the absolute pressure of the lyophilization process was 0.035 mbar with the manufacturer's adjustment to the condenser temperature.

2.1.1 Bromatological and physicochemical determination of postharvest residues of dried basil

The bromatological and physicochemical analysis was determined based on the dry matter obtained in the drying processes with a moisture of less than 10%. The variables determined were pH and conductivity previously calibrated with a Bante 900P Multiparameter, water activity (aw) with a Hygropalm probe from the Rotronic brand, moisture % through the gravimetric technique (ISO 6496:2009-NTC 4888:2000), ash content (AOAC 942.05, Ed. 21, 2019), ether extract (AOAC 2003.06-2006 21 th 2019), protein (AOAC 960.52-2008 21 th 2019), and crude fiber (ISO 6865:2000-NTC 5122:2002) of dried and macerated basil leaves.

2.1.2 Dry substrate rehydration capacity

The rehydration capacity of the samples was determined according to the method described by Telfser and Gómez Galindo [4]. Three leaves were weighed, and each was placed in a different beaker with 100 mL of distilled water at room temperature. After 1 h, the samples were extracted, and the excess water on their surface was removed with blotting paper to measure the weight gained. The leaves were then placed back into the beakers. This procedure was repeated every hour for 24 h. The rehydration capacity (%) was calculated as the ratio between the weight of the rehydrated sample and the weight of the dried sample.

2.1.3 Color Determination

It was carried out following the methodology proposed by Díaz Castro [5]. Color measurements were determined with a Konica Minolta colorimeter (Model No: CR-400) in a light-controlled room; L*, a*, and b* values were measured for fresh and dry leaves. The color index was calculated as described by Vignoni et al. [6]. according to Eq. 1, where L, a, and b are the parameters and color identification was carried out according to Table 1.

$$IC * = \frac{a * 1000}{L * b} \quad (1)$$

Table 1.
Ranges for color index (CI*)

Range of CI*	Color
-40 to -20	From blue-violet to deep green
-20 to -2	From deep green to yellowish green
-2 to +2	Greenish yellow
+2 to +20	From pale yellow to deep orange
+20 to +40	From intense orange to deep red

Source: Own elaboration

2.1.4 Determination of total phenol content and antioxidant activity

2.1.4.1 Preparation of extracts from dried basil leaves

The dried basil leaves were macerated with liquid nitrogen. Extraction was carried out with 80% ethanol in a 1:15 w/v ratio, and the sample was shaken in an orbital shaker brand for 2 h on a bench of ice. The sample was centrifuged at 6000 RPM for 20 min; the supernatant was separated and filtered using a Büchner funnel with a Whatman grade 1 filter.

2.1.4.2 Total phenols

The total phenolic content was quantified by the Folin-Ciocalteu method with modifications reported by Mahmoud et al. [6]. A volume of 100 µl of the extract of dry basil leaves was taken, 2100 µl of distilled water was added, followed by 350 µl of Folin Ciocalteu reagent at 1N concentration. Subsequently, it was shaken in a Heidolph brand vortex for 30 s, and 700 µl of 20% Na_2CO_3 was added and placed in the dark for 2 h. The absorbance was measured in a Thermo Scientific brand Helios zeta spectrophotometer at 765nm. The total phenolic content was quantified with a gallic acid calibration curve, and the results were expressed in mg gallic acid/100 g of dry leaves.

2.1.4.3 Antioxidant capacity

The DPPH method was used with some modifications to determine the antioxidant capacity [7]. A volume of 20 µl of ethanolic extract from dried basil leaves was taken, and 300 µl of DPPH was added, allowing it to react for 30 min, and the absorbance was measured at 517 nm in a Thermos Scientific brand Multiskan plate reader. From a calibration curve with Trolox, the trapping capacity of the DPPH radical was calculated in mg Trolox/100 g of dry leaves.

2.1.5 Extraction and obtaining of essential oil

The extraction of essential oils from basil residues was carried out by the hydrodistillation method. microwave-assisted (MWHD). A hydrodistillation equipment was used, with a capacity of 2L, in which 400g of leaves, with 300mL of distilled water, were introduced into the extraction flask. and heated for 30 min, divided into three 10 min cycles; As a source of microwave radiation, an oven was used conventional. The essential oils were collected in a Dean Stark type device; The separation of the essential oil was carried out by decantation, it was immediately stored at 4°C in amber glass bottles, until analysis.

2.1.5.1 Determination of the volatile fraction in solids by HS-SPME/GC-MS

The simultaneous concentration extraction of the compounds in the sample(s) was carried out using a fused silica fiber coated with PDMS/DVB of 65 µm thickness, an equilibrium time of 10 min, an extraction time of 30 min, an extraction temperature of 60°C, a desorption time in the chromatographic port of 10 min, and a desorption temperature in the injection port of 250°C. The certified C_6-C_{25} hydrocarbon mixture (AccuStandard, New Haven, CT, USA) was used as reference material.

2.1.6 Descriptive Sensory Analysis

The sensory effect consisted of evaluating and assessing aromatic infusions from the drying treatments of the basil residue, considering attributes such as flavor, aroma, color, and acceptance. The test was effective in a global panel of 90 untrained people who showed some taste or affinity for this type of infusion. The descriptive test included the following appreciations: I don't like it; I neither like it nor dislike it; I like it; and I like it a lot, to establish a description of the parameters evaluated with respect to the effect of drying techniques. The samples were coded, and a commercial sample was used as a control. The level of acceptance of the drying techniques was determined in comparison to a commercial sample concerning the evaluated variables.

2.1.7 Data Analysis

Chemical composition and sensory acceptance data were analyzed by ANOVA—one-way and two-way (samples and participants as the source of variation), respectively—and Fisher's LSD test ($p \leq 0.05$) using the statistical package Statgraphics Centurion XVII.

3 Results

The drying conditions that basil residues were subjected to according to different drying methods are shown in Table 2.

3.1 Bromatological and physicochemical determination of dried basil

The analysis of the results of the physicochemical characterization of dried basil under different techniques recorded significant differences at a confidence level of 95% for the moisture and protein variables, forming two homogeneous groups in the LSD test. The variables fat percentage, water activity, conductivity, and ash formed three homogeneous groups in the multiple-range test. Moisture grouped the results of the freeze-drying, convection, and refractive window technique in the first group with the lowest recorded moisture content, followed by the marquee with polyshade technique in the second group, and the commercial control, which recorded the highest moisture content with respect to the other samples. The water activity of the evaluated treatments was found to be between 0.19 and 0.65 for the dried basil samples from the refractive window and convection drying techniques, respectively (Table 3).

Table 2.
Drying conditions of basil residue in different drying methods.

Drying Method	Drying Conditions	Advantages	Desventajas
Freeze drying	Stage 1: Freezing T°: -22°C ± 2 Time: 3-4 h Stage 2: Principal drying T°: -51°C ± 2 Time: 16 h Vacuum pressure: 0.035 mbar Stage 3: End drying T°: -51°C ± 2 Time: 2 h Vacuum pressure: 0.035 mbar	- Better quality by-product - Best color - Low oxidation - Better palatability - Greater freshness feeling - Good preservation of antioxidant activity	- High costs - Longer dehydration time. - Low essential oil content - Lower loading capacity per drying batch - Low performance
Forced Convection Oven	Oven T°: 50°C Hatch: 100% Ventilation: 50% Drying Time: 14 h	- Low cost - Shorter dehydration time - Greater loading capacity per drying batch - Good preservation of antioxidant activity - Little volatilization of essential oil - High performance	- Greater oxidation - Less freshness sensation - Greater color loss
Refractive Window	Mix with Water Ratio 1:3 w/w Sonication time: 1 h Amplitude: 100% Cycles: 0.5 Window T°: 80°C	- 4th generation technology - Conservation of bioactive compounds - Low direct heat transfer	- High-cost technology
Marquee with Polyshade	Polyshade 65% (20.4–52.5°C, 24.5–95% moisture)	- Low production cost - Higher performance - High conservation of antioxidant activity - Greater conservation of essential oil volatilization	- Long drying times - Greater oxidation - Less control of microbial contamination

Source: Own elaboration

Table 3.
Physicochemical characterization of dried basil subjected to different drying treatments.

Treatments	M (%)	Aw	pH	C (mS/cm)	Ash (%)	Fat (%)	Protein (%)	Fiber (%)
Commercial control	10.17± 0.76	0.62±0.012	6,21±0.04	7.86± 0.03	10.3±0.86	4.57± 0.21	17.17± 0.79	11.60±1.32
Forced convection	7.58± 0.13	0.65±0.002	5.91±0.02	6.82± 0.166	15.67±0.40	1.51±0.12	22.85± 0.51	9.55±0.41
Lyophilization	6.78± 0.13	0.58±0.019	6.07±0.05	7.40± 0.628	16.30±0.34	2.53±0.09	21.13± 0.32	11.03±0.26
Refractive window	7.59± 0.78	0.19±0.018	5.93±0.25	5.12± 0.08	14.04±0.95	3.16±0.18	21.97± 0.76	8.56±0.39
Marquee with polyshade	10.00± 0.69	0.56±0.027	6.16±0.06	4.38± 0.108	17.44±0.90	3.06±0.58	22.07± 0.79	11.73±1.17

M: Moisture, C: Conductivity
Source: Own elaboration

3.1 Rehydration capacity

The rehydration capacity of the postharvest residue of dehydrated basil presented statistically significant differences in the drying systems evaluated, at a confidence level of 95%, forming three homogeneous groups corresponding to the freeze-drying technique in the first group, forced convection, marquee with polyshade and the commercial control in the second group, and finally, the third group with refractive window (Table 4), which recorded the highest rehydration capacity, reflected in shorter rehydration time to reach osmotic balance, leaving the lesions evident caused in the cell wall and high permeability, allowing the rapid diffusion of water at the cellular level [8].

Table 4.
Rehydration capacity of dried basil subjected to different drying methods

Treatment (Drying methods)	Rehydration capacity (%) Mean	SD
Lyophilization	20.23^{a}	0.72
Forced convection	26.23^{b}	0.64
Refractive window	45.27^{c}	0.79
Marquee with polyshade	34.11^{d}	1.16
Commercial sample	32.93^{d}	0.64

^{a,b,c,d} Different letters indicate statistically significant differences in LSD Fisher's test at P<0.05
Source: Own elaboration

3.2 Total phenol content and antioxidant capacity

The average value of the total phenolic content and antioxidant capacity of the drying techniques studied is shown in Fig. 1. The evaluated techniques presented significant statistical differences with a P-value of 0.0000 for the variables total phenolic content and antioxidant capacity. According to the results obtained, marquee with polyshade drying was the technique that allowed the highest content of total phenols to be preserved in dried basil with 223.69 mg gallic acid/100 g dry leaves, followed by the forced convection oven techniques with 194.76 mg gallic acid/100 g dry leaves and refractive window with 191.50 mg gallic acid/100 g dry leaves, which did not show significant differences by homogeneous groups.

Drying by lyophilization and the commercial control obtained values of 146.02 and 58.72 mg gallic acid/100 g dry leaves, respectively, showing commercial dried basil as the sample with the lowest total phenols values.

Regarding the antioxidant capacity of dried basil leaves, the forced convection and marquee with polyshade techniques presented the highest values with 330.11 and 320.06 mg Trolox/100 g dry leaves, which did not show significant differences for this group, in contrast to dried basil by lyophilization, refractive window and the commercial control that showed significant differences between them, with contents of 306.23, 170.38, and 110.42 mg Trolox/100 g dry leaves, respectively.

3.3 Color index

Dried basil showed differential behavior in terms of color index for the drying techniques to which fresh basil was subjected (Fig. 2). According to the results of Table 5, the CI* showed statistically significant differences with a P-value of 0.0001 for the drying methods. The commercial control did not show good results, showing a CI* of 7.29±0.43, ranging from pale yellow to intense orange. Likewise, the refractive window and lyophilization

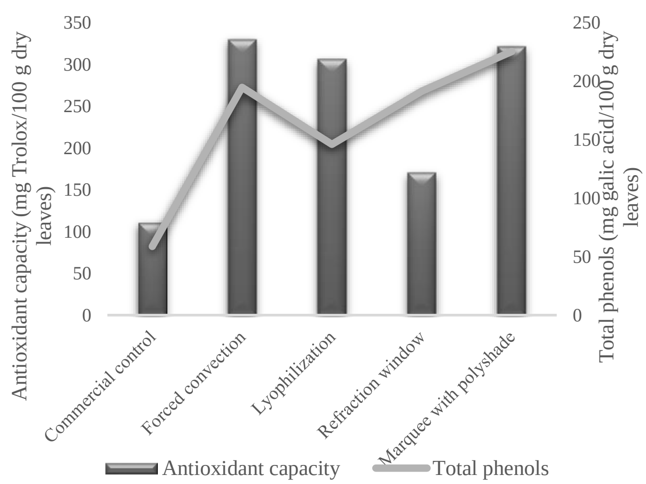


Figure 1. Total phenolic content and antioxidant capacity of dry basil subjected to different drying techniques.
Source: Own elaboration

Table 5.
Color index (CI*) of dry basil samples with different drying methods

Treatments (drying methods)	CI*	
	Mean	SD
Commercial control	7.29[a]	0.43
Refractive window	1.99[b]	0.45
Forced-convection	-0.19[c]	0.02
Marquee with polyshade	-1.52[c]	0.61
Lyophilization	-3.41[d]	0.53

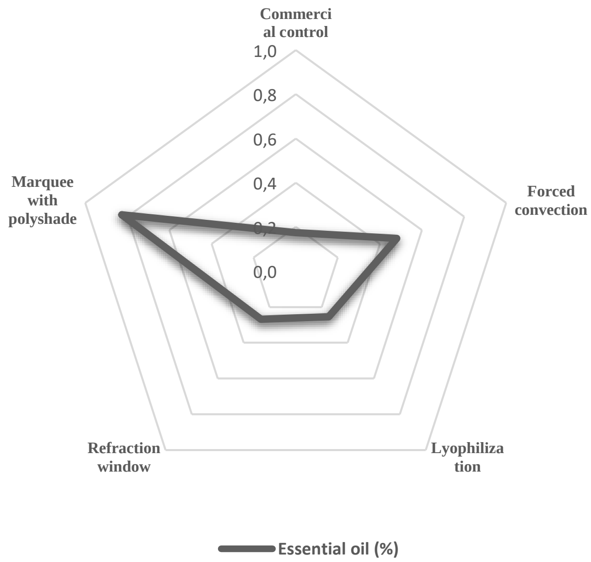
[a,b,c,d] Different letters indicate statistically significant differences in LSD Fisher's test at $P<0.05$
Source: Own elaboration

Figure 2. Color of samples of dried basil leaves subjected to different drying techniques (top, from left to right: commercial control, lyophilization, forced convection oven; down, from left to right: marquee with polyshade, and refractive window).
Source: Own elaboration

techniques presented a CI* of 1.99±0.45 and -3.41±0.53, respectively, registering colors from greenish yellow and deep green to yellowish green, showing that lyophilization preserved the expected coloration for dried basil leaves. In the forced convection and marquee with polyshade techniques, the leaves showed a greenish-yellow color with a CI* of -0.19±0.02 and -1.52±0.61, respectively.

3.4 Percentage of essential oil

The essential oil content of the evaluated treatments showed significant differences at a confidence level of 95%, generating four homogeneous groups. The first includes the commercial control which registered the lowest value with 0.175%, followed by a second group comprised of lyophilization and the refractive window techniques, which registered an average of 0.25% and 0.26%, respectively. The third and fourth groups included the forced convection and marquee with polyshade techniques with percentages of 0.48% and 0.41% of essential oil, respectively (Fig. 3).



Source: Own elaboration
Figure 3. Percentage of essential oil from dried basil residue under different drying techniques.

3.5 *Volatile compound profile*

The volatile composition of the analyzed samples (Table 6) showed the effect of the drying technique, finding different concentrations of the compounds when the postharvest residues were subjected to different dehydration treatments. The volatile compounds most present in the basil samples were trans-oxide, linalool with up to 40.3% in the sample dried by lyophilization, linalool, and estragole with 33.3% and 21.5%, respectively for the sample dried by forced convection. Eugenol was detected in proportions of 5.8% and 2.8% for basil from lyophilization and marquee with polyshade drying techniques. These compounds have been associated with the typical basil aroma and good antioxidant properties [9].

Table 6.
Volatile compound profile of dried basil subjected to different drying techniques.

Volatile compounds	Relative concentration (%)				
	Commercial control	**Forced convection**	**Lyophilization**	**Refractive window**	**Marquee with polyshade**
α-pinene	0.2	0.2	0.3	0.1	0.2
benzaldehyde	0.1	0	0	0	0
sabinene	0.1	0.3	0.3	0.1	0.2
β-pinene	0.4	0.6	0.7	0.2	0.4
β-myrcene	0.2	0.2	0.3	0	0.2
limonene	0.1	0.1	0.1	0	0.1
1,8-cineole	5.9	5.9	7.6	1.5	4.3
trans-β-ocimene	0.1	0.4	0.4	0.1	0.2
γ-terpinene	0.1	0	0	0	0
cis-linalooxide	1.9	0	0	0	0
ethyl 2-(5-methyl-5-vinyltetrahydrofuran-2-yl)propan-2-yl carbonate	1.7	0	0	0	0
fenchone	0.1	0	0	0	0
pinocarvone	0.1	0	0	0	0
sabinene transhydrate	0	0.4	0.3	0.1	0.3
trans-oxide linalool	0.4	0.2	40.3	0.1	0.1
linalool	17	33.3	0.1	12	21.4
hotrienol	0	0	0	0.1	0.1
phenylethanol	0	0	0	0	0
camphor	0	0.1	0.1	0.1	0.1
δ-terpineol	0.2	0.1	0.1	0.1	0.2
cis-linalool oxide	0.4	0	0	0	0
terpinen-4-ol	0.1	0	0	0	0
2,6-dimethyl-3,7-octadiene-2,6-diol	0.7	0	0	0.1	0.2
estragole	1.5	21.5	19	4.1	15.8
octyl acetate	0.1	0.2	0.3	0.1	0.4
hydroxycineum	0.1	0	0	0	0
3-exo-Hydroxy-1,8-cineole	0.2	0	0	0	0
methylethylmaleimide	0	0	0	0	0.1
chavicol	0	0	0.6	0.2	0.3
linalyl acetate	0	0.1	0	0.1	0.1
2,6-dimethyl-1,7-octadien-3,6-diol	0.3	0	0	0	0.1
cis-methyl cinnamate	7.7	0	0	0	0
3-exo-hydroxy-1,8-cineyl acetate	0.2	0	0	0	0
2-exo-hydroxy-1,8-cineyl acetate	0.3	0	0	0	0
α-cubebene	0.3	0	0	0	0
bornyl acetate	0	0	0	0.1	0.1
eugenol	0.1	2.7	5.8	1.7	2.8
α-copaene	0.5	0.6	0.5	0.5	0.5
trans-methyl cinnamate	29.9	0	0	0	0
β-bornonene	0	0.3	0	0.3	0.5
β-elemene	0	3.4	2.7	4.9	3.2
methyleugenol	0	0	0	0.8	1.2
β-ylangelo	0	0.4	0	0.5	0.3
trans-β-caryophyllene	0.6	0.9	0.7	0.9	1
β-Cedrene	0.4	0	0	0	0
β-Copaene	0.4	0	0	0	0
trans-α-bergamotene	0	1	0.9	1.4	1.4
α-guaien	1.5	1	1	1.3	1.1
trans-Muurola-3,5-diene	0.5	0	0	0	0
trans-β-farnesene	0	0	0	0.7	0.7
α-humulene	1.1	3.6	2.6	4.4	4.7

muurola-4, 14(5)-diene	1	1.1	0.8	2	1.3
γ-curcumene	0	0.4	0	0.7	0.4
germacrene D	2.2	7	5.1	6.7	4.2
β-selinene	0.5	0	0	0	0
bicyclogermacrene	1.2	3.4	2.2	3.9	2.1
α-bulnesene	1.9	1.3	0.9	2	1.6
γ-cadinene	5.4	3.8	2.6	7.9	6
calamenene	0.8	0	0	0	0
δ-cadinene	0	0	0	0.5	0.3
cis-calamenene	0	0.4	0	1.1	0.8
10-epi-cubebol	0	0	0	1	0.3
dihydroactinidiolide	0	0	0	0	0.3
α-cadinene	0	0	0	0.2	0.2
trans-nerolidol	0.3	0.4	0.3	3.8	1.9
maaliol	0.3	0	0	0	0
spatulenol	0.9	0.6	0.3	3.8	3.8
viridiflorol	0.7	0	0	0	0
caryophyllene oxide	0	0	0	0.3	0.3
humulene epoxide II	0.2	0.1	0	1	1.3
1,10-di-epi-cubenol	1.4	0.5	0.3	3.5	1.7
isospatulenol	0	0	0	0.4	0.4
methyl jasmonate	0.2	0	0	0	0.2
epi-α-cadinol	5.3	2.4	2.2	20.6	8.1
α-cadinol	0.3	0	0	1	0.4
β-eudesmol	0.3	0	0	1.2	0.6
neointermedeol	0.6	0	0	0	0
6,10,14-trimethyl-2-pentadedione	0.1	0	0	0	0.1
cis-14-nor-muurol-5-en-4-one	0.2	0	0	0	0
mint sulfide	0	0.2	0	0.3	0.2

Source: Own elaboration

3.6 Sensory evaluation

Fig. 4 shows the sensory evaluation results that 90 untrained evaluators carried out on the preference and taste for the aromatic infusions prepared with the dehydrated material obtained through the different drying methods evaluated. Infusions are usually accepted for taste (a), smell (aroma) (b), and color (c), where there is no significant difference between treatments. However, it is worth highlighting the higher degree of acceptance by the commercial sample in each of the parameters, most likely due to the treatment and mixture with other aromatic species that increase the sweetness in the infused drink.

The results analyzed in each graph for flavor, aroma, and color are very heterogeneous, considering each variable individually. For flavor, the drying methods implemented do not present a significant difference, most panelists like the flavor of the aromatic infusions in contrast to the commercial sample.

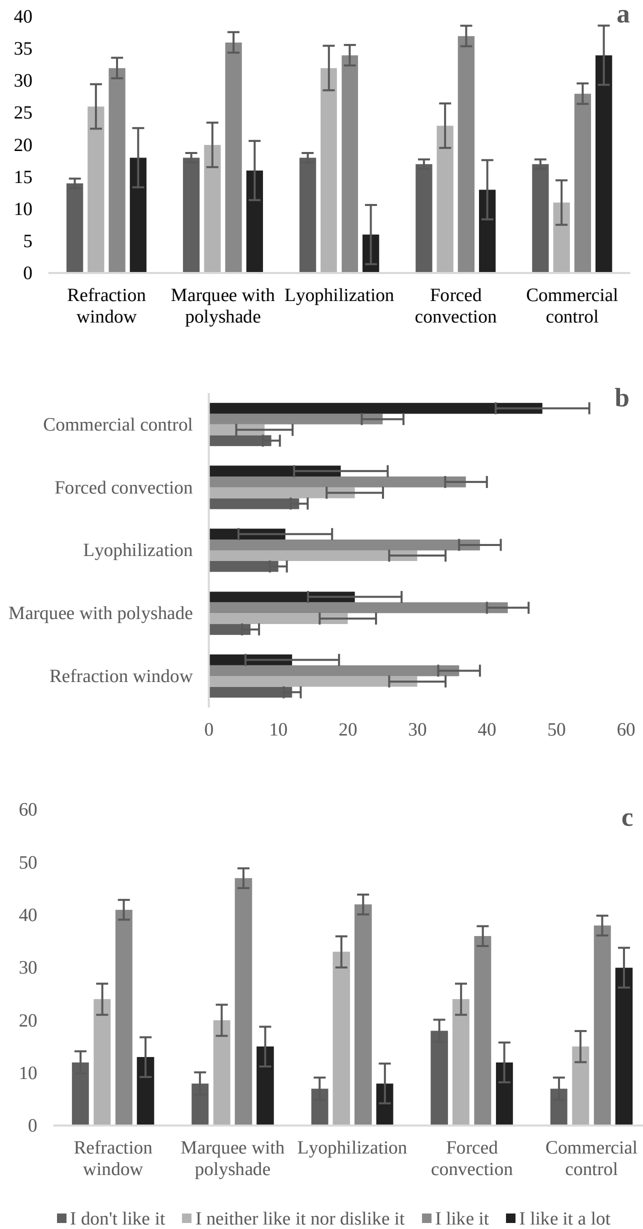


Figure 4. Results of the sensory evaluation of the dry basil leaves subjected to different drying methods concerning a. flavor, b. aroma, and c. color.
Source: Own elaboration

A very marked difference is evident in the aroma variable between the commercial sample and the drying methods, with a value higher than 50% of the evaluators expressing that they "really" like this aroma.

There is no significant difference in the drying systems compared to the commercial sample for the color variable of the infusions. It should be noted that the oxidation and browning process of the infusions is very marked as time passes and cooling before being consumed. Color is a variable "liked" or "liked very much" without differences in the drying systems used in the dehydration process.

3.6.1 Degree of acceptance

Table 7 presents the sensory analysis results of the dehydrated basil infusions in the different drying systems. In this table, the degree of acceptance is evident considering the evaluated variables of flavor, aroma, and color and comparing them with the control as a commercial sample. Regarding the degree of acceptance as the sum of "I like it" and "I like it a lot," the commercial sample has the greatest acceptance, with 203 points, followed by the sample dried in a marquee with polyshade, with 178 points. The samples dried with forced convection and refractive window do not show a major difference, with 154 and 152 points, respectively. Regarding the sample dehydrated by lyophilization, it registers a value of 140 points and is presented as the sample with the least acceptance.

Table 7.
Sensory analysis results of dried basil infusions under different drying techniques.

Drying method	Acceptance degree	Characteristics			Acceptance degree points
		Flavor	Aroma	Color	
Liofilizacion	I don't like it	18	10	7	140
	I neither like it nor dislike it	32	30	33	
	I like it + I like it a lot	40	50	50	
Forced convection	I don't like it	17	13	18	154
	I neither like it nor dislike it	23	21	24	
	I like it + I like it a lot	50	56	48	
Commercial Sample	I don't like it	17	9	7	203
	I neither like it nor dislike it	11	8	15	
	I like it + I like it a lot	62	73	68	
Refractive Window	I don't like it	14	12	12	152
	I neither like it nor dislike it	26	30	24	
	I like it + I like it a lot	50	48	54	
Polyshade Marquee	I don't like it	18	6	8	178
	I neither like it nor dislike it	20	20	20	
	I like it + I like it a lot	52	64	62	

Source: Own elaboration

4 Discussion

In the dehydration processes, the aim is to maintain the physicochemical qualities of the sample, bringing it to a safe level of moisture and water activity. Values below 0.6 have been established as a safe range of water activity to guarantee biochemical stability in foods, limiting the development of enzymatic and non-enzymatic reactions that affect nutritional quality, color, and flavor [4].

Reactions such as Maillard's are related to the maximum and minimum water availability values since it plays a double role as a solvent and reagent in the kinetics of the reaction, which, when increased, promotes browning [10]. The water activity of the basil residue subjected to the forced convection technique and the commercial control exceeded this value. However, the moisture contents found are within the limit established in the standard for dried basil CXS 345-2021 of the Codex Alimentarius [11], which requires a maximum of 12% moisture for chopped or crushed dried basil samples.

The refractive window technique generated the greatest effect on the physicochemical quality, reflected in lower percentages of protein, fiber, and minerals expressed in percentage of ash, which, together with a lower percentage of essential oil, revealed the damage caused to the cell wall of the basil residue due to the previous sonication and grinding treatment, since, as the structure of the tissue is altered, the permeability of the cells increases, facilitating the transit of compounds, including essential oils [12]. This behavior agrees with the quantification of volatile compounds, which recorded lower concentrations in most of the compounds in the dried basil residue subjected to the window technique.

The marquee with polyshade technique reported the highest percentage of essential oil, proving to be a less aggressive technique, which, thanks to the adaptation, maintains the drying system at temperatures below 45 °C, suggested as the ideal dehydration temperature without generating loss of volatile compounds [13,14].

The drying system affects the rehydration capacity, considering that the dehydration process damages the plant material since it loses hydrophilic properties for water retention it is important to highlight that the rehydration percentage does not reach the real moisture value of basil under natural conditions before dehydration [15,16].

The different drying techniques to which fresh basil was subjected showed that phenols and antioxidants were significantly preserved at the end of drying, with a high correlation with these compounds. Temperature has a direct impact on these secondary metabolites. Phenols and antioxidants are characterized by being thermosensitive [17], which is related to the conservation of their contents in drying by forced convection and marquee with polyshade.

The temperatures reached in these two methods did not exceed 55ºC, unlike drying in a refractive window and lyophilization. A study carried out by Sharma et al. (2018) [18], reported that the contents of phenols and antioxidants decreased in relation to the drying method, with microwaves maintaining the highest concentration of the compounds.

On the other hand, the color index of dried basil leaves showed a significant difference. Lyophilization allowed preserving a CI* close to deep green, unlike the other treatments that showed colors between greenish-yellow and yellowish-green. This behavior is due to the high chlorophyll contents responsible for the green coloration of the leaves, which degrade, generating compounds such as pheophytin that may be related to enzymatic browning reactions and promote a change in leaf coloration [19].

Therefore, it is essential to guarantee color in food, as this is a significant factor for the consumer when selecting a product for consumption.

The loss of aromatic compounds during dehydration is related to the temperature, drying speed, and vapor pressure of the molecules [20]. The marquee drying technique adapted with polyshading allowed the use of solar radiation, regulating the temperature of the system and achieving a maximum of 43°C inside the marquee. Thus, lower losses of volatile compounds were generated. Behavior supported by the essential oil contents that were up to four and two times higher in basil residues dried by marquee and convection compared to the commercial control.

5 Conclusions

The choice of dehydration method significantly affects the physicochemical qualities of foods. Techniques such as lyophilization (freeze-drying) or forced convection allowed the better preservation of phenols and antioxidants. The refractive window drying technique affected the nutritional composition, phenols, antioxidants, volatile compound profile, and sensory characteristics of dried basil, being the most destructive of the techniques studied, generating damage to the cell wall due to the need for a previous adaptation treatment. Marquee with polyshade drying managed to preserve the composition of the basil and its essential oil content, having the potential for processing postharvest residues due to its low cost by using solar energy as a source of dehydration and physical, chemical, and sensory conservation of the raw material, obtaining dried basil with characteristics superior to those recorded by the commercial sample. The evaluation of drying techniques used for postharvest residue in basil (*Ocimum basilicum* sp. var. Nufar) production provides valuable information to improve the efficiency, quality, and sustainability of the production chain of this crop.

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