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Drying of medicinal plants with a closed-circuit heat pump dryer

Original contributions

Introduction

In the EU, the sector of officinal plants is currently undergoing great expansion due to the many fields in which these biological products are employed as raw materials. Applications, in fact, range from direct use in the food industry (flavours and tea) to the production of homeopathic medicines and essences for the liqueur industry. Because officinal plants tend to be well adapted to precarious growing conditions, they are commonly found in marginalised areas or in hilly and mountainous regions. The establishment of such local cultivations can often provide an opportunity for revitalising depressed micro-economies. A recent investigation carried out in 2002 by European herbal growers in Austria, Denmark, France, Germany, Greece, Italy, the Netherlands and the UK estimated the total number of employees in officinal plant cultivation to be 10 139 (21% of which were in Italy) (12).

In 2001 - taking into consideration drugstores, herbalists and supermarkets - officinal plant consumption had an economic value of about 9 billion € (7% Italy, 43% Germany, 26% France, 7% UK, 4% Spain, 2% Belgium, 1% Austria) (12).

In Italy (7), over 100 officinal plant species are cultivated in a total area of approximately 3400 ha. However, less than forty of these species are of significant importance. They include bergamot, which by itself occupies approximately 1500 ha (Calabria), peppermint (Piedmont), flowering ash (Sicily), common chamomile, liquorice, lavender, lavandin and flax. The area occupied by each of the other thirty species is from 50 to 10 ha, while the remainder occupy less than 10 ha.

The purpose of the present study was to test the functioning of a drying plant with closed-circuit air circulation (*Fig. 1*), to evaluate the viability of its introduction into the traditional supply chain and to measure the energy consumption for each of the dried species. The study was carried out in Valle Camonica (Lombardy region, Brescia province), a mountainous area where the cultivation of officinal plants was introduced in 2002 as part of a Regional Research and Development Project (Lombardy Region Project „Development of the Production of Officinal Plants in a Mountain Area").

Abstract

A closed-circuit heat pump dryer system was tested to run drying cycles on six different species of medicinal plants (*Melissa officinalis* L., *Achillea millefolium* L., *Alchemilla vulgaris* L., *Mentha* x *piperita* L., *Urtica dioica* L. and *Lippia triphylla* (L'Hérit.) Kuntze (*Verbena odorosa*). The purpose was to introduce this system into the supply chain traditionally applied in Valle Camonica (Lombardy region, Italy), evaluating, in particular, the energy consumption as a function of the dried species. During 2005, a total of twenty-seven trials were carried out, measuring the initial green mass (kg) and corresponding moisture content (% wb), the average power absorbed by the system (kW_{el}), the electrical energy consumption (kWh_{el}), the final dried mass (kg) and corresponding moisture content (% wb), the specific energy consumption (kWh_{el}/kg_{dried} and kWh_{el}/kg_{H2O}) and the duration of the cycle (h). Three indexes were used to evaluate the mechanical loss (k_1), the production (k_2) and the energy consumption (k_3) of each single species. The results showed that *Achillea millefolium* L. (k_1 = 1.06, k_2 = 2.44 and k_3 = 0.56) was the species that responded best to the studied heat pump dryer system. *Lippia triphylla* (k_1 = 2.76, k_2 = 0.63 and k_3 = 1.45) was the species that showed the worst results.

Key words

Dry matter loss, drying process, energy consumption, heat pump dryer system, medicinal plants

The drying of medicinal plants

The cultivation of medicinal plants in Valle Camonica represents not only a financial proposition but also a chance for the area to regain its local identity through its products.

Until now, the post-harvest technique has always been at an elementary level, using natural resources, often with wastage and without any optimisation of the process. A good example is the drying technique, a crucial phase, during which the local producers have always simply left the herbs in contact with the air, usually for two to three weeks, depending on the product and climate.

The increase in the medicinal plant market and the needs to improve and standardise the quality of products require new technologies to improve the post-harvest process.

During the drying process of medicinal plants, it is fundamental to monitor the aspects connected to the loss of

Fig. 1: Closed-circuit heat pump dryer (Valle Camonica, Italy)
Abb. 1: Umluft-Kondensationstrockner (Lombardei)

product, the quality of the dried plant, the technical plant production and the energy consumption. Only by putting all these factors together can an evaluation be made on the efficiency of drying plants related to each dried species. Most drying plants utilise ventilated warm air. This is carried out by using the heat exchange method (fed by natural gas, LPG - liquefied petroleum gas, or diesel fuel) or by electrical heaters. There is an alternative method of drying herbs based on the application of a heat pump system.

Since the mid 1970s (7), there have been many studies investigating the heat pump system applied to the drying process, evaluating both theoretical results (3, 5, 10, 11) and practical ones (2, 4, 6). Even if there have been few studies on the drying of medicinal plants by heat pump (6), there has been a lot of interest as these herbs have a high financial value. Therefore, the production system can accept the higher energy costs. This aspect, however, can be counter-balanced by improved production flexibility, more simply obtained energy sources and a higher production sustainability.

Materials and methods

Nomenclature

The following table gives a survey on the used symbols and abbreviations.

Symbol	Unit (Einheit)	Explanation	Erläuterung
A	(m^2)	Harvested area	Erntefläche
CE_{max}	(kg_{H2O}/h)	Maximum evaporating capacity	Maximale Verdunstungsleistung
CE_{ave}	(kg_{H2O}/h)	Average evaporating capacity	Mittlere Verdunstungsleistung
T_{drymax}	(°C)	Maximum temperature of the drying air	Maximaltemperatur der Trocknungsluft
Q_v	(m^3/s)	Fan flow	Luftdurchsatz des Ventilators
ΔT	(°C)	Air temperature difference	Temperaturdifferenz der Luft
T_{dry}	(°C)	Dry air temperature	Temperatur der trockenen Luft
T_{wet}	(°C)	Wet air temperature	Temperatur der feuchten Luft
$M1_{wm}$	(kg)	Total matter at loading	Gutmasse bei der Beschickung
$M1_{dm}$	(kg)	Dry matter at loading	Trockenmasse bei der Beschickung
$M2_{wm}$	(kg)	Total matter at unloading	Gutmasse beim Beräumen
$M2_{dm}$	(kg)	Dry matter at unloading	Trockenmasse beim Beräumen
Δ M	($M1_{dm}$ - $M2_{dm}$), (kg)	Dry matter loss	Trockenmasseverlust
U_{dry}	(%)	Moisture content	Gutfeuchtegehalt
P	(kW)	Electrical power	Elektrische Leistung
E_{el}	(kWh)	Electrical energy consumption	Verbrauch an Elektroenergie
CS_s	(kWh/kg)	Specific energy consumption	Spezifischer Energieverbrauch
t	(h)	Test duration	Versuchsdauer
R_{dm}	(kg_{dm}/m^2)	Production yield	Flächenbelegung
k_1		Mechanical losses index	Index für mechanische Verluste
k_2		Drying performance index	Index der Trocknerleistung
k_3		Energy index	Energieindex
$P\%_s$	(%)	Dry matter losses of a single species (see *Tab. 3*)	Trockenmasseverluste einer einzelnen Art (siehe *Tab. 3*)
$P\%_{ave}$	(%)	Average dry matter losses (see *Tab. 3*)	Mittlere Trockenmasseverluste (%) (siehe *Tab. 3*)
CO_s	(kg_{dm}/h)	Specific drying capacity of a single species (see *Tab. 3*)	Spezifische Trocknungskapazität bei einer einzelnen Art (siehe *Tab. 3*)
CO_{ave}	(kg_{dm}/h)	Average drying capacity (see *Tab. 3*)	Mittlere Trocknungskapazität (siehe *Tab. 3*)
CS_{ave}	(kWh/kg_{H2O})	Average specific energy consumption	Energieverbrauch
M_{H2O}	(kg_{H2O})	Evaporated water	Verdunstetes Wasser

The dryer

The experimental trials were carried out on a highly compact system (CFT-Technik, Gumligen/Switzerland) (*Fig. 2*) with manual loading, consisting of a dryer chamber (width 2 m, depth 2.5 m, usable height 1 m; total capacity 5 m^3) divided into two sections by a partition, with a grille at the bottom on which the green product is placed and then dried by the warm air passing. The air is conditioned by a refrigeration unit installed on the upper part of the dryer which is a classical heat pump system; after being dehumidified by the evaporator (maximum and average evaporating capacities: CE_{max} = 13 kg_{H2O}/h and CE_{ave} = 6-10 kg_{H2O}/h), which removes the moisture absorbed during passage through the product, the air is heated (T_{drymax} = 55-56 °C) by the condenser to the temperature required within the drying chamber. A centrifugal fan (Q_v = 0.2-1.0 m^3/s) circulates the air through the system, conveying it from the refrigeration unit to the drying chamber. These units are powered by electricity (380 V) from the distribution grid.

All the process parameters and the du-

Tab. 1: Harvested area, harvested quantities (wet and dry matter) and yields (dry matter) of the medicinal plant species under the tests
Tab. 1: Ernteflächen, Anfangsgewichte des Trocknungsgutes (frisch und trocken) und Ausbeuten (Trockenmasse) der geprüften Arzneipflanzenarten

Trait (Merkmal)		Unit (Einheit)	*Melissa*	*Achillea*	*Alchem.*	*Mentha*	*Urtica*	*Lippia*	Total trials (Alle Versuche)	Value for total trials (Wert für alle Versuche)
Harvested area	A	m^2	2241	712	248	627	288	146	4262	
(Erntefläche)		% of tot	52.6	16.7	5.8	14.7	6.8	3.4	100	
Loaded weigth	$M1_{wm}$	kg_{wm}	1016	479	368	563	284	127	2837	
(Anfangsgewicht)	$M1_{dm}$	kg_{dm}	209	140	87	95	65	35	631	
		% of tot	33.1	22.1	13.8	15.1	10.3	5.6	100	
Yield (Ausbeute)	R_{dm}	kg_{dm}/m^2	0.093	0.196	0.351	0.152	0.226	0.241	-	0.148

ration of the drying phases are determined by a programmable logic controller (PLC), on the basis of the temperatures measured by thermocouples installed upstream of the fan (moist air) and downstream of the condenser (dry air), and the resultant air temperature difference $\Delta T = (T_{dry} - T_{wet})$, which must reach a pre-established value.

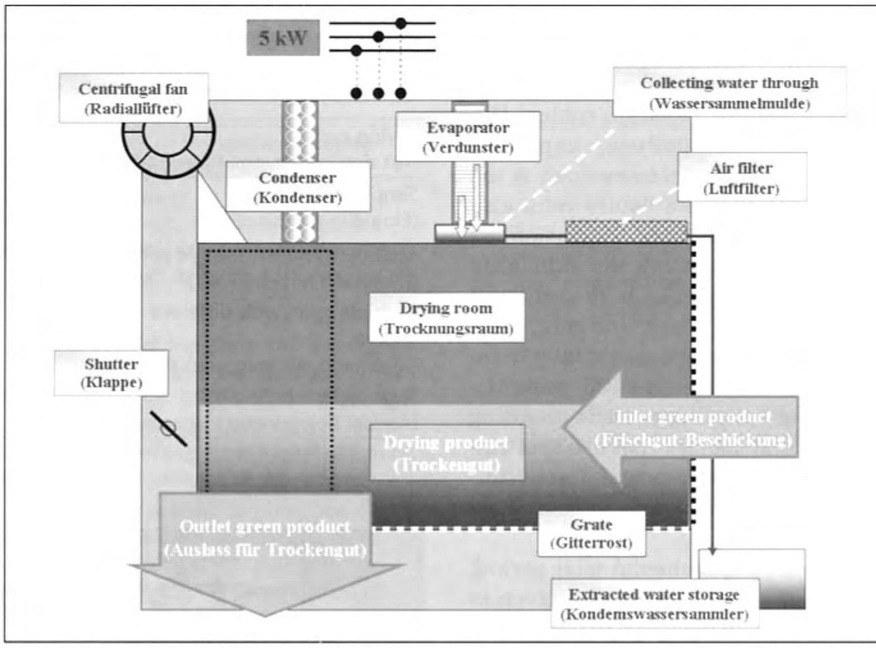

Fig. 2: Scheme of the drying plant
Abb. 2: Schema der Trockenanlage

Experimental method

The dryer system under study was tested by running drying cycles on six different officinal species: *Melissa officinalis* L., *Achillea millefolium* L., *Alchemilla vulgaris* L., *Mentha* x *piperita* L., *Urtica dioica* L. and *Lippia triphylla* (L'Hérit.) Kuntze (*Verbena odorosa*). The data relating to the harvested areas and the corresponding green product weights loaded into the dryer are given in *Tab.1*.

The dryer was used to carry out three different types of cycles, depending on the quantity of available raw materials:

- Simple cycle: a single batch of green product is loaded at the beginning and undergoes the drying process.
- Multiple cycle with single species: the green product is loaded in two successive batches of the same species; the second batch is loaded 6-7 hours after the first, when the initial mass has already lost a large part of its moisture and ΔT has reached the pre-established value.
- Multiple cycle with different species: as above, but the second loaded batch is of a different species, kept opportunely segregated from the first within the drying chamber to prevent cross-contamination.

A total of twenty-seven trials was carried out during a five-month period in the spring-summer of 2005. Six trials were of a simple cycle, five of a multiple cycle with single species, and sixteen of a multiple cycle with different species (*Tab. 2*).

The following values were measured in each case:

- The initial mass ($M1_{wm}$,kg) (loaded product) and the final mass ($M2_{dm}$) (unloaded product), using a scale or dynamometer depending on the quantities involved.
- The initial and final (U_{dry}) moisture (% wet basis), measured in the laboratory on samples of green and dried product, using a precision balance and drying oven. The temperature and drying time were, respectively, 103 °C and 24 h, in agreement with the standard ASABE S358.2 FEB03 (13). Knowing the initial humidity, by calculating the corresponding dry mass, the losses of dry matter were calculated.
- The temperatures of the drying air and of the moist air (°C), by thermocouples placed within the air flows circulating in the plant.
- The reduction in the residual moisture content (% wet basis), only for the simple cycles, by measuring the amount of water removed from the product during drying and discharged outside the plant.
- The average power absorbed by the plant (P, kW_{el}) and its electrical energy consumption (E_{el}, kWh_{el}), using a grid analyser.
- The specific energy consumptions (CS_s), referring to the weight of dry matter (kWh_{el}/kg_{dm}) and to the weight of evaporated water (kWh_{el}/kg_{H2O}), using a grid analyser and verified with a dedicated energy meter.
- The duration of the drying cycle (t, h), using a dedicated chronometer.

The measurements taken in each experimental trial were entered into a spreadsheet, which was used to cal-

Trocknung von Arzneipflanzen in einem Umluft-Kondensationstrockner

Zusammenfassung

Ein geschlossenes Zirkulations-Trocknungs-System wurde mit sechs unterschiedlichen Arzneipflanzenarten (*Melissa officinalis* L., *Achillea millefolium* L., *Alchemilla vulgaris* L., *Mentha* x *piperita* L., *Urtica dioica* L. und *Lippia triphylla* (L'Hérit.) Kuntze (*Verbena odorosa*) getestet, um die Eignung dieses Systems für die Produktion im Valle Camonica (Lombardei in Italien) zu prüfen mit dem Schwerpunkt der Untersuchung des Energieverbrauches als Funktion der zu trocknenden Arten. Im Jahre 2005 wurden insgesamt 27 Versuche durchgeführt, wobei folgende Daten erfasst wurden: anfängliche Frischmasse (kg) mit entsprechendem Feuchtegehalt (% wb), mittlerer Energieverbrauch des Systems (kW_{el}), Verbrauch an Elektroenergie (kWh_{el}), Masse des getrockneten Gutes am Ende des Trocknungsprozesses (kg) mit entsprechendem Feuchtegehalt (% wb), spezifischer Energieverbrauch (kWh_{el}/kg_{dried} und kWh_{el}/kg_{H2O}) und Dauer des Trocknungszyklus (h). Anhand von drei Indices wurden der mechanische Verlust (k_1) und der Produktions- (k_2) und Energieverbrauch (k_3) jeder einzelnen Art bewertet. Die Ergebnisse zeigten, dass *Achillea millefolium* (k_1 = 1.06, k_2 = 2.44 und k_3 = 0.56) bei den untersuchten Bedingungen die besten Ergebnisse brachte. Die ungünstigsten Werte wurden bei *Lippia triphylla* (k_1 = 2.76, k_2 = 0.63 und k_3 = 1.45) festgestellt.

Schlagwörter

Arzneipflanzen, Energieverbrauch, Trockenmasseverlust, Trocknung, Wärmepumpe

culate the output values (yields, energy consumption, duration) and plot curves of the temperature T_{dry} and T_{wet} (°C) and residual moisture content U_{dry} (%) of the product (only for simple cycles) (*Fig. 3*). To assist in evaluating the results, the absolute values were also used to compute three dimensionless indexes for comparing the suitability of the different species to the artificial drying process. These indexes, valid only within the process context under study, were designed to guide the growers of Valle Camonica in choosing the officinal species that are best suited to the drying process. The definitions of the performance indexes used are given in *Tab. 3*.

During the experimental trial period, particular attention was also given to the management of the drying plant and its interactions with the upstream and downstream links in the supply chain, in order to assure its rational introduction into the production system, and give operators sufficient autonomy in the running of the plant. The analysis of the results was carried out both in terms of the overall performance of the drying plant, i.e. without distinguishing between the different species being dried, and also by evaluating the suitability of the individual officinal species to the drying process.

Tab. 2: Types of cycles (simple, multiple cycle with single species and multiple cycle with different species) for each species
Tab. 2: Art der Trocknungsbelegung (einmalig, mehrfach mit einer einzigen Art, mehrfach mit mehreren Arten) für jede Art

Drying cycles (Art der Trocknungs-Belegung)	*Melissa*	*Achillea*	*Alchem.*	*Mentha*	*Urtica*	*Lippia*
Simple cycle (Einmalig mit einer Art)	2	-	2	1	1	-
Multiple cycle with single species (Mehrfach mit einer Art)	3	2	-	-	-	-
Multiple cycle with different species (Mehrfach mit mehreren Arten)	5	1	1	4	3	2
Total cycles (Anzahl Belegungen insgesamt)	10	3	3	5	4	2

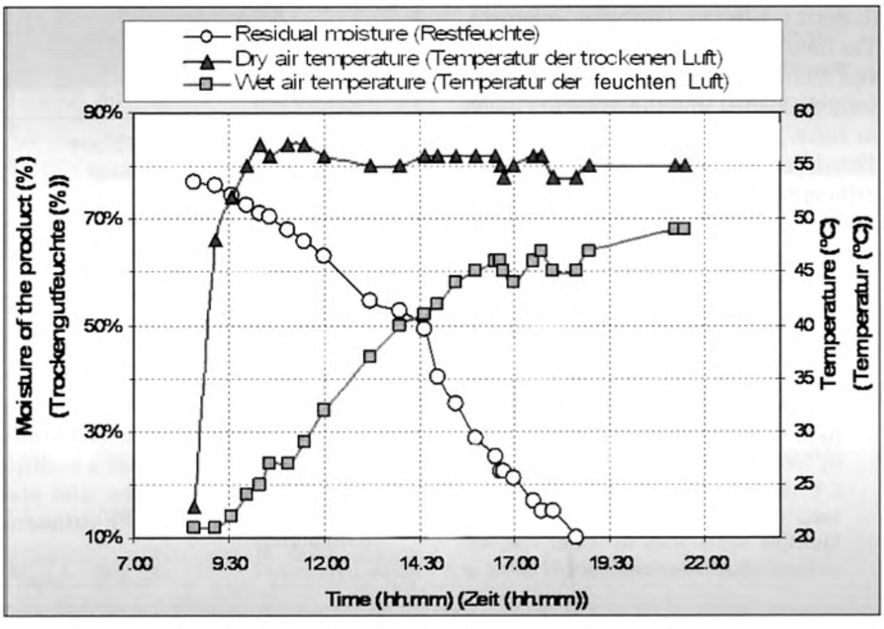

Fig. 3: Course of the dry (T_{dry}; °C) and wet air temperature (T_{wet}; °C) and residual moisture of the product (U_{dry}; %).
Abb. 3: Verlaufskurven der trockenen (T_{dry};°C) und feuchten Lufttemperatur (T_{wet};°C) und der Restfeuchte des Trocknungsgutes (U_{dry}; %)

Results and discussion

The results of the experiments are summarised in *Tab. 4*.

The total energy expenditure during 831 hours of operation of the drying plant was 3,329 kWh_{el}, used for drying a total of 2837 kg of green officinal plants, with a finished product yield of 648 kg (corresponding to 578 kg of dry matter).

The three index values are reported in the diagram of *Fig. 4*, which shows the different behaviour of the analysed species in a direct and synthetic way.

The resultant dry matter losses of 53 kg_{dm} were therefore considerable, corresponding to 8.3% of the total dry matter loaded into the plant. The comparison with the two-step haymaking, referring to large leaf forages (pulses, alpha-alpha), is related to mechanical total losses (both in the field and in handling) of about 15% (11), which leads us to consider the value found for spice plants as negligible and to be improved. The average specific consumption of electrical energy from the distribution grid, used to evaporate 2189 kg of water, was 1.52 kWh_{el}/kg_{H2O} (5.27 kWh_{el}/kg_{dm}), and the average power absorbed by the plant was slightly more than 4 kW_{el}.

Referring to the results of *Tab. 4*, the analysis indicates significant variability in the suitability of the individual species, connected primarily to their different morphologies and methods of cutting/harvesting.

The measured values, in fact, extend over fairly wide ranges, reflecting very different levels of suitability of each herb to the drying process, therefore giving a good indication of the most optimal choices of medicinal plant species for the cultivation introduced in Valle Camonica.

In particular, we note first of all that the initial production yield of *Alchemilla vulgaris* (R_{dm} = 0.351 kg_{dm}/m^2) is far greater than that of the other species which, apart from *Melissa officinalis*, all have values of around R_{dm} = 0.15-0.24 kg_{dm}/m^2.

From a technical point of view, an analysis of the performance indexes defined previously leads to some interesting observations (*Fig. 4*), in fact:

- The values of k_1 indicate that *Alchemilla vulgaris* is the species with the smallest mechanical losses (P% = 3.2%; k_1 = 0.39), as compared with the group of *Melissa officinalis – Achillea millefolium – Mentha* x *piperita – Urtica dioica* (P% = 5.8-12.3%; k_1 = 0.69-1.47) and *Lippia triphylla* (P% = 23%; k_1 = 2.76).
- The values of k_2 and k_3 both indicate that *Achillea millefolium* is the species best

Tab. 3: Indexes introduced for comparative evaluation of the dried species
Tab. 3: Indices für die vergleichende Bewertung der getrockneten Pflanzenarten

Index (Index)	Definition (Definition)	Notes (Erläuterungen)
Mechanical losses (Mechanische Verluste)(k_1)	$k_1 = \frac{P\%_s}{P\%_{ave}}$	$P\%_s$ (%) = dry matter losses of the species = ratio between the d.m. lost and the d.m. loaded into the plant for the species in question. $P\%_{ave}$ (%) = average d.m. losses = ratio between the total d.m. lost and the total d.m. loaded into the plant. Lower values of k_1 correspond to better performance of the species.
Drying performance (Trocknungs-leistung)(k_2)	$k_2 = \frac{CO_s}{CO_{ave}}$	CO_s (kg_{dm}/h) = productivity of the plant with the species in question = ratio of d.m. yield to the duration of the drying process for that species. CO_{ave} (kg_{dm}/h) = average productivity of the plant = ratio of the total d.m. yield to the total operating time of the plant.Higher values of k_2 correspond to better performance of the species.
Energy (Energie)(k_3)	$k_3 = \frac{CO_s}{CO_{ave}}$	CSd (kW_{hel}/kg_{H2O}) = average specific consumption of the species = ratio of energy consumed to weight of evaporated water for that species. CS_{ave} (kWh_{el}/kg_{H2O}) = average specific consumption of the plant = ratio of total energy consumption to total water evaporated by the plant. Lower values of k_3 correspond to better performance of the species.

suited to the drying process. In fact, this species had both the highest productivity (CO_s = 1.70 kg_{dm}/h), with a value nearly 1.5 times better (k_2 = 2.44) than the average, and a specific energy consumption (CS_s = 0,86 kWh_{el}/kg_{H2O} evaporated) of only around 55% of the average (k_3 = 0.56). *Alchemilla vulgaris*, on the other hand, despite an above-average productivity index (k_2 = 1.23), exhibits poor performance in terms of specific energy consumption, as reflected in k_3 = 1.17.

- The morphologically substantial (thick stems, late cutting) species, such as *Urtica dioica* and *Lippia triphylla*, despite having fairly good productivity (R_{dm} = 0.23 kg_{dm}/m^2), exhibit other drawbacks in the drying process (k_2 = 0.65; k_3 = 1.2-1.45).

It should be noted that in nearly all cases (*Tab. 4*) the final moisture level of the dried product was too low (U_{dry} < 15%), thereby having a negative impact on the process costs as well as

Tab. 4: Unloaded weight, losses of dry matter, duration, productivity, energy consumption, evaporated water, specific consumption, absorbed power, final moisture and percentages of the cycles with the final moisture less than 15%. The results concern all types of cycles.
Tab. 4: Endgewicht, Trockenmasseverlust, Dauer, Produktivität, Gesamtenergieverbrauch, verdunstetes Wasser, spezifischer Energieverbrauch, absorbierte Energie, Endfeuchte und Anteile der Trocknungsbelegungen mit einer Endfeuchte von unter 15%. Die Ergebnisse betreffen alle Trocknungs-Belegungstypen.

Trait (Prüfmerkmal)		Unit (Einheit)	*Melissa*	*Achillea*	*Alchem.*	*Mentha*	*Urtica*	*Lippia*	Total trials (Alle Versuche)	Value for total trials (Wert für alle Versuche)
Unloaded weight (Endgewicht)	$M2_{wm}$	kg_{wm}	212	139	92	106	69	30	648	-
	$M2_{dm}$	kg_{dm}	197	127	84	83	60	27	578	-
Losses of dm (TM-Verluste)	ΔM	kg_{dm}	12	12	3	12	6	8	53	-
	P%	%	5.8	8.8	3.2	12.3	8.7	23.0		8.3
k_1		-	0.69	1.06	0.39	1.47	1.04	2.76		1.00
Duration (Dauer)	t	h	277	75	99	193	125	61	831	-
	t_u	h/kg_{dm}	1.41	0.59	1.17	2.32	2.11	2.26	-	1.44
Productivity (Produktivität)	CO_s	kg_{dm}/h	0.71	1.70	0.86	0.43	0.47	0.44	-	0.70
k_2		-	1.02	2.44	1.23	0.62	0.68	0.63	-	1.00
Energy consumption (Energieverbrauch)	E_{el}	kWh	1210	292	489	726	394	216	3329	-
Evaporated H2O (H2O-Verdunstung)	M_{H2O}	kg	803	340	275	457	215	98	2189	-
Specific cons. (spezifischer Energieverbrauch)	CS_s	kWh_{el}/kg_{dm}	6.15	2.29	5.80	8.72	6.63	7.97	-	5.27
	CS_s	kWh_{el}/kgH_2O	1.51	0.86	1.78	1.59	1.83	2.21	-	1.52
k_3		-	0.99	0.56	1.17	1.05	1.20	1.45	-	1.00
Absorbed power (Absorbierte Energie)	P	kW	4.4	3.9	5.0	3.8	3.1	3.5	-	4.01
Final moisture (Endfeuchte)	U_{dry}	% weight	7.30	8.44	8.72	12.20	13.10	8.29	-	-
Cycles U_{dry}<15% (Zyklen U_{dry}<15%)		%	90	100	100	60	75	100	-	-

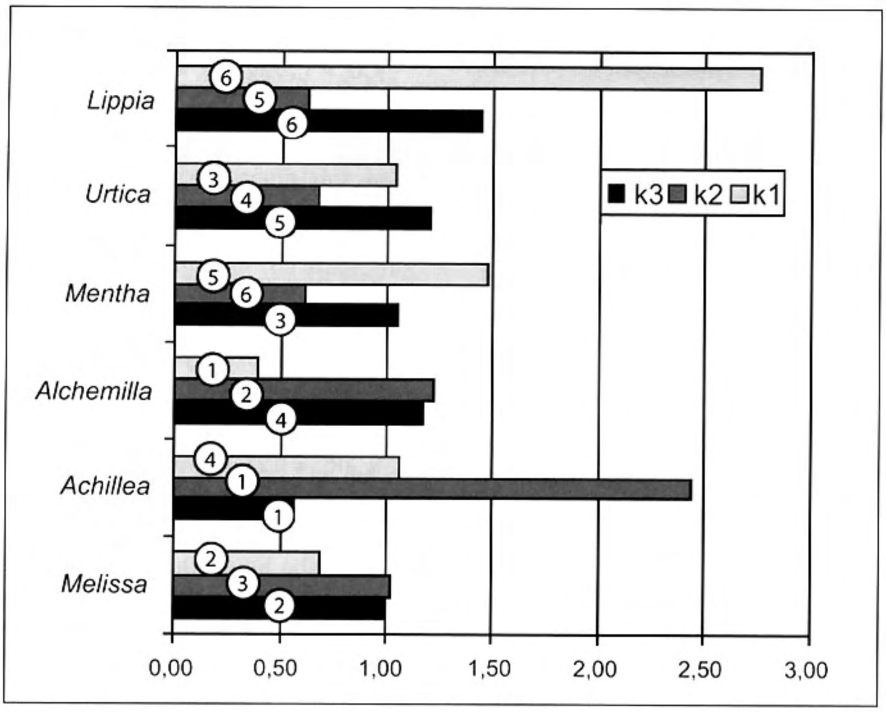

Fig. 4: Performance indexes k_1, k_2 and k_3 for the different officinal species. The numbers on the bars indicate the classification of each species.
Abb. 4: Leistungsindices k_1, k_2 und k_3 der verschiedenen Arzneipflanzenarten. Die Nummern auf den Säulen zeigen die Klassifikation jeder Pflanzenart an.

on the energy balance. The spice plants, in fact, are hygroscopic and have to undergo the customary practices for transport/storage and commercial preparation of the product. So, the drying process could be terminated earlier, to avoid waste both for the over-dried herbs and for the high energy production costs.

From an operational perspective, during the course of the experimental trials, the drying plant proved to be highly reliable and practical to manage, with simple working procedures that were perfected and fine-tuned during the first year of collaboration with the operators.

The drying plant tested during the 2005 season, owned by the Herbane Camune local growers' association, was able to process the entire officinal plant harvest of the association's members. Its incorporation into the supply chain presented some organisational difficulties (primarily connected with coordination of harvested plant material), and useful indications were obtained for selecting the most appropriate species for the territorial setting and, in particular, for the drying process phase.

It was found, in particular (*Fig. 4*), that three out of the six species (*Achillea millefolium, Alchemilla vulgaris, Melissa officinalis*) are well suited to the drying process, which has been implemented and organised within the supply chain of Valle Camonica.

From an energy perspective, a comparison of the plant's performance with that of conventional dryers equipped with direct combustion hot air generators (running on natural gas, LPG – liquified petroleum gas, or diesel fuel) indicated that the plant under study has a high consumption, arising from the use of electricity as an energy source. In fact, the conventional dryers used for two-stage forage haymaking (a process comparable to the drying of officinal plants) have specific consumption values in the order of 1.35-1.45 kWh_{th}/kg_{H2O} water evaporated (11), in primary energy terms and taking into account the average efficiency of grid electricity generation (8). The dryer under test, instead, has an energy consumption that is approximately three times higher than the direct combustion hot air generators.

The comparison with the results obtained by other researchers with heat pumps (2, 4, 6) shows that the tested plant and species are in line with previous studies, even if the incomplete optimisation of the system in terms of thermodynamic behaviour (air flow, drying temperature and others) suggests a margin of improvement. An alternative energy source, given the average power absorption of the drying plant and its location in a valley with many small waterfalls, could be the use of a small Pelton turbine for generating the electrical energy required. However, it would also be necessary to consider the cost of such an investment, the availability of suitable waterfalls that could assure continued water flow during the spring-summer period, and finally the considerable bureaucratic difficulties which still get in the way of micro-hydroelectric power plants.

The mechanical losses incurred during the drying process are an aspect which can certainly be improved upon by adopting special handling procedures for the more morphologically delicate species, which are more susceptible to crumbling or disintegration during drying. By the same token, the over-drying of the finished product can be readily corrected through more careful monitoring of the residual moisture content during the final hours of the process.

The two operational aspects described above, if they are adequately remedied, can lead to significant economic benefits for the process chain although testing will be completed, evaluating aspects related to the quality of the product that have not been investigated in this research.

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