Experimental trials of a dryer for officinal plants

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Introduction

The sector of officinal plants is currently undergoing strong 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 (flavourings, tisanes and infusions) to the production of homeopathic medicines and essences for the liqueur industry.

Because officinal plants tend to be well-adapted to precarious growing conditions (such as are commonly found in marginalised areas or in hill and mountain regions), the establishment of such local cultivations can often provide an opportunity for revitalising depressed micro-economies.

On a nation-wide scale [1], over 100 officinal plant species are cultivated on a total area of approximately 3,400 ha. However the species of significant importance are less than 40, and include: *bergamot,* which by itself occupies approximately 1500 ha (Calabria), *peppermint* (Piedmont), *flowering ash* (Sicily), *common chamomile*, *liquorice*, *lavender* and *lavandin*, *hypericum* and *flax*. Another 30 species occupy between 50 and 10 ha, while the remainder account for less than 10 ha.

The purpose of the present study was to test the functioning of an artificial drying plant with closed-circuit air circulation, evaluating the viability of its introduction into the traditional supply chain, any operational issues, and the energy consumption for each of the dried species.

The geographical context of the study was Valle Camonica (Lombardy Region, Brescia province), a mountain area where the cultivation of officinal plants was introduced in 2002 as part of a Regional Research and Development Project[1].

Process cycle of officinal plants.

The purpose of the technological process is to preserve the active principles found in the plants, making them available to the finished preparations for which the plants are used. The typical processes undergone by officinal plants are summarised in **Figure 1**, which shows how the operations after harvesting vary depending on the final application. There are in fact differentiated supply chains ending in the production of medicinal drugs (by drying or solvent extraction in analytical processes) or of essential oils (by distillation).

In the case of the production of medicinal drugs, a crucial phase is the drying process in which the moisture content of the plant tissues is reduced, thereby inhibiting respiratory and microbial activity and so better preserving the active principles. The above, also achievable through natural drying of

[1] Lombardy Region Project "Development of the production of officinal plants in a mountain area"

the green product, has historically been (and continues to be) the preservation method most favoured by growers [2], who are thus able to obtain a product that is easier to handle and has a higher market value.

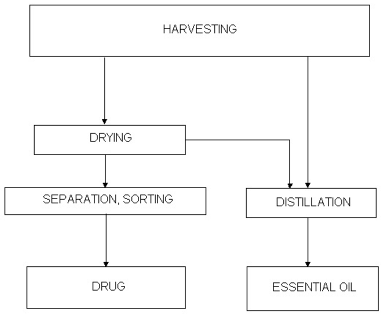

Figure 1 – Principal process operations and end uses of the products.

Materials and methods

1 - The dryer

The experimental trials were carried out on a highly compact system (**Figure 2**) with manual loading, consisting of a dryer chamber (capacity: $5m^3$) 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 hot air passing through. The air is opportunely conditioned by a refrigeration unit installed on the upper part of the dryer; 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, it 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) then circulates the air through the system, conveying it from the refrigeration unit to the drying chamber. These units are powered by electricity from the distribution grid.

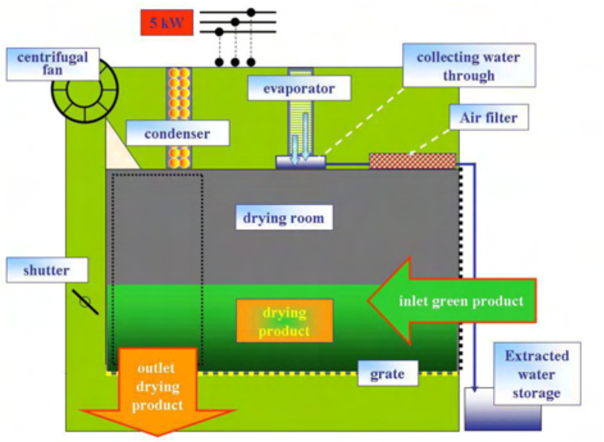

Figure 2 – Diagram of the drying plant.

All the process parameters and the duration of the drying phases are determined by a PLC controller, 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 differential $\Delta T = (T_{dry} - T_{wet})$ which must reach a pre-established value.

2 – Experimental method

The dryer system under study was tested by running drying cycles on 6 different officinal species: *Melissa officinalis, Achillea millefolium, Alchemilla vulgaris, Mentha piperita, Urtica dioica* and *Lippia triphylla.* The data relating to the harvested areas and the corresponding green product weights loaded into the dryer are given in **Table 1**.

Table 1 – Harvested areas, quantities and yields of the officinal species under test.

		UNIT	MELISSA	ACHILLEA	ALCHEMILLA	MENTHA	URTICA	LIPPIA	TOTAL
Harvested area	A	m^2	2241	712	248	627	288	146	**4262**
		% of tot	52.6%	16.7%	5.8%	14.7%	6.8%	3.4%	100.0%
Input weigth	$M1_{hv}$	kg_{hv}	1016	479	368	563	284	127	**2837**
	$M1_{dm}$	kg_{dm}	209	140	87	95	65	35	**631**
		% of tot	33.1%	22.1%	13.8%	15.1%	10.3%	5.6%	100.0%
Yield	R_{dm}	kg_{dm}/m^2	0.093	0.196	0.351	0.152	0.226	0.241	**0.148**

The dryer was used to carry out 3 different types of cycles:

- *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 27 trials were carried out during a 5 month period in the spring-summer of 2005. Of these, 6 were of a simple cycle, 5 of a multiple cycle with single species, and 16 of a multiple cycle with different species. The following values were measured in each case:

- The *initial mass (kg)* (green product) and the *final mass* (dried product), using a scale or dynamometer depending on the quantities involved.
- The *initial and final moisture* (% of green mass), measured in the laboratory on samples of green and dried product, using a precision balance and drying oven.
- The *temperatures of the drying air and of the moist air* (°C), by means of thermocouples placed within the air flows circulating in the plant.
- The reduction in the *residual moisture content* (% of green mass), 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 (kW_{el}) and its electrical energy consumption (kWh_{el}), using a grid analyser.
- The *specific energy consumptions* referred 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 meter.
- The *duration* of the drying cycle (h), using a dedicated chronometer.

The measurements taken in each experimental trial were entered into a spreadsheet which was used to calculate 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).

To assist in evaluating the results, the absolute values were also used to compute three dimensionless indexes for comparing the performance of the different species in the artificial drying process. These indexes, valid only within the process context under study, were designed to guide the growers of Valle Canonica in choosing the officinal species that are best suited to the drying process. The definition of the performance indexes used is given in **Table 2**.

Table 2 – Indexes introduced for comparative evaluation of the dried species.

INDEX	DEFINITION	NOTES
Mechanical losses (k_1)	$k_1 = \frac{P\%_d}{P\%_{ave}}$	$P\%_d$ (%) = 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.*
Productivity (k_2)	$k_2 = \frac{CO_d}{CO_{ave}}$	CO_d (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 (k_3)	$k_3 = \frac{CS_s}{CS_{ave}}$	CS_d (kWh_{el}/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.*

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.

Results

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 performance of the individual officinal species in the drying process (**Table 3**).

The overall evaluation found that the total energy expenditure during 831 hours of operation of the drying plant was 3329 kWh, 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 resultant total mechanical losses of 98 kg_{dm} were therefore considerable, corresponding to 15.5% of the total d.m. loaded into the plant.

The average specific consumption of electrical energy from the distribution grid, used to evaporate 2189 kg of water, was 1.52 kWh_{el}/kg_{H20} (5.27 kWh_{el}/kg_{dm}), and the average power absorbed by the plant was slightly more than 4 kW_{el}.

Table 3 – Results

VALUE		UNIT	MELISSA	ACHILLEA	ALCHEMILLA	MENTHA	URTICA	LIPPIA	TOTAL
Loaded weight	$M2_{hv}$	kg_{hv}	212	139	92	106	69	30	**648**
	$M2_{dm}$	kg_{dm}	197	127	84	83	60	27	**578**
Losses of dm	ΔM	kg_{dm}	28	24	5	17	11	14	**98**
	P%	%	13.2%	16.9%	5.4%	17.7%	17.4%	39.8%	15.5%
k1		-	**0.85**	**1.09**	**0.35**	**1.14**	**1.12**	**2.56**	**1.00**
Duration	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	CO_d	kg_{dm}/h	0.71	1.70	0.86	0.43	0.47	0.44	**0.70**
k2		-	**1.02**	**2.44**	**1.23**	**0.62**	**0.68**	**0.63**	**1.00**
Energy expended	EE	kWh	1,210	292	489	726	394	216	**3,329**
Evaporated H_2O	M_{H2O}	kg	803	340	275	457	215	98	**2,189**
Specific consumption	CS_d	kWh_{el}/kg_{dm}	6.15	2.29	5.80	8.72	6.63	7.97	**5.27**
	CS_d	kWh_{el}/kg_{H2O}	1.51	0.86	1.78	1.59	1.83	2.21	**1.52**
k3		-	**0.99**	**0.56**	**1.17**	**1.05**	**1.20**	**1.45**	**1.00**
Absorbed power	P	kW	4.4	3.9	5.0	3.8	3.1	3.5	**4.01**
Final moisture	U_{dry}	% weight.	7.30%	8.44%	8.72%	12.20%	13.10%	8.29%	
Cycles U_{dry}< 15%		n.	90%	100%	100%	60%	75%	100%	

Referring to the results of **Table 3**, the analysis indicates significant variability in the performance 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 performance in the drying process and so pointing toward the most optimal choices of officinal species for the cultivations 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} = 0.200-0.240 kg_{dm}/m^2.

From a technical standpoint, an analysis of the performance indexes defined previously leads to some interesting observations (**Figure 3**) , in fact:

- The values of k_1 indicate that *Alchemilla vulgaris* is also the species least subject to mechanical losses ($P\%_d$ = 5.4%; k_1 = 0.35), as compared with the group of *Melissa* *officinalis-Achillea millefolium-Menta x piperita-Urtica dioica* (P$\%_d$ = 13-18%; k_1 = 0.85-1.14) and *Lippia triphylla*.

- The values of k_2 and k_3 both indicate that *Achillea millefolium* is the species best suited to the drying process. In fact this species had both the highest productivity (CO_d = 1.70 kg_{dm}/h), with a value nearly 1.5 times better (k_2 = 2.44) than the average, and a specific consumption (CS_d = 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 more morphologically substantial (thick stems, late cutting) species such as *Urtica dioica* and *Lippia triphylla*, despite having fairly good productivity ($R_{dm} \cong 0.23$ kg_{dm}/m^2), exhibit other drawbacks in the drying process ($k_2 \cong 0.6$; k_3 = 1.2-1.3).

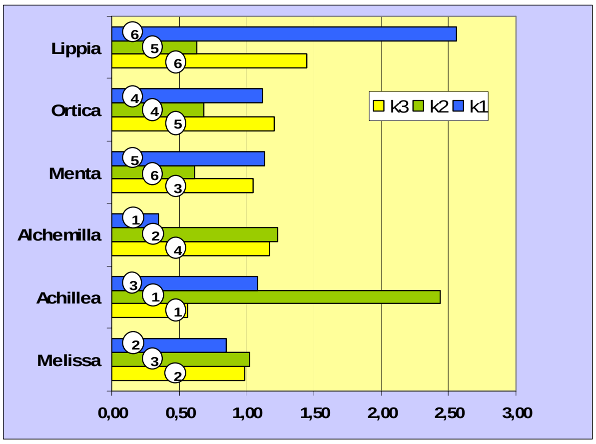

Figure 3 – Performance indexes k_1, k_2 and k_3 for the different officinal species. The numbers on the bars indicate the classification of each species

It should be noted that, in nearly all cases, the final moisture level of the dried product was too low (U_{dry} < 15%), thereby negatively impacting on the process costs as well as on the energy balance. Dried officinal plants are in fact hygroscopic, and therefore--given the customary practices for transport/storage and commercial preparation of the product, as well as the kinetics of the drying process—over-drying is a significant source of waste that can be easily remedied.

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.

Conclusions

The drying plant tested during the 2005 season, owned by the "*Herbane Camune*" local grower's association, was able to process the entire officinal plants harvest of the association's members. Its incorporation into the supply chain presented some organisational difficulties (primarily connected with coordination of harvesting with available plant capacity), 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, (Figure 3) that 3 out of the 6 species (*Achillea millefolium, Alchemilla vulgaris, Melissa officinalis*) are especially well-suited to the drying process as it 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, 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, if we consider that 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} evaporated [3], in primary energy terms and taking into account the average efficiency of grid electricity generation [4, 5], the dryer under test has an energy consumption that is approximately three times higher.

One technically feasible means for improving the overall energy balance, given the average power absorption of the drying plant and its location in a valley with many small water drops, 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 a suitable water drop that assures continued water flow during the spring-summer period, and finally the considerable bureaucratic difficulties which still stand 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 procedures for the more morphologically delicate species, that 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.

Addressing the two operational aspects described above, if they are adequately remedied, can lead to significant economic benefits for the process chain.

Bibliography and websites

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