XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

EVALUATION OF OPERATIVE ASPECTS OF A HEAT PUMP TO DRY CHESTNUTS

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CSBE100935 – Presented at Section VI: Postharvest Technology, Food and Process Engineering Conference

ABSTRACT The Italian chestnuts market, with a capacity of 50,000 tons per year, is in a leading position among European countries, and the fourth worldwide. The production of chestnut flour is a viable alternative to fresh consumption. The process includes a step of drying that can be done by different methods like the traditional one that uses coal, the dryer based on forced air by convection ovens and the innovative ones based on heat pumps. The last ones drying at low temperatures, allow to obtain qualitative properties of greater value. Drying is an energy intensive operation, heat pump drying allows the decrease of process costs. The research studied the efficiency of the dried plant based on a heat pump which provides a drying temperature of 30 °C and an air flow rate of about 5 m^3/s. We monitored two cycles of drying of chestnuts to obtain the drying curves (from 45% to 10% humidity variation). The behavior of the process on the product (temperature and humidity levels) and the efficiency of the heat pump were analyzed. Thanks to an electric analyzer, in addition, it was possible to define the consumption of individual electric utilities and the techno-economics of the whole process. Some parameters were evaluated to characterize the final products resulting from the drying methods.

Keywords: heat pump, chestnut, dry efficiency.

INTRODUCTION

The chestnut area in Italy is nearly 800 thousands hectares out of total forested area of 8.8 million of hectares. Forestry statistic shows that the chestnut fruit area is about 150 thousand hectares, concentrated along the Apennine ridge, but the area under cultivation is actually much more limited and did not exceed 54 thousand hectares in 2007, distributed in 30 thousands farms. Italy is the main European producer of chestnut, with a leading position among European countries, and the fourth worldwide after China, South Chorea and Turkey.

The average yearly value of chestnuts production goes from 50 to 85 million €/year; the international trade is quite relevant, as Italy exports about 20 thousand tons per year; the imports ranging from 3 to 12 thousand tons per year, related to the domestic supply.

Chestnuts are seasonal fruit, harvested in October and November and are characterized by a limited shelf-life due to their high water activity and sugar content. The drying process is the oldest method for the conservation of these fruit (Breish, 1996), it is an old but still

used storage method, especially in areas where there has been a long tradition of production and use of this treatment (G. Bounous, 2006).
The drying process, according to the traditional method is still now in special masonry commonly called "dryers", located within the chestnut grove or in corporate houses. The dryers were stone structures, generally and almost always formed from a single room divided roughly half the height of a single deck consists of chestnut wood plate, and more recently in wire mesh. Through the window load, located at the top of dryer, it's possible to introduce the chestnuts that are laid out on the towers to be subjected to drying, usually forms a layer of fruit at least 30 cm. In the space below is lit the fire, fed exclusively with chestnut wood and kept burning, strictly without flame, taking care to contain the heat within the 35-40 °. The drying process is concluded in about 40 days. The draw-back of traditional method, was often disagreeable smoky flavour the nuts acquired (M. Crawford, 1995). This traditional production process is very costly, today there are modern technologies which improve the yield.
Forced convection by hot and dry air is the most common industrial technique to perform food drying. This process is generally realized in ovens where air flows with specific velocity profiles through the food positioned on suitable supports. Typical values of air temperature range between 40°C and 80°C, while air velocity normally changes from 0.5 to 5 m/s, reaching, in some cases, the value of 10 m/s (M. Aversa, 2007).
Drying technique have been used for centuries, undergoing important evolutions. Studies on drying processes are numerous because it is one of the most common industrial operations and involves high energy consumption (Mujumdar and Passos, 2000, T. Koyuncu et al. 2004).
In the literature much attention is focused on the impact of different heat treatments on chestnut composition, with the aim to check and to conserve the quality of fresh chestnut (G. Attanasio et al., 2004; R.M.C., Fernandes et al., 2005).
Drying is an energy intensive operation. Timely and low temperature (30-35°C) drying chestnut is essential for producing high quality products and prolonging the shelf life of active ingredients in the itself. A drying system that is both energy efficient and preserves product quality is desired. The heat pump dryer, carrying dried at low temperatures, with more efficiency than conventional dryers (O.A.Filho at al., 1996; K. Phani et al, 2005) allow to obtain qualitative properties of greater value.
Manufactured chestnut-based products show interesting nutritional characteristics and can be also included in the diet of celiac patients due to their low gluten content.
The objective of this work was to study heat pump dryer for performing experiment particularly to optimize the chestnut's drying process in order to reduce the processing time and increase productivity. In particular, a study was conducted in order to verify the effective usefulness of the operation of regular mixing of the chestnuts quantifying its impact on the process both in terms of time and economic aspects and to measure parameters to indicate the principals differences between flour produced with traditional method and flour resulted for drying process with heat pump.
In literature there are no real parameters to describe the really quality of chestnut flour. It speaks rather of its characterization (R.M.C., Fernandes et al., 2005; Attanasio G. et al., 2004; U. Kunsch, 2001; De la Montana et al., 2004) so in this paper were defined some quality parameters based on the color and on the smell.

EXPERIMENTAL APPARATUS AND PROCEDURE

Chestnuts used for testing were collected from areas located at an altitude between 300 and 1000 meters, in Valle Camonica, near Paspardo (Italian Alps, Lombardy).

Re-circulating heat pump dryer system

The drying process is based on the ability of dry and warm air to transfer heat to the product resulting in the evaporation of water contained in plant tissues.

In this case, the air-vapor mixture that is formed at the exit of the drying cells is not dispersed but is properly "treated" by the heat pump which is the main component of the plant, making it suitable for a subsequent drying process. The operation is not automatic, but "semi-automatic, thus it require the planting needs an intervention and control by an operator with specific tasks in the management and control of the drying process.

Drying system

The plant is composed by three identical drying cells (Length: 3680 mm Width: 3770 mm Height: 3120 mm) for a unit volume of about 43 m^3. The cells are made of masonry and, internally, have walls lined with insulating material to minimize heat loss, the common wall between contiguous cells, however, consists only of an insulating material. Inside each cell there is the conduit for the air adduction of dry size 1140x460 mm (0.524 m^2) terminated with 2 nozzles adduction, grilled and each of which opening 980x130 mm, for a section of the total input air dried 0.254 m^2.

Each cell also includes 3 air vent in the ceiling of the room, each of size 500x300 mm, for a section of the total emission of 0.450 m^2. The air vent are connected to the return air conduct which has dimensions of 760x760 mm (0.578 m^2).

The dry air duct in each branch to the drying cells, presents a slide gate latch that allows to send the flow of dry air to the selected cell that will be used according to the operational necessity.

In addition, 1 electrical resistance of the power of 3.0 kW_e, is installed in each cell within the supply main air dry in its basal part immediately before the air vent.

Heat Pump System

The basic purpose of a heat pump in a re-circulating hot air dryer is to supply drying chamber at the desired temperature and simultaneously to dehumidify the exhaust air coming from the drying chamber.

Instrumentation

A hotwire anemometer located in the drying chamber, at the level of the inlet of dry and hot air provender from fan, was used to measure the air velocity in the closed loop system.

To detect air temperature and air moisture in each cell there was a thermocouple positioned and relative humidity sensor.

Experimental procedure

Chestnuts were monitored for two drying cycle, the environmental parameters (temperature, relative humidity) and energy (power consumption, power draw) were also measured for studying the dynamics of the process from the point of view of the product (mass, humidity).

The research studied the efficiency of the dried plant based on a heat pump which provides for the use of drying temperatures of 30° C and air flow rate of about 5 m^3 / s.

Were monitored two cycles of drying of chestnuts to obtain the drying curves.

Every 8 hours (at precisely 8:00 am, 16:00 and 24:00 each day for the entire duration of the trial) were taken of samples (about 5-6 chestnuts) in 9 different locations in the cell,

representing the whole surface of the product. For each position are identified 2 samples, one at 5 cm from the surface of the mass of chestnuts and one at 5 cm from the base (support network). For each sample, therefore, you get 18 samples, whose mass was measured with a precision balance.
Dry weight, and so, relative humdity RH (%), was measured using an oven (thermostability C4, OVENLAB). The analytical methods used included the complete drying of the product at a temperature of 103 ° C, until constant weight at 24 hours.
The 2 cells used were managed in a different way during the drying process:

- First cell: the whole mass of chestnuts was deposited on the bed of the network, making sure to get the product to a height of 30 cm. In the first cell the product was mixed (2 times a day) during the drying process in order to standardize the mass of the product during the process.
- Second cell: the whole mass of chestnuts was also filed in this case on the bed of the network, making sure to get the product to a height of 30 cm. In this case, however, there was be no operation of regular mixing of the chestnuts throughout the process. The comparison of these two different operational mode was usefull to verify the effectiveness of mixing operation in relation to working time required for this procedure and then evaluate the opportunity to make it or not in the future.

Energy evaluation

The presence of a power analyzer in the electrical system has allowed to measure the main characteristics of energy (power (kW) and energy (kWh)) of all electric utilities of the dryer, the total energy consumption of drying process and the specific moisture extraction rate for heat pump dryer.

Flour characterization

Determination of color

The color of flour was measured with Minolta CR 410, according to the CIE (Commission Internationale de l'Eclairage) system, determining L* (lightness), a* and b* (chromaticity coordinates) and parameters derived from these C (equation number 1) and h (equation number 2).

$$Metric\ Chroma:\quad C* = \sqrt{a^{*2} + b^{*2}} \qquad (1)$$

$$Metric\ Hue-Angle:\quad h = \tan^{-1}\frac{b^*}{a^*}\ (degree) \qquad (2)$$

Electronic nose analysis

The electronic nose collects the information through an array of sensors, able to respond selectively and reversibly in the presence of chemicals, generating electrical signals as a function of their concentration. Consisting of ten sensors, each of which is calibrated to read specific molecules (Table 1):

Table 1 - Molecules detected by ten electronic nose sensor.

Sensor	Molecules detected
W1C	Aromatic compounds
W5S	Oxides of nitrogen, low specificity
W3C	Ammonium compounds, aromatic
W6S	Hydrogen

W5C	Alkanes, aromatic compounds, less polar compounds
W1S	Methane, low specificity
W1W	Sulfur compounds, terpenes, limonene, pyrazines
W2S	Alcohol, partially aromatic compounds, low specificity
W2W	Aromatic compounds, organic sulfur compounds
W3S	Methane

The information is initially encoded as electrical, but are immediately captured and digitized in order to be translated numerically by a computer system.

Statistical elaboration

The relative humidity data were statistically processed by analysis of variance and applying the Student t test using a significance level of P = 0.05. Techniques of multivariate analysis (Principal Component Analysis) were applied also on chestnut quality attributes.

RESULTS AND DISCUSSION

The hotwire anemometer allowed to measure the air flow rate of the plant and its flow. With the shutters for the control of the influx of air drying chambers open at 3 shows how the flow tends to increase away from the heat pump, because, at the farthest cell 3, there is the maximum value of average speed (V_{C3} = 6.36 m / s), corresponding to the scope Q_{C3} = 5829 m^3 / h. The distribution percentage of the total flow ($Q_{C1} + _{C2} + _{C3}$ = 14,938 m^3 / h): cell 1 Q_{C1}% = 27%; cell 2 Q_{C2}% = 34%; cell 3 Q_{C3}% = 39%, indicating a skewed distribution of the flow to be taken into account in the case of simultaneous use of all the cells available.

The first cycle lasted 10 days, for a total of 240 hours. Cell 2 was loaded with 1.6 t of fresh product, while cell 3 with 1.76 t (quantity selected according to the needs of the Consortium). At the end of process weight was decreased by 45% for cell 2 and 42.5% for cell 3. The end of the process has been decreed by the people of the Consortium based on experience gained over time, based on the peel, hardness and internal color of chestnuts.

Cycle II lasted 9 days, for a total of 216 hours. Cell 2 was loaded with 1.42 t and the cell 3 with 1.527 t of fresh produce. At the end of the process there was a weight loss of 45.5% for cell 2 and 39.7% of the cell 3. The second cycle lasted one day less than the first. This mainly because the moisture of the starting product was lower (4.6% of relative humidity less).

The conservation would seem in fact play an important role on the moisture initial chestnuts since these were stored in refrigerated compartments about 20 days longer than those dried in the first cycle (Chenlo et al., 2009).

Based on the analysis carried out it was possible drawing the typical curve of drying of chestnuts (Figure 1). In fact, the chestnuts have an initial moisture at about 48 - 50% to reach the target of 10% after about 240 hours of drying.

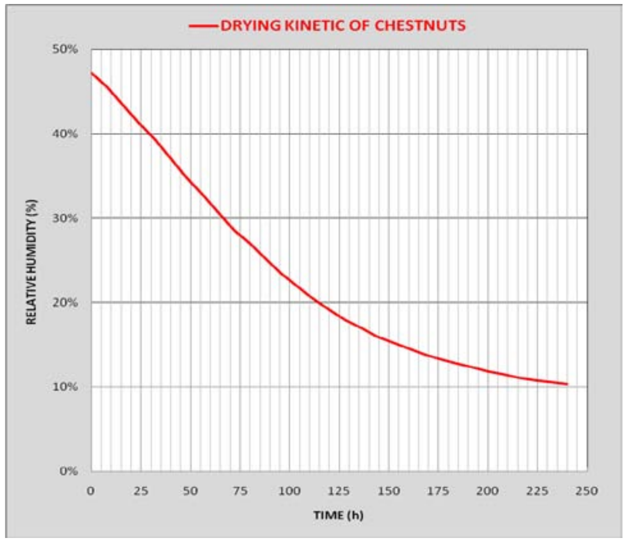


Figure 1- Typical curve of drying chestnut obtained from the experimentation.

Energy evaluation

Energy consumption has been possible thanks to the network analyzer at the plant in the electrical panel. Cycles monitored, in fact, were not used other facilities that would have affected the measurement of parameters such as power and electricity consumption. 3030 kWh were consumed within 10 days of the trial, due entirely to the plant drying. Whereas the sum of the total dried chestnuts, for this cycle was 1892 kg, can be traced to the energy consumption per kg of dried chestnuts: 1.60 kWh / kg of dried chestnuts. Knowing that the cost of energy and € 0.11 per kWh (electricity bill in July 2009_Valle Camonica energy services), energy consumption is 0.18 € / kg of dried chestnuts. The operator, now adopted, making the inversion twice daily in two cells drying takes 60 minutes (15 minutes for a single task of turning) for a total cost of 8 € per day, multiply by 10 days drying it comes at a cost of 80 € for the whole process of labor . So this operation provides a cost of 0.04 € / kg of dried product. Suppose we add this cost to the electricity consumed per kg of dried chestnuts, the total cost reached € 0.22 / kg of dried chestnuts. The use of labor increases the cost of one kg of dried chestnuts by 18%. As already mentioned, this operation directed not bring benefits in terms of time, so this cost is considered to be useless.

Load curve

The power analyzer has determined the absorption of power related to the electrical components on the installation of drying (Table 2).

Table 2 - Power consumption of the plant components measured by network analyzer.

DRYER PARTS	POWER CONSUMPTION (kW_e)
Fan air drying (F)	3,30
Resistors (R)	3,30
Heat pump (HP)	4,30
Lamp inside the dry chambre (n. 2 neon) (I)	0,12
Lamps external to the drying (n. 2 neon) (E)	0,12

Based on these findings it is interesting to highlight some examples of cumulative absorption or load curves, typical operating states of the drying quite common (Table 3)

Table 3 - Some typical power requirements combined F = Fan; HP = Heat Pump R = Electrical resistance, I= lamps inside the cell, E = external to the lamps. In the case of multiple users (resistances, lamps) the number in parentheses following the symbol indicates the number of devices in use.

STATE OPERATING SYSTEM	COMPONENT IN FUNCTION	POWER CONSUMPTION
Drying with resistance in 3 drying cell (fully loaded, winter)	F; HP; R(3); I(6); E(9)	19,3 kW_e
Drying without resistance in 3 drying cell (full load, summer-autumn)	F; HP; I(6)	8,3 kW_e
Drying with resistance in 1 cell (partial load, winter)	F; HP; R(1); I(2); E(9)	12,2 kW_e
Drying without resistance in 1 cell (partial load, summer-autumn)	F; HP; I(2)	7,9 kW_e
Dryer not working, presence of personnel in the warehouse	I(9)	1,1 kW_e

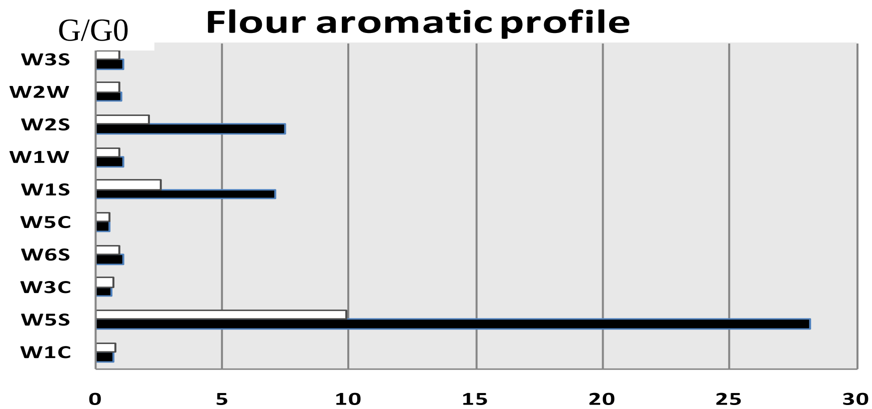
In Table 4 is showed that the final humidity of the cells 2 and 3 have significant differences only in the cycle II. But for the latter is more efficient than the cell cycle in which there was no actual revolt. This underlines the futility of mixing chestnut and the greater efficiency of the cell 3, compared to 2.

Table 4 – Indicates the results of the statistical analysis carried out between the two cycles between the 2 cells of each cycle.

<table>
<tr><th colspan="4"><u>Statistical elaboration</u> (Test t di Student; P=0,05)</th></tr>
<tr><th colspan="2">Comparisons</th><th colspan="2">Humidity results in the final</th></tr>
<tr><td rowspan="2">Cycle I</td><td>Cell 2</td><td rowspan="2">No significant difference</td><td rowspan="4"><u>Significant difference</u></td></tr>
<tr><td>Cell 3</td></tr>
<tr><td rowspan="2">Cycle II</td><td>Cell 2</td><td rowspan="2"><u>Significant difference</u></td></tr>
<tr><td>Cell 3</td></tr>
</table>

<u>Electronic Nose</u>

The analysis performed with the electronic nose showed, in Figure a greater flavor for flour produced by the traditional method in particular for 3 sensors detectors W2S, W1S and W5S.



	W1C	W5S	W3C	W6S	W5C	W1S	W1W	W2S	W2W	W3S
□ flour HP	0.76	9.86	0.71	0.95	0.59	2.55	0.95	2.14	0.94	0.95
■ flour T	0.71	28.17	0.65	1.06	0.53	7.09	1.09	7.50	1.06	1.09

Figure 3 – Shows the electrical response of the electronic nose, expressed as a ratio of two resistances (G/G0) as a function of the compound received.

<u>Colour analysis</u>

Parameters were measured as *L**, *a**, *b**, *C* and *h* parameters. The values seem to differentiate the two flours with good repeatability.
Samples of flour dried by the traditional method differs clearly from those dried with the heat pump dryer. This means that the colorimetric analysis Minolta, with applications multivariate analysis (Principal Component Analysis_PCA) can give interesting results for the characterization of chestnuts flours (Figures 4 and 5).
From “Loadings plot” graph (Figure 4) follows: the variables *C* and *b*, on the right of the graph at the bottom, show a certain degree of correlation, as well as variables *h* and *L* at the base of the left of the same figure.

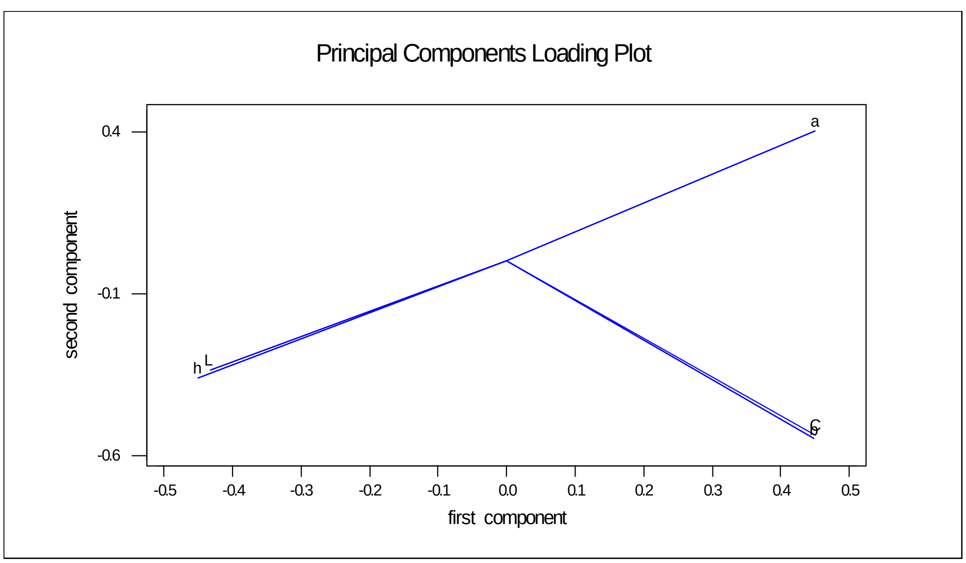


Figure 4 – Represents the distribution of 5 variables (*L **, *a **, *b **, *C* and *h*), representing the color of samples studied, developed according to the 2 main components.

The graph of the scores can be deduced: it's possible to recognize the similarity of intra-group of flours produced with conventional drying (traditional drying) than those resulting from drying with heat pump (HP drying) or neighbors in the Figure 5.
The two flours are separated along the first component alone explained 93.6%.

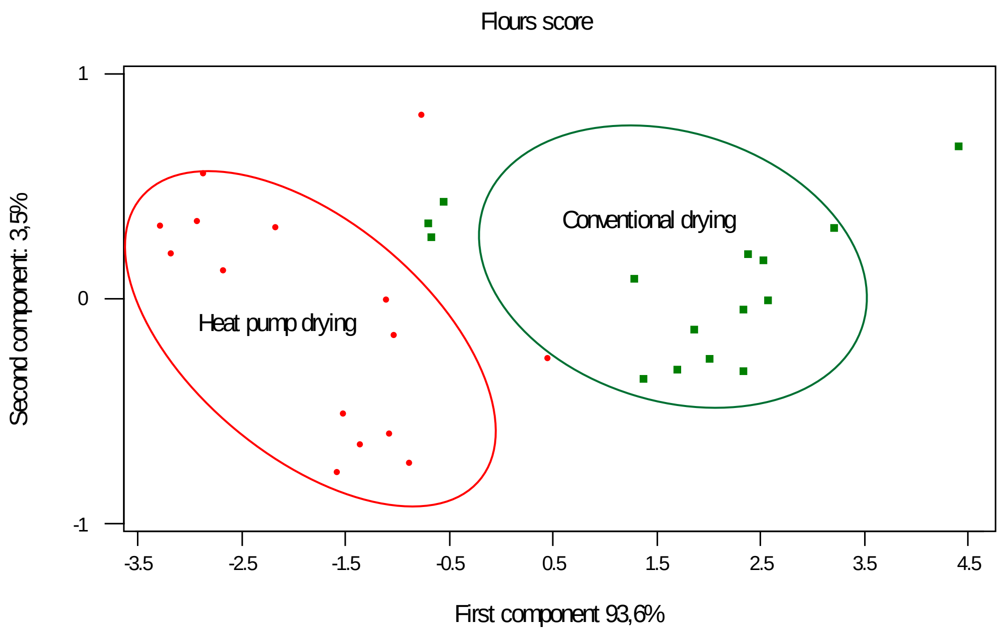


Figure 5 – Shows the distribution of samples of flour on the basis of 2 main components.

CONCLUSION

One of the problems in the cultivation of chestnut is the almost simultaneous ripening of all the cultivars, which is concentrated from late September to late October, and the high perishability of fruits. Improve the drying process, reducing the time and by implementing conservation techniques, should allow to harvest and to work a major number of chestnuts, with the goal of postponing the offering on the market.
For this purpose, measuring the parameters that influence the process of drying of chestnuts, were analyzed and interpreted data from the instruments used to monitor these important variables (time, temperature, relative humidity, energy consumption). The revolt of the product during the process was assessed not advantageous because it don't allows to shorten the process so that they can justify the cost of labor for this operation. In fact not making the revolt of the product will save about 0.04 euro / kg of dried chestnuts. The specific moisture extraction rate for heat pump dryer is about 0.3 kg / kWh_e.
The color analysis and the results arising from the electronic nose is able to recognize and characterize the dried flours produced with different processes (traditional and heat pump). They also have the advantage of being non-destructive analysis.

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