Grasas y Aceites
Vol. 47. Fasc. 3 (1996), 136-141

Power consumption and quality features in the hammer crushing process for olive oil production (*)

By **B. Bianchi** (1) and **P. Catalano** (2)

(1) Istituto di Meccanica Agraria, Universitá di Bari, Via Amendola 165/A, 70126 Bari (Italy)
(2) Dipartimento S.A.V.A.–Sezione Ingegneria and Ambiente, Universitá del Molise, Via Cavour 50, 86100 Campobasso (Italy)

RESUMEN

Consumo energético y características de calidad en el proceso de trituración mediante molino de martillo para la producción de aceite de oliva

En una investigación previa, se ha llevado a cabo un análisis preliminar sobre el balance térmico en diferentes sistemas de trituración para la producción de aceite de oliva.

De acuerdo con los resultados previos, en este trabajo el estudio se ha extendido a aspectos del consumo energético relacionados con las principales características de calidad del aceite de oliva extraído, limitando el análisis sólo a la trituración mediante molino de martillo (variedad *Coratina*), la cual representa el peor caso.

En particular, se ha estudiado el efecto de la alimentación de aceitunas sobre el consumo energético y calidad del aceite extraído.

Los ensayos experimentales, llevados a cabo en una planta de laboratorio durante los períodos de producción de aceite de oliva de 1993-94 y 1994-95, mostraron que, aunque el diagrama del consumo energético tuvo un incremento parabólico, la energía específica disminuyó con la alimentación de aceitunas.

Con todo, estudiando el proceso de trituración de aceitunas mediante molino de martillo también desde el punto de vista cualitativo (polifenoles, índice de acidez, índice de peróxido y tiempo de inducción), es posible definir un rango óptimo del valor de alimentación de aceitunas.

Este rango óptimo (140 kg/h - 249 kg/h) para el molino de martillo estudiado) representa la mejor solución de trabajo tanto desde el punto de vista del balance energético como de la calidad del aceite extraído.

En particular, al inicio del período de producción de aceite de oliva es necesario trabajar cerca de la banda más baja del rango óptimo definido. Con el paso del tiempo de recolección, la alimentación de aceitunas tiene que ser incrementada, alcanzando valores cercanos a la banda más alta al final del período de producción de aceite de oliva.

PALABRAS-CLAVE: Aceite (calidad) – Alimentación de aceitunas (efecto de) – Consumo energético – Molino de martillo.

SUMMARY

Power consumption and quality features in the hammer curshing process for olive oil production

In a previous research, a preliminary analysis on the thermal balance in different crushing systems for olive oil production was carried out.

According to the previous results, in this paper the study has been extended to power consumption aspects related to the main quality features of the extracted olive oil, restricting the analysis only to the hammer crushing (*Coratina* cultivar), which represents the worst case.

In particular, the effect of the olives delivery on the power consumption and quality of the extracted oil has been studied.

The experimental trials, carried out on a laboratory plant during the 1993-94 and 1994-95 olive-oil seasons, show that, even though the diagram of power consumption has a parabolic increasing trend, the specific power decreases with the olives delivery.

Anyway, studying the olives hammer crushing process also from the qualitative point of view (polyphenols number, acidity, peroxide number and induction time), it is possible to define an optimal range of olives delivery values.

This optimal range (140 kg/h-240 kg/h for the studied hammer crusher) represents the better working solution from both the point of view of the power consumption and the quality of the extracted oil.

In particular, at the beginning of the olive oil season it is necessary to work near the greatest lower bound of the optimal range just defined. With the passing of the harvesting time, the olives delivery has to be increased, reaching values near the greatest higher bound at the end of the olive oil season.

KEY-WORDS: Hammer crusher – Oil (quality) – Olives delivery (effect of) – Power consumption.

1. INTRODUCTION

In a previous paper (*Bianchi et al., 1993)* the operative conditions of different olive-crushing systems were studied, paying particular attention to the temperature effect on te olive-paste mainly in relation to the quality of the extracted oil.

It was found that the hammer crushing system represents the worst condition. In fact, during a traditional crushing process (roller crushing) the paste temperature increases about 4°C above the environmental temperature, instead of the hammer crushing plant from which the olive paste comes out at a temperature of about 12°C above the environmental temperature.

* Research supported by National Council of Italy, Special Project RAISA, Subprojet N. 4.2.09, Paper N. 2384.

Then, it was noticed that the parameters which mainly influences the temperature rise in the hammer crusher are: olives delivery and heat exchange surface.

More precisely, in order to work with high deliveries, it was found that should be necessary to modify the industrial plants, according to their production potential, properly designing the heat exchange surface.

The present research has been carried out during the last two olive oil seasons (1993-94 and 1994-95), using a pilot hammer crusher having a suitable heat exchange surface, with the main aim to evaluate the delivery effect both on the power consumption and the quality of the extracted oil.

2. MATERIALS AND METHODS

2.1. Plant description

The pilot plant used for all the experimental trials, consists of the following components, all made of stainless steel:

- olive feedbox,
- screw conveyor,
- hammer crusher,
- mixer.

The shape of the olive feedbox is a truncated pyramid with rectangular bases (upper base: 53.8 cm x 30.7 cm, base below: 8.0 cm x 14.0 cm, height: 23.0 cm) which can contain up to 30 kg of olives.

The olives pass from the feedbox to the hammer crusher through a screw conveyor wich has a pitch of 5.0 cm, a length of 24.0 cm and a diameter of 5.8 cm. The cylindrical duct, containing the tangent screw, has a diameter of 6.5 cm.

The feeding system is designed in order to work with different olives deliveries: 40 kg/h, 80 kg/h, 120 kg/h, 240 kg/h, 360 kg/h. These delivery values were obtained connecting a motor reducer to the screw conveyor shaft.

The olives fall from the screw conveyor end into the crushing system which consists of four hammers, horizontally disposed on a single plane, and of a cylindrical grid. The hammers are fixed on the driver shaft of an induction motor, without any motor reducer, rotating at 293.2 rad/s.

The optimal theoretical value of the olives delivery Q [kg/h] is related to the grid height H_g [m], its diameter D_g [m] and the hammers angular velocity ω [rad/s] according to the following equation (*Chelazzi, 1966*):

$$Q = kD_g^2 H_g \omega^2 \qquad (1)$$

where $k = 1.0$ kg $s^2m^{-3}h^{-1}$ is the units conversion factor.

The main characteristics of the hammer crusher components are summarized in Table I. During each test almost the total surface of the grid was in contact with the external air, thus realizing a large heat exchange surface.

At last, the crushed paste falls into a mixer which, in our trials, has been used only as a temporary tank (mixing time 15 minutes).

Table I
Geometrical and electrical characteristics of the hammer crusher used in the experimental trials

GRID	Height: H_g	0.065 m
	Diameter: D_g	0.155 m
GRID HOLES	Number n_h	500
	Diameter: D_h	0.005 m
HAMMERS	Number (single plane): N	4
	Angular velocity: ω_c	2800 rpm (293.2 rad/s)
INDUCTION MOTORS	Max. current	13.5 A
	cos ϕ	0.94

2.2. Experimental tests

In order to evaluate the most suitable production potential of the hammer crusher, 13 experimental trials on the previously described pilot plant were carried out.

Main aim of these trials was to relate the power consumption analysis to the quality of the extracted oil in different operating conditions, using the *Coratina* cultivar which is particularly subsceptible of damaging during hammer crushing (*Angerosa et al., 1995- Solinas, 1987).*

The olives, just harvested, were directly transported to the laboratory, divided in samples of 20 kg each and immediately processed. The independent variables considered in this research were harvesting time and feeding delivery for two olive-oil seasons (1993-94 and 1994-95).

During the crushing process, current-voltage measurements were performed with a data acquisition system consisting of a wattmeter, inserted in the power line, and an oscilloscope, used to acquire the line current and voltage waveforms on the corresponding coils of the wattmeter. The voltage-to-current correction factor was set to the admittance value of the current coil.

The oscilloscope trigger was driven by the current measurement channel, setting its threshold to a value a little above the minimum measured current (i.e. without olives feeding).

Basing this choice on the actual root-mean-square current value, only the waveforms corresponding to the highest power consumptions during processing were stored.

Then, also considering the little phase shift of the induction motor driving the hammer crusher (cos ϕ = 0.94), instant power consumption can be easily computed.

After each test, carried out with constant delivery, the obtained olive paste was divided in two samples, from which was extracted the oil, respectively, without and with mixing. The main aim of this test procedure was to more precisely define the effect of the crushing process (*Angerosa et al., 1990 - Sacchi, 1995*), separated from the following mixing one, on the olive-oil quality, then to verify that the results are confirmed also extracting the oil after the mixing process.

On this purpose the mixing time was maintained constant in all the trials (15 minutes). We extracted the oil by means of a pan centrifuge and separated from the vegetable water using a centrifugal separator (vertical axis). Then the oil was sent to the laboratory of the *Industrie Agrarie* Institute (University of Bari - Italy) for the following chemical analysis: acidity, peroxide number (N.G.D., 1976), total polyphenols (*Cortesi et al., 1981*) *(Favati et al., 1994)*, induction time at 130° C (Rancimat-Metrohm).

3. RESULTS AND DISCUSSION

In fig. 1 the power consumption, depending on the olives delivery and referred to the first olive oil season (november 1993), is shown. In particular, by means of the above described data acquisition system, different values of the instant power consumption were measured, then the mean value was computed.

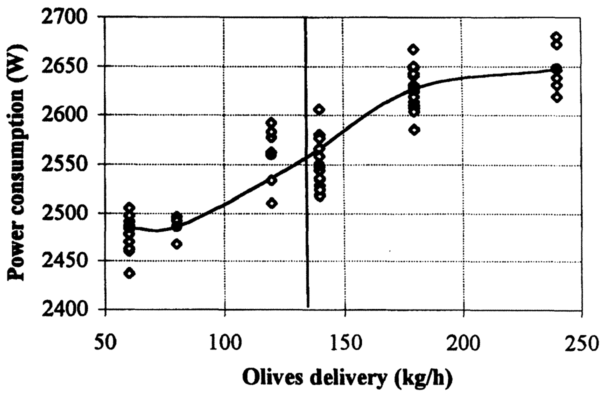

Figure 1
Power consumption depending on the olives delivery, november 1993. (◊) Instant values, (•) Mean values, (—) Power trend, (I) Optimal theoretical delivery.

Total polyphenols of the oil extracted both from the crushed-only paste and the mixed one, very according to the olives delivery as it is shown in fig. 2.

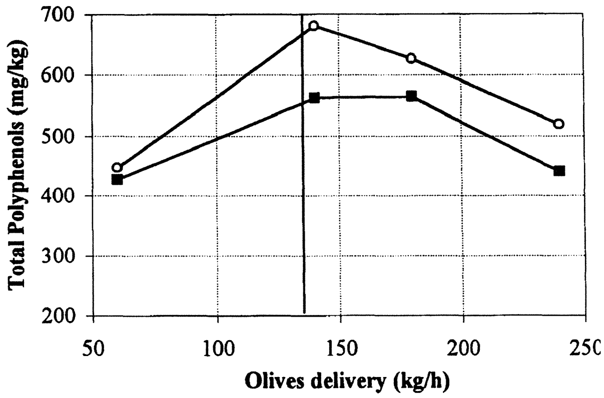

Figure 2
Total polyphenols (individual values expressed as gallic acid) versus olives delivery, november 1993 *(Favati et al., 1994).*
(o) Oil extracted afterhammer crushing only, (■) Oil extracted afterhammer crushing and mixing,
(I) Optimal theoretical delivery.

In both the two figures, the optimal theoretical delivery (135 kg/h), calculated by means of Equation (1), is also shown.

Analyzing the diagram of the total polyphenols of the oil extracted from the not mixed paste (fig. 2), a peak in the trend can be pointed up, which is near the theoretical optimal olives delivery. After the mixing process the maximum total polyphenols content decreases and it is obtained working in a wide range of delivery values.

In fact, it is well known that the mixing process, while leading to an unavoidable partial dilution of the polyphenols in the vegetable water, it is necessary to achieve a good oil yield of the extraction plant.

The above mentioned qualitative results, obtained considering only the total polyphenols content, are confirmed in table II, where other significant quality parameters are reported. These parameters are referred to the oil extracted during the same season.

It can be noticed that the acidity and the peroxide number begin to decrease working with olives deliveries a little more (140 kg/h) than the theoretical optimal one.

However, wrong results could be obtained stopping the study only at the qualitative aspect. From this point of view it seems convenient to work near the maximum value of the olives delivery in the optimal range, thus reducing the crushing process time: this condition corresponds to an increase of the machine productivity without any significant loss in the total polyphenol content and with lower values of the peroxide number (4.9) and acidity (4.0 g/kg).

On the contrary, it can be noticed in fig. 1 that the power consumption rapidly increases changing the delivery from 80 kg/h to 180 kg/h.

Table II
Peroxide number and acidity (individual values) depending on the olives delivery, november 1993 (N.G.D., 1976)

Olives delivery (kg/h)	Peroxide Number	Acidity (%)
60	6.0	0.70
140	6.0	0.41
180	4.9	0.40
240	4.8	0.31

Then, it is possible to define an optimal value (about 140 kg/h) of the olives delivery analyzing all together the experimental data (fig. 1 and fig. 2) from both the points of view of the olive oil quality and the crushing power consumption. This value is near the theoretical one calculated with Equation (1).

During the second olive oil season (1994-95), in the same period of the previous one (november 1994) the study was extended to higher delivery values, in order to verify the increasing trend of power consumption with olives delivery (fig. 3).

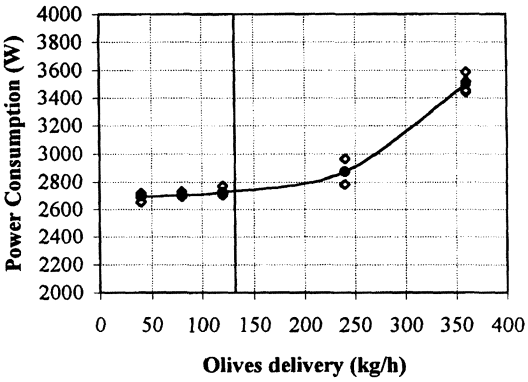

Figure 3
Power consumption versus olives delivery, november 1994.
(◊) Instant values, (•) Mean values, (—) Power trend,
(I) Optimal theoretical delivery.

According to the results of the first olive oil season, also in this case power consumption begins to increase near the theoretical optimal olives delivery.

Moreover, increasing the working delivery to values higher than 240 kg/h, it is possible to notice an unacceptable parabolic increase of power consumption (*Chelazzi,1966).*

It can be underlined that the most acceptable power consumption values correspond to the range 140 kg/h - 240 kg/h of the olives delivery. In particular the greatest lower bound of this range is very near to the theoretical optimal delivery, confirming what it has been already exposed about the previous olive oil season.

In Fig. 4 the trend of the energy necessary to process the olives mass units (kJ/kg) is reported.

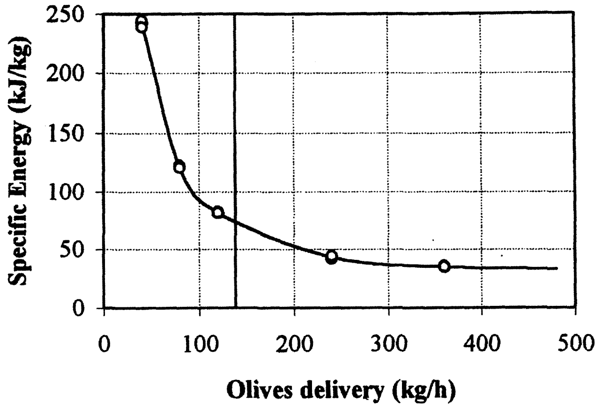

Figure 4
Specific energy versus olives delivery, november 1994.
(o) Instant values, (•) Mean values, (—) Power trend,
(I) Optimal theoretical delivery.

In this case, only analyzing the specific energy trend it could be asserted that high olives delivery values (more than 240 kg/h) lead to the least specific energy values, although the absolute power consumption rapidly increases (Fig. 3).

But, on the contrary, it is important to underline that (see Fig. 5 - curve A) the total polyphenols content rapidly increases up to 120 kg/h, improving the extracted oil quality, then tends to decrease over 120 kg/h. These results were obtained processing the olives harvested in the same period, during the previous olive oil season, when the experimental trials were carried out.

The total polyphenols content has a similar trend at a later harvesting date (fig. 5 - curve B: december 1994), but the peak moves to a higher olives delivery value: 240 kg/h.

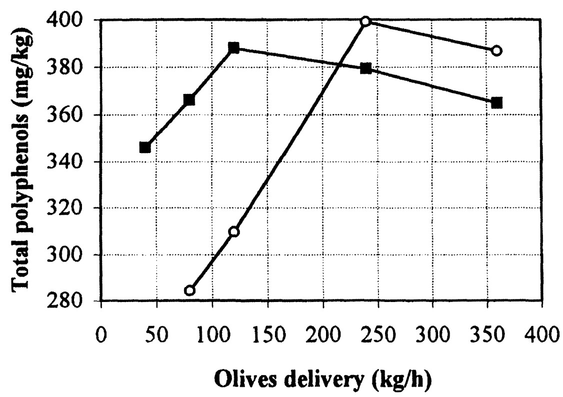

Figure 5
Total polyphenols (individual values expressed as gallic acid) depending on olives delivery (oil extracted after hammer crushing only). (■) curve A ⇛ november 1994, (o) curve B ⇛ december 1994 *(Favati et al., 1994).*

Table III
Quality Parameters (individual values) of the oil extracted during the second olive oil season, 1994/95

Harvesting time	Olives delivery (kg/h)	Peroxide number	Acidity (%)	Rancimat (Metrohm) (Induction time: h at 130 °C)
November 1994	40	7.0	0.49	3.98
	80	7.6	0.42	4.47
	120	7.5	0.51	4.53
	240	6.9	0.57	4.47
	360	6.9	0.44	4.42
December 1994	80	11	0.40	2.95
	120	12.5	0.26	3.25
	240	8.9	0.36	4.92
	360	8.3	0.16	3.88

This value corresponds to the greatest higher bound of the optimal delivery range defined just analysing the energy consumption aspect (fig. 3-4). In particular, at the beginning of the olive oil season it has been noticed that it is necessary to work near the greatest lower bound of the optimal range just defined. With the passing of the harvesting time, the olives delivery has to be increased, reaching values near the greatest higher bound at the end of the olive oil season.

In this case, not only the peroxide number and acidity, but also the induction time (h at 130° C) were evaluated (see table III): it is evident the movement of the optimal delivery towards higher values with the passing of the harvesting time.

At the beginning of the olive oil season, the most significant parameter is the induction time which has a peak at 120 kg/h, while the peroxide number and the acidity are a little influenced by the olives delivery.

On the contrary, at the end of the olive oil season, the peak of the induction time moves to 240 kg/h and the peroxide number becomes acceptable only working with olives delivery equal or greater than 240 kg/h. The acidity remains always below 0.60% (extravirgin oil) because of the chosen harvesting technique (picking on nets).

4. CONCLUSIONS

This research points out that, during the industrial olive-oil production, the olives delivery highly influences power consumption and qualitative yield of the hammer crusher.

Infact, although the diagram of power consumption has a parabolic increasing trend, the specific power decreases with the olives delivery, expecially working below the theoretical optimal delivery (135 kg/h, see Equation (1)).

Anyway, studying the olives hammer crushing process also from the qualitative point of view (polyphenols number, acidity, peroxide number and induction time), it is possible to define an optimal range of the olives delivery.

This optimal range (140 kg/h - 240 kg/h) represents the better working solution from both the point of view of the power consumption and the quality of the extracted oil.

In this range the optimal theoretical value of the olives delivery, computed by the Equation (1), is very near to the greatest lower bound.

In particular, it can be underlined that at the beginning of the olive oil season it seems better to work near the greatest lower bound of the optimal range just defined, while the olives delivery should be increased to the greatest higher bound at the end of the olive oil season.

Therefore, the theoretical optimal delivery represents a reliable reference value for the used hammer crusher, from both the points of view of the power consumption and olive oil quality.

However, due to the several variables, more than those considered (olive oil season, harvesting time and olive delivery), it is possible that, working with operative conditions different from those realized in laboratory, the optimal range of the olives delivery can slightly move. So, if it is not possible to easily control the olives delivery in an industrial plant, during the whole olive oil season, it should be convenient to work near the middle of the theoretical optimal range (in this case about 160 kg/h), in order to limit the risk to be outside the true one.

BIBLIOGRAPHY

Angerosa, F., D'Alessandro, N., Panajotis, K., Di Giacinto, L. (1995). –«GC-MS Evaluation of Phenolic Compounds in Virgin Olive Oil».– J. Agric. Food Chem. **43,** 1802-1807.

Angerosa, F., Solinas, M. (1990). –«Crushing influence on the olive oil quality».– Presented at the Int. Seminar on *Olive Oil and Table Olives: Technology and Quality», Città S. Angelo (PE-I) April 25-28.*
Bianchi, B., Catalano, P. (1993). –«Analisi teorica e prove sperimentali su diversi sistemi di frangitura».– Atti del V Convegno Nazionale dell' A.I.G.R., Maratea 7 - 11giugno.
Chelazzi, A. (1966). –«Potenzialità e potenza delle macchine olearie».– Riv. It. Sost. Grasse **XLII,** 79-103.
Cortesi, N., Ponziani, A., Fedeli, E. (1981). – «Caratterizzazione degli oli vergini e raffinati mediante HPLC dei componenti polari».– Riv. It. Sost. Grasse **LVIII,** 108-114.
Favati, F., Caporale, G., Bertuccioli, M. (1994). –«Rapid determination of phenol content in extra virgin olive oil».– Grasas y Aceites **45,** 68-70.
Metrohm Italiana s.r.l. –«Determinazione della stabilità all'ossidazione di oli e grassi con il metodo Rancimat».– mod. 679 (Milano).
(N.G.D.) (1976). –«Norme Italiane per il controllo dei grassi e derivati».– Staz. Sper. Ind. Oli e Grassi, Milano.
Sacchi, R. (1995). –«Effect of oil extraction systems on the phenol components of virgin olive oils».– 21st World Congress and Exhibition of the Int. Soc. for Fat Res., The Hague (Netherlands), October 1-6.
Solinas, M. (1987). –«HRGC analysis of phenolic components in virgin olive oils in relation to the ripening and the variety of olives».– Riv. It. Sost. Grasse, **LXIV,** 255-262.

Recibido: Julio 1995
Aceptado: Noviembre 1995