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Trends in olive oil production

Olive oil extraction and quality

By **Marino Uceda, Antonio Jiménez** and **Gabriel Beltrán**

CIFA 'Venta del Llano'. Instituto Andaluz de Investigación y Formación Agraria, Pesquera, Alimentaria y de la Producción Ecológica (IFAPA). CICE, Junta de Andalucía.
P.O. Box 50, 23620 Mengibar, Jaén. Spain.

RESUMEN

Extracción y calidad del aceite de oliva

El sector de la extracción del aceite de oliva ha mejorado durante las últimas décadas desde el punto de vista tecnológico siempre en el concepto de extracción del aceite. En este artículo el proceso de extracción del aceite de oliva, incluyendo las operaciones previas, sistemas de extracción y almacenamiento del aceite, ha sido descrito, y sus efectos sobre el rendimiento del proceso y características del aceite. La evolución tecnológica se ha relatado desde los diseños más tradicionales hasta los más novedosos. Los avances recientes y las tendencias futuras aplicadas a la tecnología de extracción del aceite de oliva son descritos, especialmente aquellas relacionadas con la automatización de procesos.

PALABRAS-CLAVE: Aceite de oliva virgen – Automatización – Centrifugación – Sistema de extracción.

SUMMARY

Olive oil extraction and quality

Olive oil extraction sector has improved over the last decades from a technological point of view even in the oil extraction concept. In this manuscript olive oil extraction process, including previous operations, extraction systems and oil storage, has been described and its effect on process yield and oil characteristics. Technology evolution has been reported from the most traditional to the newest designs. Recent advances and future trends applied to the olive oil extraction technology are reported, especially those related to the process automation.

KEY-WORDS: Automation – Centrifugation - Extraction system - Virgin olive oil.

1. INTRODUCTION

In Spain, the virgin olive oil production sector has improved over the last decades introducing technological advances and increasing its total milling capacity even in the oil mill model. For the last 20 years the trend has been to achieve a majority of the production sector looking for a size economy and a reduction in production costs. In the seventies, there was 6000 oil mills in Spain while nowadays around 1750 are registered with MAPA (Spanish Agriculture, Fisheries and Food Ministry) to apply for subsidies for recent crop years.

The Spanish olive oil sector has made an important effort to significantly increase its milling capacity in order to adapt to the annual needs of olive growers. In this way, the daily milling capacity reported at the end of the 80s was 400000 T/day, achieving more than 237000 T, which is currently six times higher.

In theory a mean crop year (around 5.5 million T of olive fruits) can be milled in 2.5 days. Extraction technology has changed considerably from the press extraction system (70s and 80s) to the continuous systems by centrifugation called 'Three phases'. However the contaminant capacity of the liquid by-product (alpechín) (COD 100000 ppm), its amount produced (1.2 L/kg olives) and the growing interest in the environmental quality promoted a technological solution for this problem, the development of the 'two way' system (in the 90s) that reduces the liquid by-product and its contaminant capacity.

At present, both systems (two and three way) are working. The Two way system represents more than 90% of the milling capacity while the press systems have practically disappeared.

2. SCHEME OF THE EXTRACTION PROCESS

The olive oil extraction process starts in the olive fruit, the first step in the oil industry. Because of that, its harvesting and transport have great importance since they affect, sometimes significantly, the oil quality and process yield. However, considering that olives arrive in optimal conditions to the oil mill, we can focus on the process steps that are shown in the following scheme:

– Previous operations
– Fruit reception
– Fruit characterization
– Fruit preparation
– Cleaning
– Washing

– Fruit storage
– Paste preparation
– Milling
– Malaxation
– Solid phase separation
– Press
– Centrifugation
– Two way system
– Three way system
– Liquid phases separation
– Natural decanting
– Centrifugation
– Oil storage and maturation

3. PREVIOUS OPERATIONS

Fruit reception is one of the most important steps in the oil extraction process since the olive fruit should be characterized in order to determine the next step. It has to be done by a reception area manager, who has to visually evaluate the fruit characteristics and decide how to manage each fruit pool.

One of the basic practises to obtain quality oils is good fruit management where the fruit has to be cleaned and washed, depending on the characteristics of the fruit (Uceda et al., 1989).

Olive cleaning consists of the elimination of waste particles that can be found among the olives, leaves and small branches, with lesser density than fruits. The method allows the waste to be removed by flowing an air stream through the fruit. Other machines used to clean are the branch removers to eliminate branches that passed the air stream.

The ground-picked fruits, and sometimes the tree-picked fruits, contain other waste such as soil, slush and small stones. Their separation is needed since they produce undesirable machine abrasion and can even break, reducing the process yield. They are eliminated using olive washers based in a water stream with a determined flow rate, sometimes helped by a air stream, that moves the fruit floating on the water while the heavier parts deposit on the machine bottom where they are removed back stream by shaking sieves or a screw.

In general, as reported by CIFA 'Venta del Llano' researchers, the tree-picked fruits should not be washed, only when needed, because of the special fruit characteristics. Since the extractability is reduced because of an increase in fruit moisture and lower oxidative stability and sensory score due to a reduction in phenol content (Hermoso et al., 1991a).

The olives, after washed and cleaned, have to be stored until their milling in a storage hopper. Their storage capacity should be calculated in order to regulate the fruit entrance in the oil mill. During prolonged storage the fruits show some alterations produced by spontaneous hydrolysis, enzymatic activity or micro-organism development (fungus or yeast) that reduce the oil quality from a chemical and sensory point of view (Camera et al., 1978). These alterations are greater as the storage period is longer (Rodriguez de la Borbolla et al., 1959). To reduce the negative effects of the storage period post harvest techniques have been applied as low temperature storage although the high cost limit its industrial application (Garcia et al., 1996). From CIFA 'Venta del llano' we recommend the immediate olive processing although in the beginning of the crop year the so-called 'difficult pastes' can appear. For these conditions the use of technological coadjuvants such as micronized talc may be needed.

4. OLIVE PASTE PREPARATION

Olive paste preparation can be separated into two phases, fruit milling and paste kneading. The fruit milling has the main objective of breaking the plant tissues in order to liberate the oil drops contained in the mesocarp cells.

In the press system stone mills are generally used, the cylindrical or truncated conical shaped stones rotate on a granite base. Nowadays, although this system shows some advantages such as the 'torn effect', emulsions are avoided and there is no metal contamination, they are not used because of their low capacity and the large amount of space needed.

At present the crushing is performed with metal mills, especially hammer mills equipped with a single or double sieve. Disc mills are used as the finishers of fruit crushing. This step is very important to avoid the emulsions produced by a non optimal milling level, water addition in this step or even the use of small size sieves. On the other hand, the crushing level is essential to obtain good process yields. The milling should be adapted to the fruit characteristics using smaller sieves for unripe olives or for cultivars with hard consistence pulp whereas for ripe fruits the milling grade can be higher.

To obtain quality oil, metal traces should be avoided in the olive paste because of their negative effects on oil color and flavor, reducing its oxidative stability by their catalysts activity in the oxidation process. In order to reduce this problem the mills are made using inert material as stainless steel although a complete elimination is difficult.

The malaxation of the olive paste is used to group the oil drops liberated during the fruit milling, giving a continuous oily phase that can be separated later. The oily phase is separated by mechanical malaxation that improved the drop coalescence into larger drops and breaks the oil/water emulsions. The olive paste kneading can be improved by heating since it reduces the oil viscosity helping the oil drops to group whereas the enzymatic activity into the paste is increased. This operation is performed in a thermo-beater formed by one or more malaxation containers where inclined blades or spiral shaped parts stir the paste giving a shearing effect. Depending on the rotation axis location the thermo-beaters can be classified in horizontal and vertical mixers although based on technical and economical reasons horizontal mixers are more often used.

This step is essential to obtaining optimal oil yields especially when hammer mills are used since emulsions often appear and they can be broken by an efficient malaxation. Two variables can be regulated in the paste mixing to obtain good quality oil and oil yield, kneading time and temperature.

From experimental results, on laboratory and industry scales, it can be concluded that a minimum kneading time is needed to obtain a reasonable process yield although the kneading time interacts with temperature. This minimum time may be established between 60 and 90 minutes. When malaxation temperature is fixed and three different times are compared (50, 75 and 105 min), the pomace oil content is lower for 75min whereas no differences were obtained for 105 min. In experiments at varying temperatures, significant differences were observed at 18ºC, showing the lowest values for 90 min. This trend was found for higher temperatures (30 and 40ºC) although the differences were not significant. Furthermore, a long kneading time produces a decrease in oil phenol content and the related parameters such as oxidative stability and bitterness. Similar results have been described by Solinas et al 1978.

The kneading temperature has a great influence on the process yield since the oil droplets are grouped due to a reduction in the oil viscosity. However for excessive heating undesirable effects can be observed: loss of aromatic compounds responsible for oil flavor and fragrance and accelerates its oxidative process.

In an experiment performed in the experimental oil mill of IFAPA during three crop years (2000, 2001 and 2003) it has been observed that as kneading temperatures increased the oils had a more intense green color because of the higher chlorophyll content and higher phenol and orthodiphenol contents and therefore, they were more bitter and unbalanced showing a decrease in oil flavor due to a volatile loss.

Now the use of inert atmosphere in the mixer is being studied preliminarily. Inert gas is used, mainly nitrogen, to control the oxidation process and enzymatic activities presents in the olive paste during its malaxation in order to obtain an equilibrium between the oil characteristics and the process yield. Both, oil quality and process yield show antagonism that should be solved. For this reason, for high quality oils the malaxation should be performed at low temperatures for a sufficient time although these conditions can produce some difficulties during the oil extraction reducing the process efficiency. ‘Difficult pastes’ appears even when kneading conditions are aimed to obtain the maximum process yields.

In general, the solution to ‘difficult pastes’ proposed by some industrial mills was the fruit storage but it produces lower oil quality or increasing the malaxation temperature that has no effect and negatively affects the oil quality. Another method, more interesting and efficient, is to reduce the process capacity of the oil mill but it increases the production costs and the fruit storage period. A technological approach to this problem has been the application of technological coadjuvants. As a result of these studies Spanish regulation authorizes the use of natural micronized talc (hydrated magnesium silicate). The addition of micronized talc to difficult pastes improves the paste structure, reducing emulsions. Visually, its use can be distinguished by a higher free oil amount in the mixer, clean mixer blades, a reduction in emulsions and clearer oils in the outlet of horizontal centrifuge. The dose ranges between 0.5 and 2% on fruit dry weight, depending on the paste difficulty.

From the analytical point of view, the correct application of micronized talc reduces the by-products in oil content and therefore, improves the process yield. As described, for three way systems micronized talc increases the process yield by a decrease in the oil content of the waste water (alpechín) and higher oil content in the pomace. Talc overdose, depending on the paste characteristics, can reduce the process yield since the higher pomace oil content does not compensate for the oil content of the waste water. Therefore the optimal use of talc and its dosification should be monitored checking the alpechín and pomace oil contents and performing quantitative balances. The use of automatic dispenser is the only accurate way to control the talc dose.

For the two way continuous system, the micronized talc has shown high efficiency for difficult pastes since the oil content on the dry weight of pomace was reduced significantly and the process yield was greater.

Micronized talc, does no affect the oil composition and sensory characteristics significantly although it has shown higher phenol content and slightly more bitter and pungent flavor.

5. SELECTIVE FILTRATION OR PERCOLATION

This system consists in the extraction of the free oil that appears after the milling and kneading steps. The rest of the oil has to be extracted by pressing or centrifugation systems. The selective filtration is based on the differences in surface tension between the liquid phases of the olive paste and a stainless steel plate. Oil has lower surface tension and when the metal surface comes into contact with the olive paste it is coated mainly with a film of oil.

Based on this principle described at the end of twentieth century by Miguel Prado y Lisboa, Marques de Alcapulco, several machines were developed. At present there are two different systems: Thermoextractor Palacín similar to the original ‘Acapulco-Quintanilla’ and the Alfin system available as Sinolea. When the extraction starts, the oil amount is high and the waste water is extracted in a small percentage, however as the extraction goes on the waste water and its dissolved solids content raises and the oil extracted is lower. For this reason, the residence time of olive paste in the extractor should be less than 30 minutes. In these conditions between 20-50% of oil contained in the olive paste can be extracted, with variable waste water content depending on the paste difficulty. The main advantages of selective filtration are:

– Virgin olive of high quality considering sensory and chemical indexes
– A higher amount of oil is obtained
– The efficiency of the plant is improved since the extracted oil does not pass through the horizontal centrifuge.

6. SOLID-LIQUID PHASES SEPARATION

The olive, and then its paste, is formed by three basic components: oil, water and dry matter. The aim of this step is to separate the oil from the others. At present, the press system coexists with centrifugation systems although press plants can be found on a marginal level. Therefore, we are going to describe the horizontal centrifuges.

Fundamentals of Centrifugation

The system widely used is the continuous extraction system (the paste is loaded and the phases separation are performed continuously) based on the centrifugal force applied to the olive paste. The mathematic expression for centrifugal force is:

$$Fc = \rho\omega^2 r$$

Where, ρ = mass of the centrifuged element
ω = angular speed
r = turning radius

Each horizontal centrifuge has specific values for ω and r, considering mass as a density function (d), it can be established that centrifugal force depends on the density of centrifuged elements Fc = k d. When applied to olive paste, formed by components (pomace, vegetation water and oil) with different density (1.2, 1.082 and 0.916 g/cm^3 respectively) three concentric rings will be separated whose radius are related to the element density with the highest for pomace and the smallest for the oil (Figure 1).There are outlets at different distances from the rotation radius allowing the liquid phases to be separated (oil and vegetation water).

In a decanter the solid phase is separated as follows, the centrifuge is formed by a cylindrical-conical bowl inside where there is a hollow space, with a similar shape, with helical blades. They rotate in the same direction at 3000-5000 rpm although there is a slight difference between the speeds of both parts (10-20 rpm). For this reason a relative movement is produced in the contact point between these centrifuge parts, and pomace is thrown in the opposite direction of the liquid outlets and the movement of the hollow space

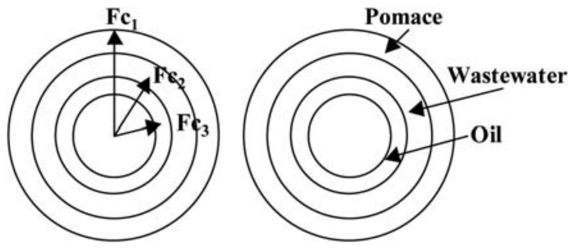

Figure 1
Distribution of centrifugal forces in a decanter for two and three way systems.

7. CENTRIFUGATION SYSTEMS

Nowadays, two centrifugation systems can be found working the so-called two phases and three phases. These names are incorrect since for both types three phases are produced and therefore they should be called two way or three way systems. In the seventies the three way system appeared commercially: one way for pomace and the others for the liquid phases (oil and vegetation water). In this system the olive paste is loaded with water (around 50% of the fruit dry weight) to increase the vegetation water phase thickness. The main problem is the large amount of waste water (alpechín) produced (1.2 L/kg olives) and its strong contaminant capacity (COD = 80000 ppm), its elimination shows some technical difficulties and is expensive. Environmental regulations have more restrictions, and then a new system had to be developed. During the crop year 1991/92 the system 'two phases' or 'two way' appeared. The name is explained because there is one outlet for oil and another for vegetation water + pomace. For normal olive pastes the addition of water to the decanter is not needed. Longitudinal and cross sections for both two and three way systems, are shown in Figures 2 and 3. In the cross section two ways for liquid phases can be observed in the three way system, while there is only one for oil in the two way system. Operation schemes for both centrifugation systems are shown in Figure 4, where the most important differences between both extraction designs can be distinguished. The main advantages for the two way system are:

- Water saving
- Energy saving
- Lower capital investment
- Very low by-product production, only waste water from oil washing (0.25 L/ kg olives) and its contaminant capacity is smaller (COD = 10000 ppm).

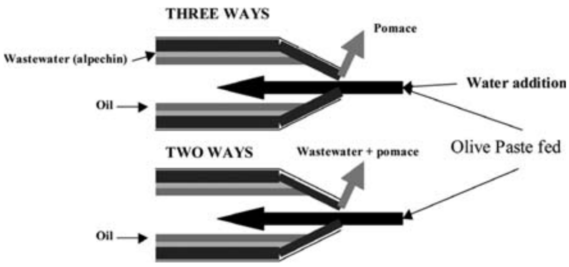

Figure 2
Longitudinal section for two and three way centrifugation systems.

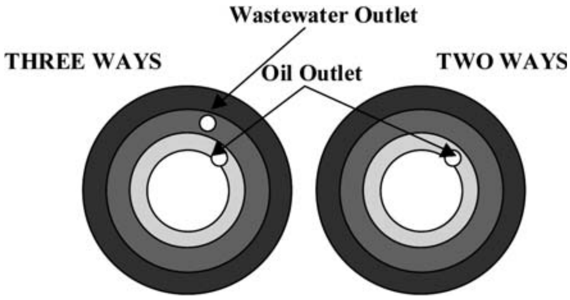

Figure 3
Cross section for two and three way centrifugation systems.

The disadvantages are:

- Management and exploitation of pomace. It is produced by 60% higher, its moisture is around 60%, has high sugar content and dissolved solids from alpechín.
- Few visual control points for oil mill management since alpechín disappeared and thus, pomace has to be monitored more often.
- Matching the decanter performance to olives with different characteristics since water addition to the paste injection is eliminated.

In addition to a centrifugation system description, its effect on oil quality and process yield should be discussed. The process yield can be evaluated by the oil content on the dry weight of pomace since most of the oil loss will be in the pomace. The pomace oil content for 'Picual' should range between 5.6 and 7.1% to have similar yields to the three way system. During the crop year 1993/94, 25 oil mills in Jaén were monitored obtaining as mean oil content of pomace 6.69%, which was within the range for optimal working. For oil characteristics, the most important differences with the three way system are explained by the absence of water addition in the decanter. Oils from two way systems have higher phenol content and oxidative stability. For this reason oils are more fragrant with higher bitterness and pungent characteristics (Hermoso et al., 1991b).

8. LIQUID-LIQUID PHASES SEPARATION

Oil from decanters has between 1 and 3% waste water and waste water from three way system (alpechín) has an oil content in the range of 0.5-2%. Both have to be cleaned. After liquids are sieved, the separation of liquid phases with different density is performed by natural decantation (hardly used at present) or by vertical centrifuges. These centrifuges are formed by a double truncoconical shaped bowl

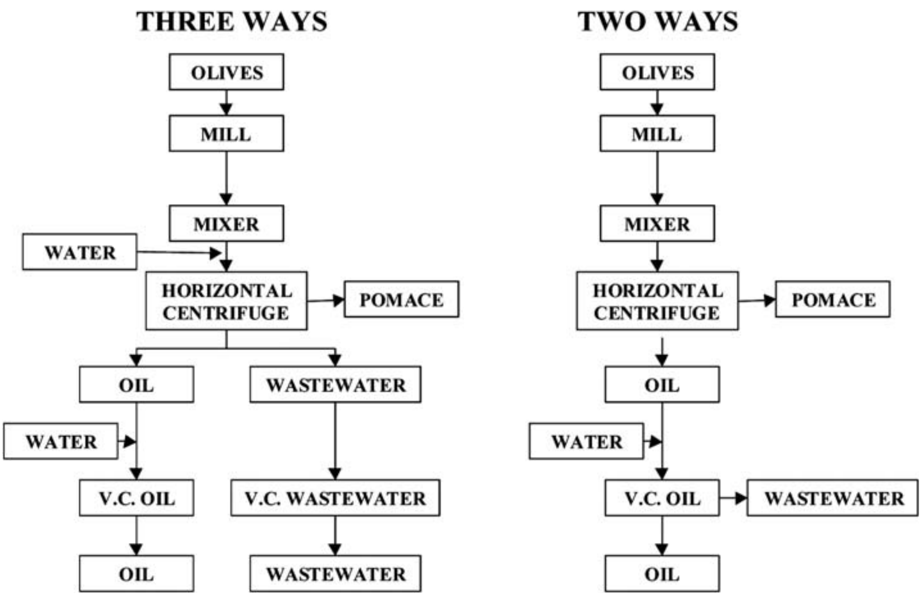

Figure 4
Schemes of continuous extraction systems

and a pool of plates inside that rotate at the same time at 6000-7000 rpm. The liquids are loaded on the top through a hollow axis which leads to a deflector where they are partitioned. Then they are introduced among the plates that work as elemental centrifuges separating the different phases:

- Solids are located in the higher radius
- Waste water remains in an intermediate radius
- Oil is in the lower radius

When working, the centrifuge inside is full of liquid, thus the liquid phases are located in their respective rings. Oil rises next to the central axis flowing through holes in the rotation axis. However the wastewater is projected from the plates to an outlet in the external wall of the bowl. Solids remain where the double truncoconical parts of the bowl are united which is the larger distance to rotation axis.

Vertical centrifuge can be used for oil cleaning or to extract the oil from alpechín, the difference is the alpechín outlet, which can be regulated by a regulation ring. As the regulation ring is higher the alpechín outlet will be grater (its oil content will be higher), it produces a movement of the hydraulic ring to the external part of the bowl, then the oil is cleaner. This is the aim of vertical centrifuges for oil, however those for alpechín, is to obtain the lesser oil content in the waste water and thus, the regulation ring will be smaller. The hydraulic ring is moved to the rotation axis and then, the oil will appear dirty.

In vertical centrifuges for oil some warm water has to be added to increase the thickness of the alpechín phase. Water affects the oil characteristics, for higher water amount oil phenol content decreases and for warmer water a decrease in phenols and aroma compounds has been observed.

10. STORAGE

The olive oil is extracted for 2-3 months but is consumed during the year and therefore it should be stored until packing. This is the last step in the quality chain, and the oil manufacturer is mainly responsible. The objectives are:

- Quality separation
- Saving the oil characteristics protecting it from oxidation and aroma losses and avoiding acquisition of negative attributes.
- Helping the oil maturation, this process reduces the astringency, bitterness.

For quality separation, the oils extracted during the day should be preliminarily catalogued according to their acidity and sensory characteristics, and stored in different tanks. For this, different storage tanks are needed (capacity lower than 50 T) or tanks with a capacity lower than the oil production for 3 days.

Fermentation should be avoided through a periodical tank bleeding since on the bottom there are impurities where fermentation can appear; because of that the bottom of tanks should be conical. To protect against oxidation and aroma losses, the oil temperature should be moderate and oil aeration, light exposure and metal trace contamination should be avoided since they act as oxidation catalysts. The storage conditions should be:

- Bodega with constant temperature (15-18ºC) which assists in oil maturation.
- Avoid oil movements between storage tanks.
- Covered tanks
- Tanks made with stainless steel.
- The bodega should be clean, ventilated and without any smell (fume, gas-oil) since oil might take on undesirable smells.

11. PROCESS AUTOMATION

The two way system helped to solve the alpechín contamination problem, but it has less visual controls in process regulation. Therefore process automation is needed to obtain a high quality product, optimal process yields at low costs (Gonzalez et al., 1997). In the 90s the first software was applied to control and monitor the extraction process regulating some important process variables, automatically and by operator order, to obtain efficient yields and high quality oils.

These systems are formed by software with a user interface that receives process data from specific sensors. Evaluating the data acquired and the order established the software changes the process parameters acting on the regulation mechanism, electro valves, automatic valves, variable speed devices, etc until the parameters are adjusted to established orders.

From 1992 in CIFA 'Venta del Llano' several automation and control systems have been evaluated (González et al., 1993). In general, instrument reliability was acceptable as observed in Figure 5 for differences between olive weight and the paste amount loaded in the decanter.

For regulation of olive paste temperature automatic differences were not found between automatic and manual measurement (Figure 6). Paste feed loaded in the decanter is very important for process regulation and showed higher reliability when automatic control is performed (Figure 7). Using automation system in CIFA 'Venta del Llano' have been obtained better process yields (Figure 8). At present, new sensors based on NIR and microwave technologies are being developed. They will help to know the process performance and its regulation.

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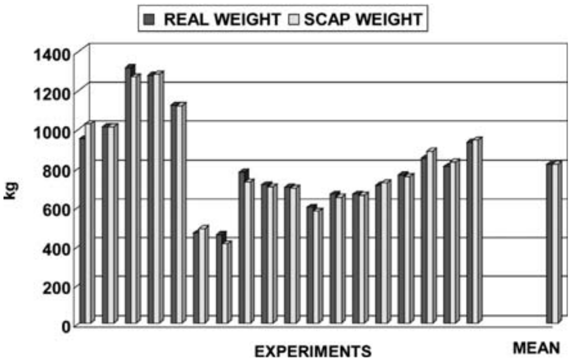

Figure 5
Reliability of olive fruit weight comparing real and automatic (SCAP) systems.

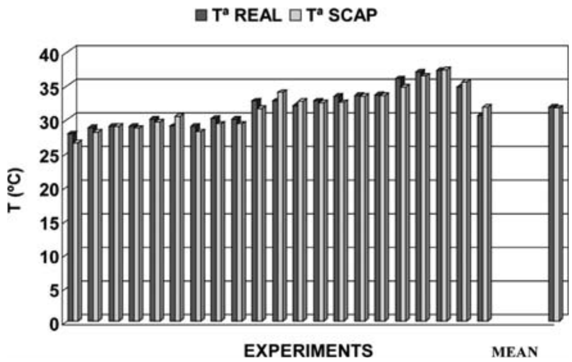

Figure 6
Reliability of temperature measurement of olive paste for manual and automatic (SCAP) systems.

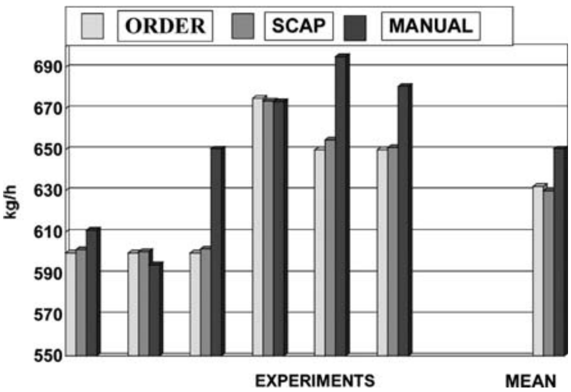

Figure 7
Reliability of olive paste fed (kg/h) to the horizontal centrifuge comparing manual and automatic system.

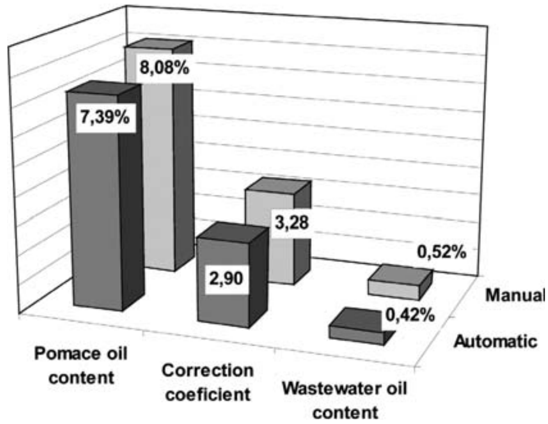

Figure 8
Process oil yield for automatic and manual systems.

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