# Good control practices underlined by an on-line fuzzy control database

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**SUMMARY**

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In the olive oil trade, control systems that automate extraction processes, cutting production costs and increasing processing capacity without losing quality, are always desirable. The database structure of an on-line fuzzy control of centrifugation systems and the algorithms used to attain the best control conditions are analysed. Good control practices are suggested to obtain virgin olive oil of prime quality.

*KEY-WORDS: Fuzzy Control - Good Manufacturing Practices - Virgin olive oil.*

## 1. INTRODUCTION

Olive oil average production from 1987/88 to 1990/91 was 1734500 mT/year of which 80% was of the E.C. (Spain: 577000 mT; Italy: 465000 mT; Greece: 295000 mT; Portugal: 37000 mT and France: 1600 mT.) though it represented only 3.5% of the total vegetable oils (Hermoso et al., 1991). However, the International Olive Oil Council has calculated that consumption will be 2040000 mT in the year 2000 against a theoretical production of 1920000 mT. This deficit will be true if and only if production and labour costs are cut and the quality standards of virgin olive oil satisfy potential consumers: Americans, Germans, etc. (Hermoso et al., 1991).

Thus, the main objectives of producers should be (i) on-line control systems that automate olive oil extraction, which would cut production costs and increase processing capacity without losing quality; and (ii) good control practices that suggest directions for the production of "prime" virgin olive oil.

Concerning the first objective, olive oil extraction has been manually controlled for ages, although various attempts at automation have been made without great success due to changes in olive characteristics over the years. Recently, a classical PID system (Gonzalez et al, 1993) –in fact a supervised control– has been achieving great success.

However, the advent of fuzzy control systems has transformed the classical control from one of exact mathematics to the encoding of inexact procedures (Mandami, 1981). Fuzzy logic control is derived from the experience of skilled operators and knowledge of manual controls. This information, which is stored in a knowledge base, can allow users to have access to all the experience of these operators all the time. The information, encoded as fuzzy rules, is applied in the on-line fuzzy control. On-line fuzzy control, like classical controls, uses rules that take into account the error of variables and their changes in error. With this information the system makes the necessary changes in the process in order to get the optimal condition at all times.

Thus, the first objective tries to select the best conditions for olive oil extraction from a computer database that stores the foremen' experience from many years. The foreman is given a panoply of conditions from the best to the worst with their percentages, in terms of probability, with respect to the best condition attained for the characteristics of olives to be processed. Thus, the foreman will be able to evaluate his decision with more background than nowadays.

The second objective concerns good control practices. Various factors, especially those associated with the type of olive or defects in the working of machinery, can produce irregularities in the processing. Some of these irregularities are evident at a glance, while others are detected using analytical procedures. Good control practices seek to give basic guidelines on avoiding the most common causes of such irregularities and finding possible methods for solving them.

## 2. ON-LINE FUZZY CONTROL DATABASE

The ideal objective of any extraction method is to extract the largest possible amount of oil without altering its original quality. We have summarized in Figure 1 the most noteworthy parts of this process, which has been widely analysed by many authors (Alba, 1975, Martinez et al., 1978; Solinas, 1992). From among these parts, beating is crucial to obtaining olive oil of high quality and optimal yield. As beating temperature is increased, the yield also increases but olive oil quality decreases due to the deterioration in minor compounds. A similar process occurs as beating time is increased above an optimum. However, each olive variety and its maturity or origin (ground or tree) has its own optima of beating temperature and time, and hence the foreman's experience is essential to reach the optimum ratio between quality and yield.

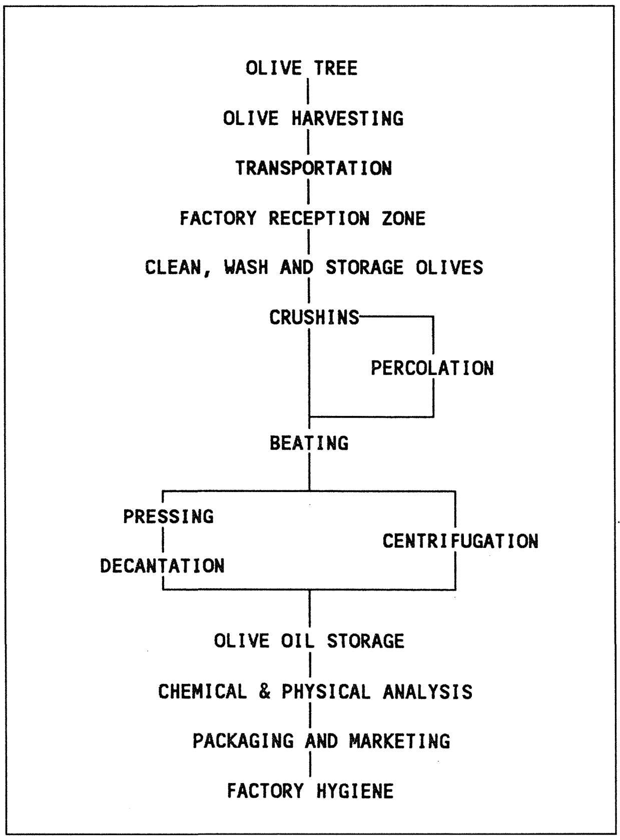


Figure 1
Flow diagram of olive oil manufacturing process.

The beating process consists of three beating receptacles (chambers) that are connected in series and, in consequence, the paste flows from one end of the receptacle to the other and is heated by running water flowing through a water pipe. Temperature sensors are located at the input and output of both the water pipe and the receptacles. The readings from these sensors are used to adjust a valve that regulates the temperature of water flowing through the pipe. As the paste heats, larger drops appear. As the drops appear, the yield increases.

However, olive oils can be obtained from different olive tree varieties and hence the olives have diverse physical characteristics (maturity, texture, ..) which affect under their extraction conditions. Moreover, the biochemical processes of these olives differ as their enzymatic activity is started at different physical conditions during the beating process (temperature, pH, etc.); olive oil from Picual variety, for example, can be obtained in optimal yields at lower temperatures than Arbequina.

The desirability of the homogeneity of olive batches to be processed, though suggested by experts (Hermoso et al., 1991), is in most cases rather impossible. Olive oil factories normally have to process olives with different grade of maturity or health, or harvested from different varieties, and in consequence, there is not a unique pattern by which the olives should be processed. Each batch of olives would have to have its own conditions under which its oil reaches the best quality and yield. The conditions for the whole of each batch would be the result of combining the general conditions of each one of the subbatches - for example, olives with different grade of maturity (e.g., 30% of unripe and 70% of normal ripe olives).

Nowadays, almost all factories and cooperatives are manually controlled by their foremen, who with their long experience can find solutions to most of the problems the various kinds of olive present. However, the foreman's decision is not supported by figures that inform him about the ratios between quality and yield for small changes of the decision - for example, 1° C or 2° C above or below the beating temperature fixed.

From a fuzzy logic point of view, the patterns of batches can be seen as membership functions representing the grade to which each j-process variable in an i-type belongs to a fuzzy set (MG:x -> [0,1]). We have defined the so-called i-type as either variety or ripeness or health condition of the olives to be processed. The j-process is the variable to be controlled (beating temperature, beating time, etc.), while the membership function is defined as a fuzzy p-number (Kandel,1986; Aparicio & Morales, 1994).

Basically three data are enough to build the membership function ($\pi$-fuzzy number): the maximum, average and minimum value of a j-process in an i-type. Thus, a small database allows storage of information of a j-process in many i-types, the long experience of many foremen being implicitly stored in the database.

Let us consider a set of reference functions ($f_{ij}(x)$), each one representing the distribution function of a j-process variable in an i-type. Two cases have been plotted in Figure 2, the j-process variable being the beating temperature conditions and the i-type the maturity ("unripe" and "normal ripe"). The distribution functions show the beating temperature in terms of probability, their maxima being the habitual conditions for these i-type variables, "unripe" and "normal ripe". Thus, the maximum for unripe olives is closer to 30°C than that for normal ripe olives.

Now, we will consider an imaginary batch of 40% "unripe" and 60% "normal ripe" olives. Figure 3 displays the result of combining the distribution functions of these stages of maturity for the beating temperature, applying an S-norm qualifier - Lukasiewicz's $S_{2.5}$ (Godo et al., 1987)

$$S_{2.5}(w_i,w_j)=(w_i+w_j-2w_iw_j)/(1-w_iw_j)$$

where $w_i$ and $w_j$ are the values associated with the distributions of "unripe" and "normal ripe".

This "OR" function (unripe + normal ripe) operation gives rise to a new curve (distribution function) which represents the outer boundary of the functions associated with "unripe" and "normal ripe" maturities.

On the other hand, the optimum value for a process variable can be inappropriate from either the manufacturing costs or quality point of view. The production of "prime" olive oils can raise the manufacturing costs due to low yield values, among others. Figure 4 shows a distribution function that displays the ratio between overall grading quality

(OGQ) (EC, 1991) and manufacturing costs (MC). This figure is the result of applying an "AND" function ($T_{1.5}$-conorm) –Lukasiewicz's $T_{1.5}$ (Godo et al., 1987)– to the distribution functions of OGQ and MC,

$$T_{1.5}(w_i,w_j)=w_iw_j/(2-(w_i+w_j-w_iw_j))$$

where $w_i$ and $w_j$ are the values associated with the distribution functions of OGQ and MC.

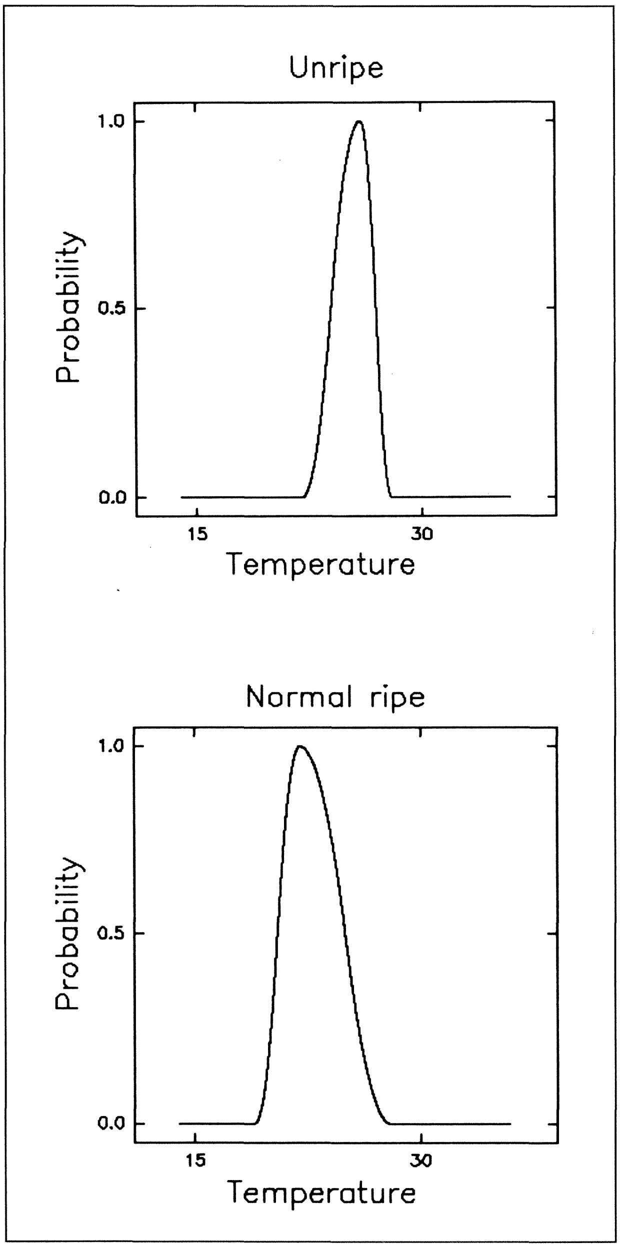


Figure 2
Distribution functions of beating temperatures for the stages of maturity: unripe and normal ripe. The top signifies the habitual beating temperature whilst the bottom means inappropiate beating temperatures for these stages of maturity.

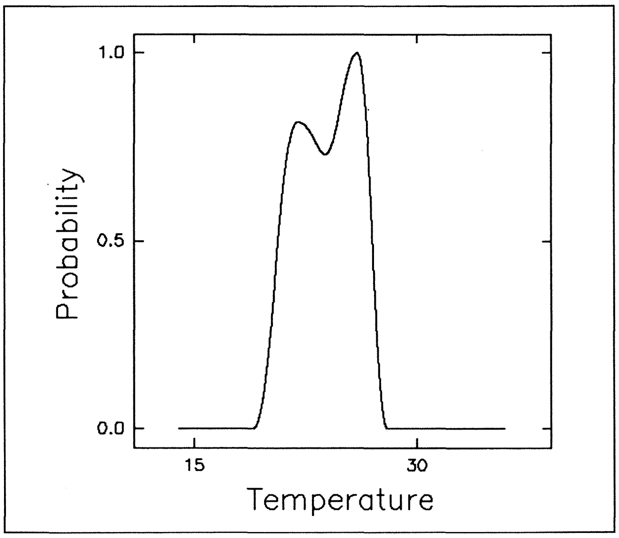


Figure 3
Result of combining the distribution functions of the beating temperature for the stages of maturity, applying Lukasiewicz's $S_{2.5}$-norm.

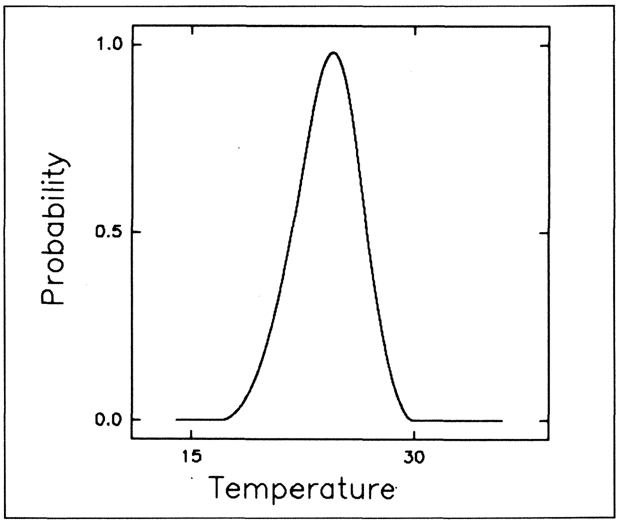


Figure 4
Result of combining the distribution functions of overall grading quality and manufacturing costs, applying Lukasiewicz's $T_{1.5}$-conorm.

Figure 3 shows that it has been possible to generate the distribution function of beating temperatures for "unripe" and "normal ripe" olives. However, this distribution function cannot completely agree with the distribution function of figure 4 that shows the ratio between sensory quality and yield. So, an intercept function - a T-conorm Lukasiewicz's $T_{2.5}$-,

$$T_{2.5}(w_i,w_j)=w_iw_j/(w_i+w_j-w_iw_j)$$

was applied on both distributions (Figure 5) to attain the agreement between them. The final distribution function, figure 6, means the relationship between the beating temperature and the optimum quality and yield, the top of the curve being the best temperature and the bottom the worst ones.

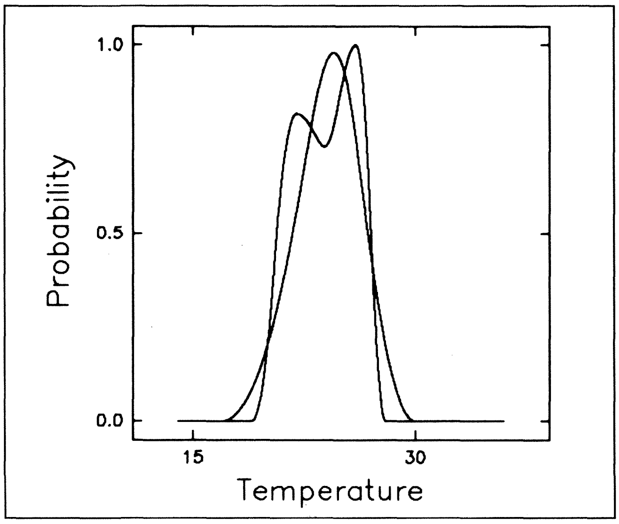


Figure 5
Overlap of the distribution functions described in figures 3 and 4.

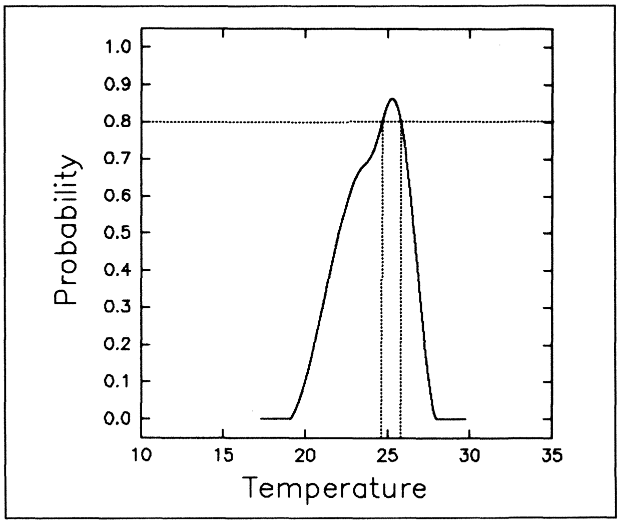


Figure 6
Final distribution function. 25.4°C is the optimum temperature. Dotted lines show the minimum (24.5°C) and maximum (25.9°C) temperatures for an on-line control at probability p=0.80.

Hence, the user can select the percentage of the optimum process to be controlled in terms of temperature. Figure 6 shows that the optimum temperature, for a balanced ratio between quality and yield, is 25.4° C and hence the user can select the minimum and maximum temperatures for control. At probability p=0.8, for example, minimum and maximum temperatures correspond to 24.5° C and 25.9° C.

The described procedure has at least four advantages:

a) the long experience in olive oil extraction of different varieties, maturities and health conditions can easily be stored in a database
b) the information kept can be combined to get the best conditions for batches of different characteristics
c) the user can objectively select his best condition in function of the percentage of the absolute best condition
d) the conditions selected for the on-line control take into account sensory quality, cost and olive characteristics.

## 3. GOOD CONTROL PRACTICES

Olive oil extraction is a complex process that requires much attention from the people involved in it. A perfect knowledge of the tasks to be carried out by each person and an appropriate schedule of them can be enough to find solutions for most of the problems presented.

Good control practices do not seek to give solutions to every problem, only broad outlines for the persons in charge involved in the process, basically the manager and foreman. Precise or specific problems are beyond the objectives of good control practices.

Many authors have written treatises about how olive oil should be processed. Some of them are specific to a part of the process (Alba, 1975; Martinez-Suarez, 1975; Muñoz, 1975; Frias et al, 1991), whilst others are more general (Martinez-Moreno, 1975; Martinez et al., 1978; Hermoso et al., 1991; Kiritsakis, 1991; Solinas, 1992). We made a compilation of them and added suggestions after wide discussion of the compiled basic broad outlines with experienced foremem.

There are basically two processes for obtaining virgin olive oil: centrifugation and pressing. More than 70% of olive oil is obtained in Spain by centrifugation. This process represents the future since it can be fully automated - reducing costs and obtaining virgin olive of the same quality as the pressing process, or better. Thus, good control practices lead to the centrifugation process.

Good control practices have been divided into three parts. The first concerns the management of centrifugation systems, the second explains the GMP for the foreman, and the third is a summary of the most important guidelines described in the two previous parts.

*Broad outlines for the management of centrifugation systems*

The following summarises the management of a centrifugation system under normal conditions:

1. On entering the factory, the olive, if it is suitable (basically with no deterioration of the skin) should be washed.
2. The sieve of the hammer mill should be suited to the type of olive. Smaller orifices if the fruit is in a very unripe state and larger ones for riper fruits or for fruits which have been stacked for longer periods.
3. Except if the olive is very dry, water should not be added to the mass during milling and beating.
4. The temperature of the beaten mass should not exceed 25-30°C.
5. If the mixer is of the horizontal type with various chambers, the passage of the mass from one chamber to another is important and care should

 

be taken that there are no currents within the mass. Provision should be made for the use of natural microtalcum powder (N.M.T.) or enzymes.

6. The rhythm of injection of the mass into the decanter should be appropriate for the type of olive being processed. The quantity of water added should, in principle, be about 0.4-0.5 l per kg of mass, if non-ecological systems are used.
7. The liquid outflow channels from the decanter should be cleaned at least once a day. To start up the equipment after cleaning, water should be injected first, followed by the mass.
8. The vibrating sieves should be cleaned frequently by pressure spraying with water so that all impurities are washed towards the outflows for the olive pomaces.
9. The unloading times for the vertical centrifuges for the vegetable waters should be programmed though the unloading time for the oil centrifuge is variable.
10. The regulating rings should be those appropriate for the different types of vertical centrifuges.
11. Periodically the insides of the vertical centrifuges should be cleaned.
12. The quantity of water added to the oil centrifuges should be less than the quantity of oil entering. The temperature of this water should not exceed 30°C-35°C.
13. On a weekly basis, the whole processing factory should be cleaned.
14. In the cellars, the oils should be separated on the basis of quality.

*Broad outlines for the foreman*

The foreman is the person with technical responsibility for the cooperative. The following roles should be made by foremen even though some of them can be carried out by the fuzzy control system.

1. Prior to the start of the season
   - 1.1. To have all equipment and personnel ready.
   - 1.2. Appoint the seasonal workers. Arrange medical check-ups.
   - 1.3. Test that all equipment is in good working order. All equipment should be well oiled.
   - 1.4. Ensure that there are stocks of equipment.
   - 1.5. Have all machine tools ready for any maintenance and repairs that might be necessary.
   - 1.6. All channels that will carry oil should be carefully cleaned, as should the deposits that will contain the oil. If the deposits are made of unlined metal, they should be cleaned immediately before they are filled.
   - 1.7. Ensure that a general cleaning of the whole factory is carried out. Cleaning should be carried out with water and soda or detergent which should then be rinsed using abundant pressurised water.

2. In season
   - 2.1. Choosing of the unloading points for olives picked up from ground and tree.
   - 2.2. Cleaning and/or washing of the fruit:
     - presence of impurities in the olive prior and after to washing.
     - control of oil losses in the wash water.
   - 2.3. Milling.
     - quantity of milled fruit.
     - fruit quality and its maturity.
     - procedence, ground or tree.
   - 2.4. Preparation of the paste.
     - Degree of milling according to the olives: variety and maturity.
     - Convenience of adding co-adjuvants (Alba et al., 1983; Alba et al., 1990).
   - 2.5. Centrifugation.
     - Quantity of mass injected.
     - Temperature and quantity of water injected.
     - Presence of emulsions.
     - Temperature and quantity of water added to the vertical centrifuge.
     - Unloading frequency of the vertical centrifuge. Monitor the amount of oil lost.
     - Cleaning of the centrifuge. Extent and time.
     - Temperature of the oil from vertical centrifuge.
     - Pomace analysis.
   - 2.6. Deposit and Oil Storerooms.
     - Cleaning of deposits.
     - Norms for fating oils according to their quality and characteristics
   - 2.7. Presence of oil in the final vegetable water tank.
   - 2.8. Knowledge of the average laboratory data.
     - humidity.
     - percentage of oil.
     - free acidity.
   - 2.9. Control of the maintenance and cleaning of the machinery.

3. End of season
   - 3.1. Know the balance of olives, oil and olive pomaces.
   - 3.2. Maintain the quality of the stored oils and monitor them periodically.
   - 3.3. General cleaning of the olive oil mill.
     - The yard and its installations.
     - Factory building and decanting tank room.
     - Whitewashing and painting.
   - 3.4. Maintenance, checks and repairs of machinery.
   - 3.5. Monitor the elimination and explotation of by-products: olive greaves and vegetable waters.
   - 3.6. Comments and suggestions to improve the process next season.

*Good control practices: basic suggestions*

1. Agriculture aspects.
   - 1.1. Pesticides should be avoided as far as possible but in any case used under The European Communities regulations and recorded to prevent conflicts with ecological olive oils

1.2. The olives should be harvested at their optimal ripeness grade, measured by the algorithm proposed by Hermoso et al. (EOC, 1976).
1.3. Mechanical facilities, vibrators, should be used in harvesting.
1.4. Olives harvested from trees must be separated from those collected from soil
1.5. Olives should be carried in perforated boxes from farms to factories.

2. Olives reception
   2.1. Olives must be cleaned from impurities by fans, washing machines and wringers
   2.2. Olives should be processed within 24 hours after harvesting but if that was impossible they should be stored under controlled atmospheres. (Castellano et al., 1993).

3. Oil manufacturing
   3.1. Crushing time should be as shorter as possible to prevent deteriorate effects on aroma, oxidative processes and emulsions.
   3.2. Percolation is suggested as the process to obtain the best olive oils. Around 30 minutes are suggested for attaining yields of 50%.
   3.3. Beating should be controlled in two aspects: Temperature and time.
   3.4. The beating time should take over 60 minutes, with boundaries around 30 and 90 minutes although it depends on the tree varieties, olive ripeness, etc.
   3.5. The paste temperature should be still between 22°C and 28°C to obtain prime olive oil. Temperatures ≥35°C have a deteriorate effect on the minor compounds in the oil.
   3.6. Beaters with 2 or 3 chambers are recommended.
   3.7. Inert extraction aids –NMT (natural micro talcum powder) (Alba et al., 1983) or enzymes (Alba et al., 1990)– can be used to prevent the excess of colloids in the paste.

4. Phase separations by centrifugation.
   4.1. The time of total process should be around 60 minutes.
   4.2. The water should be added at a temperature between 25°C and 28°C and it must be potable of high quality. However, the new systems do not add water in the centrifugation process.
   4.3. The olive oil temperature should not be upper than 28°C.

5. Olive oil storage.
   5.1. Olive oil should be stored in stainless steel tanks or at least in steel tanks covered inside with epoxi-resin.
   5.2. The temperature should be kept between 15°C and 20°C.
   5.3. The maximum capacity of every tank should be 10% of factory production and the olive oils should be classified in at least ten levels and hence stored in different tanks.

## 4. CONCLUSIONS

This paper describes the database structure of an on-line fuzzy control (Calvente and Aparicio, at present unpublished) and the basic fuzzy algorithms used to build a distribution function from which the foreman or every on-line control can select the best conditions for the centrifugation process.

However, prime olive oil with minimum costs cannot be obtained by any on-line control if the manufacturing practices are not carried out properly. The broad outlines of good control practices described, compilation of many expert authors, and on-line fuzzy control can produce a synergic effect on cutting production costs of high quality virgin olive oil.

## ACKNOWLEDGMENTS

The authors express their sincere gratitude to Dr. J. Humanes, Dr. A. García Ortiz, Mr. A. Fernandez and all members of the Estación de Olivicultura de Mengibar (Jaén) for their technical assistance in carrying out the FLAIR project. Thanks are also due to all foremen of many different Andalusian cooperatives for their collaboration.

This study was supported by FLAIR CT-91-0046 and CICYT (Spain) ALI91-0786.

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