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# Evaluation of Second Extraction of Olive Oil in Australia

OCTOBER 2012

RIRDC Publication No. 12/109

Australian Government
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by Pablo Canamasas and Leandro Ravetti

October 2012 (Updated October 2020)

RIRDC Publication No. 12/109
RIRDC Project No. PRJ-006170

ISBN 978-1-74254-451-9
ISSN 1440-6845

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*Revised October 2020*



**Researcher Contact Details**

Pablo Cesar Canamasas
Boundary Bend Limited

Email: p.canamasas@boundarybend.com
In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

**RIRDC Contact Details**

Rural Industries Research and Development Corporation
(Now AgriFutures Australia)
Building 007, Tooma Way
Charles Sturt University
WAGGA WAGGA NSW 2650

Phone: 02 6923 6900
Email: info@agrifutures.com.au
Web: https://www.agrifutures.com.au/

Electronically published by RIRDC in October 2012
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

# Foreword

This report is targeted at the relatively new and actively growing group of olive oil producers in Australia. Understanding the benefits of re-processing olive pomace generated by the first extraction will help oil producers increase their profitability, processing efficiency and production alternatives.

This report evaluates the technical and economic feasibility of mechanically re-processing olive pomace in order to obtain second extraction oils in both small and large-scale processing plants. The information generated aims to increase both extraction efficiency and profitability for olive growers and processors in the Australian industry, without negatively affecting, or even allowing an improvement of the quality of oils produced in the first extraction.

Based on expected production figures for the Australian olive industry in 2013 of 20 million litres of olive oil, the generalised adoption of second extraction technology, as suggested in this report, by medium to large processors, could provide an additional 1 million litres of virgin and/or lampante oil for an estimated value of AU$2M.

This project was funded from RIRDC Core Funds which are provided by the Australian Government with industry contributions from the Australian Olive Association and the Australian Olive Industry.

This report, an addition to RIRDC's diverse range of over 2100 research publications, forms part of our Olives R&D Program, which aims to:

- provide information which establishes the benefits of Australian olive products
- maintain the current high quality product while improving productivity, profitability and environmental management through all stages of the supply chain
- develop strategies for existing and new olive producers to reduce the effects of climate change and variability
- build and educate, collaborative, innovative and skilled industry workforce and a cost effective, well funded RD&E program.

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**Craig Burns**
Managing Director
Rural Industries Research and Development Corporation

# About the Authors

Pablo Canamasas has been involved in the olive oil industry for 23 years. In Argentina, he graduated as an Agricultural Engineer and has completed a Post Graduate Superior Course of Specialization in Oil Production and Table Olives in Jaen, Spain. In Australia, Pablo has been responsible for all matters related to olive oil processing at Boundary Bend Limited. He has also provided technical advice to several oil processing plants in Australia and overseas and has been an invited lecturer at Australian Olive Association (AOA) national conferences, as well as conferences in other countries such as Italy, USA, Argentina and Chile.

Pablo was a member of the research team in the RIRDC-funded project PRJ-000385, 'Technological and biological factors affecting sterols in Australian olive oils', as well as in the HAL-funded project 'Use of ultrasound technology for olive oil processing'. He was also the main researcher in the RIRDC-funded project PRJ-003422, 'Evaluation of processing aids for olive oil extraction and quality improvement' (see Canamasas and Ravetti 2011).

Leandro Ravetti's involvement with modern olive production covers a period of 24 years. In Argentina, he graduated as an Agricultural Engineer and has worked for the National Institute of Agricultural Technology specialising in olives. He has also studied and worked as an invited researcher at the Olive Growing Research Institute of Perugia and other olive institutes in Andalusia, Spain. In Australia, Leandro leads the Modern Olives technical team, which provides horticultural and olive-specific technical advice to most of the largest olive groves and olive oil processing plants in the country. These companies have planted nearly 3,000,000 trees, representing approximately 60 per cent of the Australian olive industry by production.

Leandro has been Executive Director of Boundary Bend Limited, Australia's leading fully integrated olive company, since 2005 and alternate director of the Australian Olive Association since 2009. Over the past 24 months, Leandro covered the position of Drafting Leader for the new Australian Standard for Olive Oil (AS 5264-2011) (Standards Australia 2011) receiving the 2011 Standards Award for outstanding contribution to standardisation in Australia.

# Acknowledgments

The authors would like to recognise the financial assistance provided by the Rural Industries Research and Development Corporation, as well as the support received from the Australian Olive Association and the technical and production team of Boundary Bend Olives and Modern Olives.

Finally, we would like to highlight the invaluable contribution to this project of Marlies Eicher and Peter Eicher from Salute Oliva, by allowing us to use their processing facility, and helping us with the small plant second extraction operation.

# Publication Review

RIRDC publication No. 12/109 *Evaluation of Second Extraction of Olive Oil in Australia* was reviewed and updated in October 2020 by one of the original authors, making minor amendments to:

- Executive summary
- Economic Analysis – Table 9
- Recommendations
- References

Pablo Canamasas
October 2020
E: pcanamasas@yahoo.com

# Abbreviations

| | |
|---|---|
| AOA | Australian Olive Association |
| DAGs | Diacylglycerides |
| E+U | Erythrodiol and uvaol |
| EVOO | Extra virgin olive oil |
| FAAE | Fatty acid alkyl esters |
| FE | First extraction |
| FFA | Free fatty acids |
| IE | Industrial efficiency |
| IND | Induction time |
| IOC | International Olive Council |
| NIR | Near infrared |
| PPH | Total polyphenols |
| PPP | Pyropheophytins |
| PV | Peroxide value |
| RIRDC | Rural Industries Research and Development Corporation |
| SE | Second extraction |
| TAA | Total aliphatic alcohols |
| UNSAP | Unsaponifiable matter |
| WAX | Waxes |

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# Executive Summary

### What the report is about

The objective of this project was to evaluate the technical and economic feasibility of re-processing olive pomace in order to obtain second extraction oils in both small and large-scale processing plants.

This proposed new project expected to maximise the technological and financial information available regarding the second mechanical extraction of olive oil from fresh pomace. The information to be generated from this project aimed to increase both extraction efficiency and profitability for olive growers and processors in the Australian industry without negatively affecting, or even allowing an improvement of, the quality of the oils produced in the first extraction.

### Who is the report targeted at?

This report is targeted at the relatively new and actively growing group of olive oil producers in Australia. Understanding the benefits of re-processing olive pomace generated by the first extraction will help oil producers increase their profitability, processing efficiency and production alternatives.

### Where are the relevant industries located in Australia?

When we think about the new Australian olive industry, we have to consider a modern olive production model with the objectives of high yields and quality. These yields are in harmony with environmental conditions, and have to be achieved with low production costs. It is estimated that 10 years ago, Australia had only 2000 hectares of traditional olive groves, which produced about 400 tonnes of oil. In 2013, Australia is expected to produce approximately 20 000 tonnes of oil. The majority of this production will come from the 30 000 hectares of modern olive groves that have been planted in the last 15 years.

More than 50 per cent of production comes from Victoria. South Australia and Western Australia are also significant contributors with approximately 15 per cent each, while New South Wales, Queensland and Tasmania complete the Australian spectrum of olive growing regions. The following table shows the distribution of planted area between groves of different scales.

| Grove scale | Number of growers | Number of hectares |
|---|---|---|
| **Large (>100 ha)** | **35** | **14 000** |
| **Medium (10–100 ha)** | **200** | **7 000** |
| **Small (<10 ha)** | **2000** | **9 000** |
| **TOTAL** | **2235** | **30 000** |

### Background

In Australia, the widespread distribution of olive processing plants, their relatively small throughput and the absence of pomace treatment plants determine that the utilisation of classical solvent extraction processes to recover the oil remaining in olive pomace is virtually impossible and economically unjustifiable.

In Europe, and increasingly in other parts of the world, processing plants have been trying the partial extraction of oil contained in the pomace from the first centrifugation using a second centrifugation (see Figure 1). In some cases, processors have implemented the use of low malaxation temperatures in first extraction with the objective of obtaining high quality oils, relying on the fact that any oil recovery inefficiencies derived from this process could be partially off-set by the implementation of a second extraction process at higher temperatures.

A second extraction process is possible if the processing plant has spare processing capacity, if it sets up additional processing lines for the second extraction or if it stockpiles the pomace to be re-processed at a later time.

The economic effectiveness of such a system will be determined by a number of variables such as the extraction efficiencies of the second process, the price of the re-processed oil and the second extraction costs.

### Aims/objectives

The objective of this project was to evaluate the technical and economic feasibility of mechanically re-processing olive pomace in order to obtain second extraction oils in both small and large-scale processing plants.

### Methods used

The evaluation of the second extraction process was carried out at a small plant (Salute Oliva, Boort, central Victoria) as well as at a large processing plant (Boundary Bend Limited, Boundary Bend, northern Victoria). Fruit from olive cultivars 'Barnea', 'Picual' and 'Arbequina' was processed. The second extraction practices evaluated were:

- delay between first and second extraction of the paste (2 hours, 24 hours and 48 hours)
- malaxing time in second extraction (75, 90 and 105 minutes)
- malaxing temperature in second extraction (35°C and 45°C).

Oil recovery was evaluated in each treatment. The chemical analyses of the oils obtained were conducted according to the methodology proposed by the International Olive Council (IOC) and other internationally recognised official methods. These analyses include: free fatty acids (FFA), peroxide value (PV), UV coefficients (K232 and K270), total polyphenols (PPH), 1,2 diacylglycerols (DAGs), pyropheophytins (PPP), shelf life, unsaponifiable matter (UNSAP), sterols composition, erythrodiol and uvaol (E+U), total aliphatic alcohols (TAA), waxes (WAX), fatty acid alkyl esters (FAAE) and sensorial analysis by a test panel.

Additionally, an economic evaluation of the cost effectiveness of the system was carried out taking into account both the results obtained in this project and costing information collected from the industry and from each processing plant used in the trials. The study cases considered were:

- small processing plant (one decanter of 1 tonne per hour processing and re-processing the paste)
- large processing plant with spare capacity (two decanters of 5 tonne per hour, one working in first extraction and the other one re-processing the pomace)
- large processing plant with purpose set up (two decanters of 5 tonne per hour, one working in first extraction and the other one re-processing the pomace).

A small processing plant is considered to be a facility with one decanter of 1 tonne per hour maximum working capacity that can process up to 200 000 kg of fruit per year. A large processing plant is considered to be a facility with at least one decanter of 4 tonne per hour working capacity that can process more than 4 000 000 kg of fruit per year.

### Results/key findings

During the second extraction trials, it was possible to recover up to one-third of the oil lost in the first extraction. This is in line with international industry standards. No significant improvements were found by delaying the second extraction or by increasing the malaxing temperature within the range studied. On the other hand, longer malaxing times provided a significant improvement in oil recovery.

Oil chemical results and organoleptic parameters are more or less significantly affected by the second extraction, regardless of olive cultivar or how the second extraction was carried out. A summary of the response of each parameter to the second extraction process is shown in Figure 2.

The FFA was negatively affected from first to second extraction, affected by both re-process delay and malaxing time. K270 was negatively affected by longer re-processing delays, longer malaxing times and higher malaxing temperatures. The DAG parameter is closely related to fruit quality at the time of crushing, and it suffers a significant decrease with second extraction. UNSAP values showed a significant increase with all values for second extraction falling outside IOC maximum limits for extra virgin olive oil.

Regarding sterol composition of the oils, only stigmasterol (in agreement with Alba Mendoza et al. 1996) , Δ-7-stigmastenol and total sterols seem to be significantly affected from first to second extraction. Both stigmasterol and Δ-7-stigmastenol suffered a significant increment with the increase in malaxing time. Total sterols experienced a significant increase from first to second extraction. E+U also experienced a significant increase from first to second extraction.

TAA – compounds found mainly in the fruit skin – increased 5 to 10 times from first to second extraction, with all values falling outside IOC limits for olive oil. WAX – compounds found in the olive fruit skin – increased 6 to 10 times in the second extraction trials, increasing significantly with the increase in malaxing temperature.

All second extraction oils showed defect intensities between 1.0 and 2.5, and the most common defects found could be classified as fusty, musty, rancid and overcooked.

Based on the results obtained, it seems clear that the most significant impact on oil quality occurs at the time of doing the second extraction of the pomace regardless of the olive cultivar and the treatment that the pomace undergoes during second extraction.

## Implications for relevant stakeholders

Based on expected production figures for the Australian olive industry in 2013 of 20 million litres of olive oil, the generalised adoption of second extraction technology could produce an additional 1 million litres of virgin and/or lampante oil for an estimated value of AU$2M.

It is possible that not all Australian producers would be able to cost-effectively adopt this technology but it is reasonable to expect that all medium-scale plants (with the capacity to process more than 200 000 kg and up to 4 000 000 kg of fruit per year), and large-scale plants (with the capacity of processing more than 4 000 000 kg of fruit per year), would be in the position to do so. Based on recent estimates from the Australian Olive Association (AOA), these medium and large-scale plants combined would represent at least 90 per cent of Australian olive oil production.

## Recommendations

Currently available technology for mechanical oil extraction would have a capability of recovering up to one-third of the olive oil lost in the first extraction. However, according to most national and international legislation, the quality of oil obtained during the second extraction process may fall outside any recognised categories. This is caused by certain chemical parameters (E+U, TAA, WAX) that tend to fall outside the maximum limits for olive oil. It is common practice in the industry to blend and/or refine these second extraction oils in order to reduce levels of the above chemical parameters so they fall within accepted limits. Final economic return depends on the scale of the operation, the total tonnage of fruit/paste available for re-processing, the need to conduct specific investment, the more efficient or less efficient use of manual labour and the price of virgin and/or lampante oil.

Consequently, the cost effectiveness of second extraction will have to be assessed on a case-by-case basis taking into consideration the overall situation of the processor and the most-likely price

scenarios. In any case, there seems to be enough evidence to show that small-scale operations will find it more difficult to benefit from the second extraction process since the limitations in processing throughput will not allow for the production of sufficient oil volumes to cover the direct costs involved in the operation. Furthermore, the lack of large volumes will most likely pose an additional hurdle at the time of trading the product. A large-scale operation with no spare processing capacity is likely to be placed in a situation where it will have to carefully consider achievable oil prices, manual labour efficiency and the total tonnage to re-process in order to justify, or not, the set up of a specific second extraction processing line. Finally, it would seem as if large-scale operations with spare processing capacity can more easily justify the adoption of a second extraction process within their premises.

Considering the results obtained in this study, processors that can economically justify this process are advised to carry out a malaxation process not exceeding both 120 minutes and 35°C in order to reach the best possible compromise between extraction efficiency and oil quality.

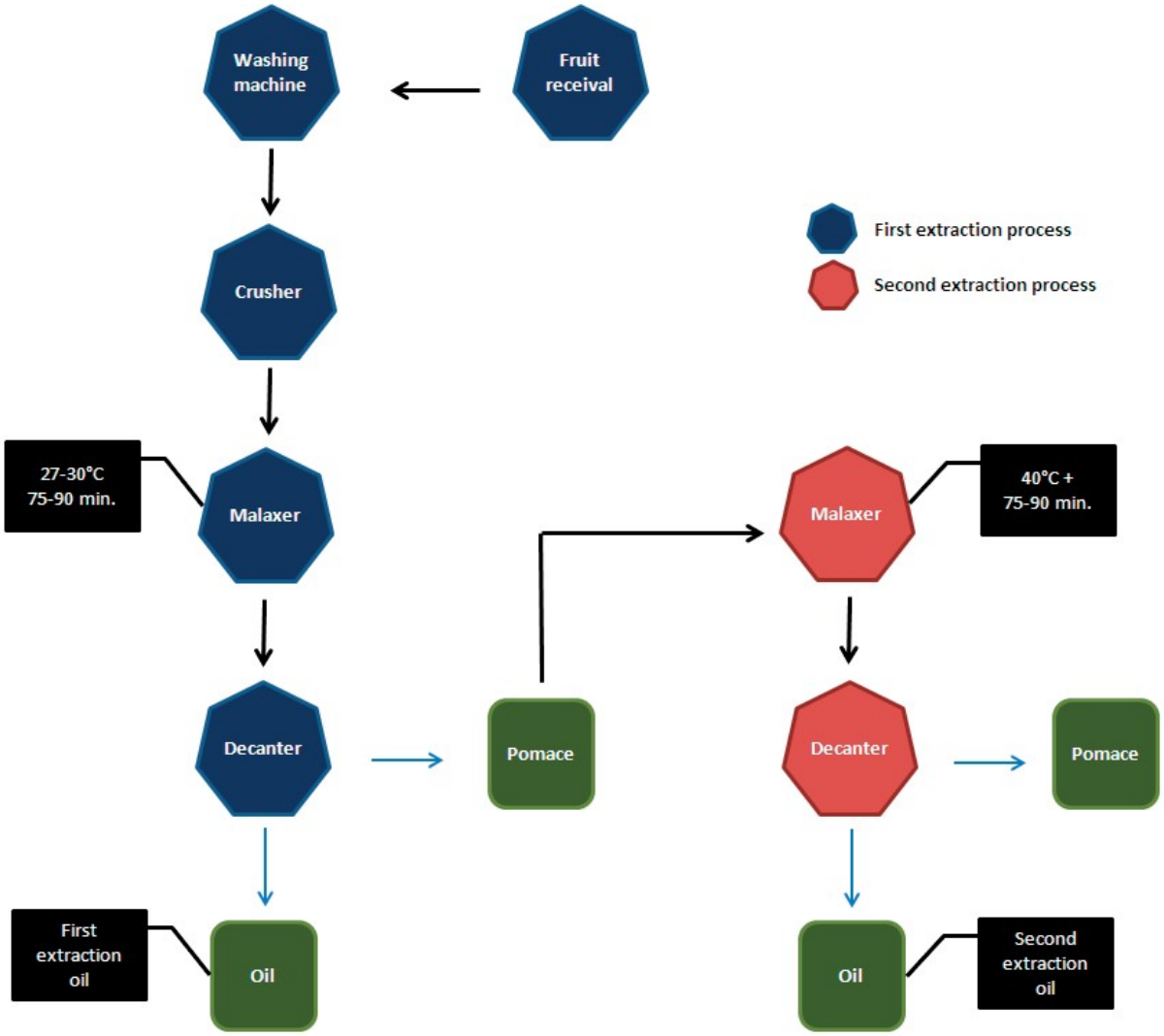


**Figure 1. Flow chart of traditional first and second extraction process**

| | Second extraction | FE-SE Delay | Malaxing time | Malaxing temperature |
|---|---|---|---|---|
| FFA (%) | ↑ | Yes | Yes | No |
| PV (meq O2/kg) | ↑ | No | Yes | Yes |
| K232 | ↑ | No | No | Yes |
| K270 | ↑ | Yes | Yes | Yes |
| ΔK | ↑ | No | No | No |
| IND (hours at 110°C) | ↕ | No | NT | No |
| PPH (ppm) | ↕ | NT | NT | No |
| PPP (%) | ↑ | Yes | Yes | Yes |
| DAG (%) | ↓ | No | No | Yes |
| UNSAP (%) | ↑ | NT | Yes | Yes |
| Cholesterol (%) | – | No | No | No |
| Brassicasterol (%) | – | No | No | No |
| Campesterol (%) | – | Yes | No | No |
| Stigmasterol (%) | ↑ | Yes | Yes | Yes |
| Δ-7-Stigmastenol (%) | ↑ | No | No | No |
| β-Sitosterol (%) | – | No | No | No |
| Total sterols (mg/kg) | ↑ | Yes | Yes | Yes |
| E+U (%) | ↑ | No | Yes | No |
| TAA (mg/kg) | ↑ | Yes | No | Yes |
| WAX (mg/kg) | ↑ | No | No | Yes |
| FAAE (%) | – | No | No | No |
| Defects | ↑ | No | No | No |
| Fruitiness | ↓ | No | No | No |
| Bitterness | ↓ | No | No | Yes |
| Pungency | ↓ | No | No | Yes |

References: FE = First extraction, SE = Second extraction, NT = not trialed, Yes = affected by the practice, No = not affected by the practice

↑ = The parameter is affected by the second extraction process and suffers a increase in its value.

↓ = The parameter is affected by the second extraction process and suffers a decrease in its value.

↕ = The parameter is both affected and not affected by the second extraction process depending on the trial.

– = The parameter is not affected by the second extraction process or there was no specific trend found.

**Figure 2. Response of the studied chemical parameters to both the second extraction process and the different re-processing trials**

# Introduction

Olive pomace is the solid by-product obtained in the olive mill when virgin olive oil is mechanically extracted from olive fruits (Di Serio et al. 2011). Olive pomace re-processing was introduced due to difficulties found in extracting oil from the paste of certain olive cultivars (cultivars that had high oil losses in pomace). Furthermore, a negative image of pomace oils associated with the presence of hydro cyclic carbons such as benzopyrene in these oils determined the necessity of exploring solely mechanical alternatives in order to obtain additional quantities of oil from the olive waste. Additional oil extraction improvements ranging between 3 per cent and 7 per cent of the overall extractability are expected by the use of this technique.

In Australia, the widespread distribution of olive processing plants, their relatively small throughput and the absence of pomace treatment plants determine that the utilisation of classical solvent extraction processes to recover the oil remaining in the olive-pomace is virtually impossible and economically unjustifiable.

In Europe, and increasingly in other parts of the world, processing plants have been trying the partial extraction of the oil contained in the pomace from the first centrifugation using a second centrifugation (see Figure 1 in Executive Summary). In some cases, processors have implemented the use of low malaxation temperatures in first extraction with the objective of obtaining high quality oils, relying on the fact that any oil recovery inefficiencies derived from this process could be partially off-set by the implementation of a second extraction process at higher temperatures.

A second extraction process is possible if the processing plant has spare processing capacity, if sets up additional processing lines for second extraction or if it stocks the pomace to be reprocessed at a later time.

The economic effectiveness of this system will be determined by a number of variables such as the extraction efficiencies of the second process, the price of the re-processed oil, and the second extraction costs.

Previous research carried out in Spain on second extraction (Hermoso et al. 1999; Alba Mendoza et al. 1996) has found that it is possible to recover up to one-third of the oil lost in first extraction. It is estimated that current industrial efficiency of the Australian olive oil industry ranges between 70 and 90 per cent (Canamasas and Ravetti 2011). Each additional point of improvement in this efficiency by removing oil left in the pomace could represent approximately AU$500 000 per year worth of oil at current production levels, and up to AU$1 000 000 per year for expected future production levels by 2015. Appropriate use of the second extraction process will allow growers and processors to be better prepared to process their fruit more cost effectively, and not compromise the oil quality and nutritional value of their product in the first extraction.

# Objectives

The objective of this project is to evaluate the technical and economical feasibility of re-processing olive pomace in order to obtain second extraction oils both in small and large-scale processing plants.

This proposed new project expects to maximise the technological and financial information available regarding the second mechanical extraction of olive oil from fresh pomace. The information to be generated from this project aims at increasing both the extraction efficiency and the profitability of olive growers and processors in the Australian industry without negatively affecting or even allowing an improvement of the quality of the oils produced in the first extraction.

# Methodology

Olives for the small processing facility trials were harvested from a commercial grove at Boort, Victoria, Australia (36.12°S; 143.72°E) during April 2011. Fruit from cultivar 'Barnea' was processed at a small processing facility at Boort (Salute Oliva processing plant, decanter Alfa Laval 911, 1 tonne per hour working capacity) in order to determine the impact of re-processing delay on oil quality and oil recovery.

The olives for the trials to determine the impact of malaxing time (cultivar 'Picual') and malaxing temperature (cultivar 'Arbequina') on both oil recovery and quality were harvested in May 2012 from a commercial grove at Boundary Bend, Victoria, Australia (34.43°S; 143.09°E) and processed at a large processing facility on site (Boundary Bend processing plant, decanter Amenduni Rex 350, 10–12 tonne per hour working capacity).

The processing practices evaluated were:

- **Second extraction delay:** Second extraction of pomace carried out 2 hours, 24 hours and 48 hours after first extraction. The second extraction malaxing temperature was constant at 39°C and the malaxing time set at 90 minutes.
- **Malaxing time:** Second extraction of pomace carried out at 75 minutes, 90 minutes and 105 minutes kneading time in the malaxer unit at a constant temperature of 40°C.
- **Malaxing temperature:** Second extraction of pomace carried out at 35°C and 45°C malaxing temperature at a constant 90 minutes of malaxing time.

## Extraction process

**Second extraction delay:** During the 2011 trials, a total weight of 1900 kg of fruit from cultivar Barnea was processed using a decanter Alfa Laval 911 of 1.0 tonne per hour working capacity at a small commercial plant in Central Victoria, Australia (see Photo 1). The pomace obtained from this first extraction process was divided into three lots of 479 kg each. The first lot of pomace was re-processed 2 hours after the first extraction took place; the second lot of pomace 24 hours after first extraction; and the third lot 48 hours after first extraction. Samples of pomace were taken on each treatment to measure oil content in dry weight. Samples of oil from the different treatments were taken for chemical and organoleptic testing.

**Malaxing time:** This trial was carried out in 2012 with cultivar Picual at a large processing plant in northern Victoria, Australia (see Photo 2), using two decanters of 10–12 tonne per hour capacity (Amenduni Rex 350) working in continuous mode. The pomace delivered by one of the decanters working in first extraction was transferred to the malaxer unit of the second decanter for its immediate re-processing. The pomace was kneaded in the malaxer unit at 75, 90 and 105 minutes to a constant temperature of 40°C. Each treatment was run for 4 hours and samples of pomace and oil were taken every hour for analysis.

**Malaxing temperature:** This trial was carried out in 2012 with cultivar Arbequina at a large processing plant in northern Victoria, Australia (see Photo 2), using the same equipment and following the same process as in the case of the malaxing time trial. However, in this case the first extraction pomace was re-processed at a malaxing temperatures of 35°C and 45°C at a constant malaxing time of 90 minutes. Each treatment was run for 4 hours and samples of pomace and oil were taken every hour for analysis.

In order to determine the fruit characteristics, a sample of each olive cultivar was taken and analysed according to maturity index (method developed by the CIFA Alameda del Obispo, Spain, 2004), fruit size (in grams), oil percentage (by near infrared (NIR)) and moisture content (NIR) (Table 1).

**Table 1. Fruit parameters in Barnea, Picual and Arbequina for second extraction trials**

| | OFM (%)[1] | Moisture (%) | ODM (%)[2] | Maturity index | Weight (gr) |
|---|---|---|---|---|---|
| Barnea | 12.8 | 63.1 | 34.7 | 1.8 | 2.7 |
| Picual | 17.7 | 62.1 | 46.7 | 3.1 | 3.2 |
| Arbequina | 22.3 | 51.8 | 46.3 | 3.0 | 2.3 |

[1] Oil on fresh matter

[2] Oil on dry matter


**Photo 1. Small plant used for the processing delay trials in 2011 (Salute Oliva, Boort)**

## Determinations

**Oil extractability:** Calculation of the oil extractability for first extraction (FE) and second extraction (SE) was carried out according to the following formulas:

FE = 1 – (%Oil in pomace * (100 – %Oil in fruit))/(%Oil in fruit * (100 – %Oil in pomace))

SE = 1 – (%Oil in pomace SE * (100 – %Oil in pomace FE))/(%Oil in pomace FE * (100 – %Oil in pomace SE))

**Basic quality parameters:** Determination of free fatty acids (AOCS Ca 5a-40) (FFA), peroxide value (AOCS Cd 8-53) (PV), UV coefficients: K232 and K270 (AOCS Ch 5-91) were carried out. The ΔK parameter was also calculated. Results were expressed as percentage of oleic acid, meq $O_2$/kg oil, and extinction at 232 and 270 nm respectively.

**Induction time:** Potential shelf life can be expressed as induction time. This parameter was measured with a 743 Rancimat (Metrohm & Co), using an oil sample of 2.5 g warmed at 110ºC and exposed to a 20 litres per hour air flow. The results were expressed in hours.

**Total polyphenols content:** The phenol extract was isolated by SPE Diol column 6 mL per 500 mg (Chromabond Macherey-Nagel GmbH & Co) using an elution solution of methanol:water. The Folin-Ciocalteu method was used to evaluate the concentration of total polyphenols (PPH) in the samples at 725 nm. The results were expressed as mg/kg of caffeic acid.

**Organoleptic assessment:** Sensory analysis of the samples was carried out by trained panel tasters according to the method described by the International Olive Council (IOC/T.20/Nº15-Rev.2) (IOC 2007). The method involved, as a measurement instrument, a group of 8 to 12 persons suitably selected and trained to identify and evaluate the intensities of positive and negative sensory perceptions (Boskou 2006). Samples were randomly presented and tasters were requested to mark their perceptions on a profile sheet and to evaluate their intensity on an unstructured scale ranked from 0 to 10. The procedure was repeated three times in different order to minimise error. The panel tasters are well-trained to identify and quantify the typical organoleptic defects associated to olive oils. Data provided by tasters were statistically processed to verify the reliability of the test. The median values of the defect and attributes perceived were used to identify the oil category.

**Pyropheophytins (PPP):** Analysis was conducted in accordance with ISO 29841. Pigments (pheophytins, pyropheophytins, chlorophyll a and chlorophyll b) were separated using silica gel columns. The elution was analysed by HPLC using a RP C18 column and a UV-detector at 410 nm. The concentration of pigments including pyropheophytins was calculated using peak areas.

**1,2 Diacylglicerides (DAG):** Analysis was conducted in accordance with ISO 29822. Miniaturised silica gel column chromatography was used to separate the isomeric diacylglycerols from the more polar fraction of other lipids. The ratios of 1,2 and 1,3-isomers were determined by gas chromatography after silylation of the sample.

**Sterols profile, total sterols and erythrodiol and uvaol (E+U):** Determinations were done in accordance with IOC method IOC/T.20/Nº10/Rev. 1. The sterol fraction was analysed by an Agilent Technology 6890N GC system, Agilent Technology 7683B series injector with a split inlet and flame ionisation detector managed by Agilent ChemStation. The analytical column was a DB-5 5% phenyl-methyl-siloxane stationary phase (30 m x 0.25 mm x 0.25 μm). The gas chromatographic conditions were as follows: inlet temperature: 280°C; oven temperature: 267°C; detector temperature: 290°C; split ratio: 30:1; amount injected: 1 μl. Hydrogen was used as the gas carrier at a flow rate of 1.2 mL per minute. Sterols were quantified using 5α-cholestan-3β-ol as an internal standard.

**Unsaponifiable matter (UNSAP):** Analysis was conducted in accordance with AOCS Ca 6a-40. The oil was saponified with potassium hydroxide, then the unsaponifiable matter was extracted with solvent (diethyl ether or petroleum ether) and the unsaponified residue was obtained after the solvent evaporation.

**Total aliphatic alcohols (TAA):** Analysis was done in accordance with IOC method COI/T.20/Doc. no.26. 5. The fatty substance, with 1-eicosanol added as an internal standard, was saponified with ethanolic potassium hydroxide and then the unsaponifiable matter extracted with ethyl ether. The alcoholic fraction was separated from the unsaponifiable matter by chromatography on a basic silica gel plate; the alcohols recovered from the silica gel were transformed into trimethylsilyl ethers and analysed by capillary gas chromatography.

**Waxes (WAX) and fatty acid alkyl esters (FAAE):** Analysis was done in accordance with IOC method COI/T.20/Doc. No 28/Rev. 1. 2010. Suitable internal standards were added to the oil and fractionation was by chromatography on a hydrated silica gel column. Recovery of the fraction eluted with hexane:ethyl ether (99:1) was followed by direct analysis by capillary gas chromatography with on-column injection.

**Statistical analysis:** Analysis was conducted using SAS version 8.02 (SAS Institute Inc, Cary, NC, USA).


**Photo 2 Large plant used for malaxing time and temperature trials in 2012 (Boundary Bend, Victoria)**

# Results

## Oil recovery

### Second extraction delay

Working in a small processing facility, results show that the industrial efficiency (IE) of oil extraction during the first centrifugation of the paste was 82.5 per cent, while the oil recovered on the second extraction process during the same day, the day after and two days later was 37.4 per cent, 40.2 per cent and 37.1 per cent respectively (Table 2).

### Malaxing time

Working in a large processing plant, the results show that longer malaxing times (105 minutes) provided a better oil recovery performance than shorter times (75 and 90 minutes), with 20.9 per cent oil recovered in the first case, and 13.0 per cent and 10.1 per cent respectively for the 75 and 90 minute treatments (Table 3).

### Malaxing temperature

Working in a large processing plant, oil recovery results showed no significant differences between 35°C and 45°C temperatures (Table 3).

**Table 2. Oil recovery results for re-processing delay trials**

| Process | Delay | Oil fresh | Moist | Oil loss (% dry) | Malax temp °C | Yield % | IE (%) |
|---|---|---|---|---|---|---|---|
| **FE** | **N/A** | **12.8%** | **63.1%** | **6.10%** | **27** | **7.49%** | **82.5%** |
| SE | 2 hours | 3.35% | 45.1% | 3.82% | 39 | 1.59% | **37.4%** |
| SE | 24 hours | 3.35% | 45.1% | 3.65% | 39 | 1.72% | **40.2%** |
| SE | 48 hours | 3.35% | 45.1% | 3.84% | 39 | 1.68% | **37.1%** |

References: FE = first extraction, SE = second extraction, IE = oil extraction efficiency

**Table 3. Oil recovery results for malaxing time and malaxing temperature trials**

Table 3. Oil recovery results for the malaxing time and malaxing temperature trials

| Malaxing temperature | Malaxing time (min) | Oil loss FE (%) | Oil loss SE (%) | Recovery | $F^2$ | Significance |
|---|---|---|---|---|---|---|
| 35.0°C | 90 | 7.1 | 4.3 a | 41.2% | **0.32** | **0.590** |
| 45.0°C | 90 | 5.9 | 3.8 a | 37.0% | | |
| 40.0°C | 105 | 7.1 | 5.7 b | 20.9% | | |
| 40.0°C | 90 | 7.4 | 6.7 a | 10.1% | **3.32** | **0.083** |
| 40.0°C | 75 | 7.4 | 6.5 a | 13.0% | | |

References: FE = First extraction, SE = Second extraction

Means followed by the same roman letter within each row do not present significant differences (Duncan's multiple range test $\alpha = 0.05$). $F^2$ tests the effect of the second extraction malaxing time and temperature

## Oil chemistry

### Free fatty acids (FFA), peroxide value (PV), K232 and K270, ΔK

The FFAs showed a significant increase from first to second extraction regardless of the treatment considered. Within the second extraction treatments, the FFA showed steady and significant increments with the re-processing delay and the increase in malaxing time, but they did not seem to be affected by malaxing temperature.

The PV parameter showed a significant increase when comparing first and second extraction and within second extraction treatments in the malaxing time and malaxing temperature trials, but did not seem to have been affected in the re-processing delay trials. In all cases the PV showed values well below the maximum limit for extra virgin quality.

The K232 parameter had a significant increase from first to second extraction in all trials and a variable response within the second extraction treatments. It showed no differences with the increment of the malaxing time but had a significant rise with the increase of the malaxing temperature. The K232 values of all treatments fell within the limits for extra virgin classification. On the other hand, the K270 of the oils fell outside IOC limits for extra virgin for all second extraction trials and showed significant increments in all treatments.

The ΔK parameter had a variable response depending on the trial but no significant changes were obtained within each second extraction treatment, with all values falling within IOC limits for extra virgin quality.

**Table 4. Chemical results for first and second extraction oils in cultivar Barnea obtained in second extraction delay trials**

| | FE | SE | SE (+ 24 hours) | SE (+ 48 hours) | $F^2$ | Significance |
|---|---|---|---|---|---|---|
| FFA (%) | 0.16 a | 0.46 b | 0.48 c | 0.60 d | 186.30 | 0.000 |
| PV (meq O2/kg) | 4.2 a | 5.6 a | 4.9 a | 5.4 a | 3.26 | 0.081 |
| K232 | 1.601 a | 1.982 c | 1.796 b | 1.799 b | 10.70 | 0.004 |
| K270 | 0.148 a | 0.317 b | 0.387 c | 0.390 c | 70.27 | 0.000 |
| ΔK | 0.001 a | 0.003 a | 0.003 a | 0.003 a | 2.15 | 0.170 |
| IND (hours at 110°C) | 35.3 a | 14.0 b | 12.2 b | 12.9 b | 371.90 | 0.000 |
| PPP (%) | 0.55 a | 1.63 b | 1.59 b | 1.70 c | 170.30 | 0.000 |
| DAG (%) | 93.5 a | 76.5 b | 70.9 b | 70.6 b | 30.23 | 0.001 |
| Cholesterol (%) | 0.3 a | 0.3 a | 0.2 b | 0.2 b | 3.33 | 0.077 |
| Brassicasterol (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 |
| Campesterol (%) | 5.0 a | 4.6 b | 4.6 b | 4.5 c | 73.30 | 0.000 |
| Stigmasterol (%) | 0.5 a | 0.9 b | 0.8 b | 0.7 ab | 4.73 | 0.035 |
| Δ-7-Stigmastenol (%) | 0.2 a | 0.3 b | 0.3 b | 0.3 b | 2.93 | 0.099 |
| β-Sitosterol (%) | 93.3 a | 93.2 a | 93.3 a | 93.6 a | 2.56 | 0.130 |
| Total sterols (mg/kg) | 1825 a | 2954 b | 3008 c | 3432 d | 6.37 | 0.016 |
| E+U (%) | 1.1 a | 3.6 b | 3.6 b | 3.6 b | 1248.00 | 0.000 |
| TAA (mg/kg) | 94 a | 843 b | 1028 c | 1158 d | 14.21 | 0.001 |
| WAX (mg/kg) | 37 a | 204 b | 220 b | 213 b | 253.90 | 0.000 |
| FAAE (%) | 16.7 a | 16.2 a | 16.0 a | 16.4 a | 0.00 | 0.990 |
| Defects | Nil a | 1.0 b | 2.3 b | 1.8 b | 7.39 | 0.011 |
| Fruitiness | 5.5 a | 3.3 b | 3.2 b | 3.7 b | 18.52 | 0.001 |
| Bitterness | 2.3 a | 1.7 ab | 1.8 ab | 1.0 b | 7.28 | 0.011 |
| Pungency | 3.8 a | 1.7 b | 1.8 b | 1.0 b | 35.78 | 0.000 |

Means followed by the same roman letter within each row do not present significant differences (Duncan's multiple range test α = 0.05)

$F^2$ tests the effect of the second extraction delay

References: FE = First extraction, SE = Second extraction, FFA = Free fatty acids, PV = Peroxide Value, IND = Induction time (Rancimat®), PPP = Pyropheophytins, DAG = Dyacilglycerides, E+U = Erythrodiol + Uvaol,TAA = Total aliphatic alcohols, WAX = Waxes, FAAE = Fatty acid alkyl esthers.

**Induction time (IND), total polyphenols (PPH), pyropheophytins (PPP), 1,2 diacylglycerides (DAG)**

IND was not tested in the malaxing time trials and provided dissimilar results in the other two trials. Second extraction delay showed a significant drop in IND from first to second extraction and no significant changes with the delay of the second extraction. On the other hand, malaxing temperature trials showed an increase in IND when comparing first and second extraction and no significant variations with the increase of malaxing temperature.

PPH were tested only for the malaxing temperature trial and they showed a significant increment from first to second extraction. Changes with the malaxing temperature were not statistically significant.

PPP had significant increments from first to second extraction in all trials and also showed significant increments within all second extraction treatments.

DAGs significantly dropped from first to second extraction in all trials but it only showed a significant decrease of its values with the increase of the malaxing temperature.

**Table 5. Chemical results for first and second extraction oils in cultivar Picual obtained in malaxing time trials**

| | FE | SE (75min) | SE (90min) | SE (105min) | $F^2$ | Significance |
|---|---|---|---|---|---|---|
| FFA (%) | 0.19 a | 0.31 b | 0.33 c | 0.37 d | 32.22 | 0.000 |
| PV (meq O2/kg) | 5.3 a | 9.3 b | 6.8 ab | 9.3 b | 4.44 | 0.028 |
| K232 | 1.423 a | 1.571 b | 1.558 b | 1.587 b | 8.23 | 0.004 |
| K270 | 0.122 a | 0.255 b | 0.278 bc | 0.291 c | 15.08 | 0.000 |
| ΔK | 0.001 a | 0.006 b | 0.006 b | 0.007 b | 39.08 | 0.000 |
| PPP (%) | 0.36 a | 0.58 b | 0.68 c | 0.69 c | 11.10 | 0.001 |
| DAG (%) | 92.4 a | 87.3 b | 86.6 b | 84.3 b | 12.95 | 0.001 |
| UNSAP (%) | 13.9 a | 16.2 ab | 19.5 b | 16.7 ab | 5.66 | 0.140 |
| Cholesterol (%) | 0.3 a | 0.2 b | 0.3 a | 0.2 b | 14.59 | 0.000 |
| Brassicasterol (%) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 |
| Campesterol (%) | 3.5 a | 3.4 a | 3.5 a | 3.5 a | 3.18 | 0.067 |
| Stigmasterol (%) | 0.6 a | 0.7 b | 0.9 d | 0.8 c | 6.39 | 0.009 |
| Δ-7-Stigmastenol (%) | 0.3 a | 0.4 b | 0.4 b | 0.4 b | 8.35 | 0.004 |
| β-Sitosterol (%) | 94.3 b | 94.7 a | 94.0 c | 94.4 b | 6.60 | 0.008 |
| Total sterols (mg/kg) | 1522 a | 2272 b | 2294 c | 2401 d | 41.72 | 0.000 |
| E+U (%) | 1.3 a | 4.2 c | 4.0 b | 4.4 d | 124.70 | 0.000 |
| TAA (mg/kg) | 90 a | 482 b | 565 b | 509 b | 78.89 | 0.000 |
| WAX (mg/kg) | 31 a | 218 b | 214 b | 250 b | 39.72 | 0.000 |
| FAAE (%) | 13.9 a | 14.8 a | 16.9 a | 17.3 a | 1.34 | 0.310 |
| Defects | 0.0 a | 1.4 b | 1.0 ab | 1.0 ab | 0.81 | 0.520 |
| Fruitiness | 5.6 a | 4.6 ab | 4.8 ab | 4.3 b | 3.87 | 0.004 |
| Bitterness | 2.3 a | 2.1 a | 2.3 a | 1.9 a | 1.56 | 0.250 |
| Pungency | 2.8 a | 2.6 a | 2.6 a | 2.2 a | 1.86 | 0.200 |

Means followed by the same roman letter within each row do not present significant differences (Duncan's multiple range test α = 0.05)

$F^2$ tests the effect of the second extraction malaxing time

References: FE = First extraction, SE = Second extraction, FFA = Free fatty acids, PV = Peroxide Value, PPP = Pyropheophytins, DAG = Dyacilglycerides, UNSAP = Unsaponifiable matter, E+U = Erythrodiol + Uvaol,TAA = Total aliphatic alcohols, WAX = Waxes, FAAE = Fatty acid alkyl esthers.

**Sterols composition and total sterols**

Regarding sterol composition changes, cholesterol values only had a significant drop with the increase in second extraction delay but showed no clear trend with variations of malaxing temperature and time. Brassicasterol was not present in any of the trials carried out. Campesterol showed significant changes only in the second extraction delay trials where a significant drop in values could be observed

between first and second extraction and also with the increase of the re-processing delay. Stigmasterol showed a significant increase from first to second extraction in all trials. This parameter showed a small drop with the increase in malaxing temperature and re-processing delay, and an increment with the increase in malaxing time. Δ-7-Stigmastenol had a significant increase from first to second extraction in all trials but had no changes within second extraction treatments. β-Sitosterol had a small but significant drop from first to second extraction in the malaxing temperature trial though it showed no changes with variation in temperature. On the other hand, this parameter did not show a clear trend in the malaxing time trials and did not seem to be affected by re-processing delay.

Total sterols showed a significant increment from first to second extraction and also with the increase of second extraction delay, malaxing time and temperature.

**Table 6. Chemical results for first and second extraction oils in cultivar Arbequina obtained in malaxing temperature trials**

| | FE (30°C) | SE (35°C) | SE (45°) | $F^2$ | Significance |
|---|---|---|---|---|---|
| FFA (%) | 0.40 a | 1.0 b | 1.0 b | 216.0 | 0.000 |
| PV (meq O2/kg) | 6.5 a | 7.3 ab | 8.1 b | 9.9 | 0.005 |
| K232 | 1.633 a | 2.175 b | 2.338 c | 19.8 | 0.001 |
| K270 | 0.122 a | 0.454 b | 0.679 c | 16.0 | 0.001 |
| ΔK | 0.000 a | 0.005 b | 0.005 b | 4.6 | 0.042 |
| PPH (ppm) | 40 a | 89 b | 95 b | 16.0 | 0.001 |
| IND (hours at 110°C) | 11.2 a | 17.7 b | 17.8 b | 14.3 | 0.002 |
| PPP (%) | 0.1 a | 0.23 b | 0.29 c | 4.2 | 0.052 |
| DAG (%) | 91.1 a | 84.7 b | 82.3 c | 101.2 | 0.000 |
| UNSAP (%) | 9.5 a | 15.6 b | 19.2 c | 35.8 | 0.000 |
| Cholesterol (%) | 0.24 b | 0.18 a | 0.27 b | 3.0 | 0.100 |
| Brassicasterol (%) | 0.00 | 0.00 | 0.00 | 0.0 | 0.000 |
| Campesterol (%) | 3.6 a | 3.6 a | 3.5 a | 2.9 | 0.110 |
| Stigmasterol (%) | 0.9 a | 1.3 c | 1.2 b | 366.8 | 0.000 |
| Δ-7-Stigmastenol (%) | 0.3 a | 0.5 b | 0.5 b | 13.5 | 0.002 |
| β-Sitosterol (%) | 94.0 a | 93.6 b | 93.6 b | 5.5 | 0.027 |
| Total sterols (mg/kg) | 2038 a | 2994 b | 3160 c | 63.3 | 0.000 |
| E+U (%) | 1.5 a | 12.2 b | 11.8 b | 103.7 | 0.000 |
| TAA (mg/kg) | 179 a | 871 b | 1235 c | 67.3 | 0.000 |
| WAX (mg/kg) | 91 a | 735 b | 909 c | 63.4 | 0.000 |
| FAAE (%) | 9.8 a | 56.5 c | 37.1 b | 159.0 | 0.000 |
| Defects | Nil a | 2.5 b | 2.0 b | 14.0 | 0.002 |
| Fruitiness | 5.1 a | 2.3 b | 2.4 b | 113.5 | 0.000 |
| Bitterness | 1.9 a | 1.1 b | 1.0 c | 78.3 | 0.000 |
| Pungency | 1.8 a | 1.2 ab | 1.0 b | 5.8 | 0.024 |

Means followed by the same roman letter within each row do not present significant differences (Duncan's multiple range test α = 0.05)

$F^2$ tests the effect of the second extraction malaxing temperature

References: FE = First extraction, SE = Second extraction, FFA = Free fatty acids, PV = Peroxide Value, PPH = Total polyphenols, IND = Induction time (Rancimat®), PPP = Pyropheophytins, DAG = Dyacilglycerides, UNSAP = Unsaponifiable matter, E+U = Erythrodiol + Uvaol, TAA = Total aliphatic alcohols, WAX = Waxes, FAAE = Fatty acid alkyl esthers.

### Unsaponifiable matter (UNSAP), erythrodiol and uvaol (E+U), total aliphatic alcohols (TAA), waxes (WAX), fatty acid alkyl esthers (FAAE)

The UNSAP was tested in malaxing time and temperature trials where this parameter showed a significant increase from first to second extraction as well as with the increase of malaxing time and temperature. UNSAP values fell outside IOC maximum limits for extra virgin olive oil (EVOO) in all second extraction treatments.

E+U had a significant increase from first to second extraction in all trials, while within re-processing trials it only showed a significant increase with the increase in malaxing time. E+U values fell outside IOC maximum limits for EVOO for all second extraction oils with the exception of those from the re-processing delay trials.

TAA had a significant increase from first to second extraction in all second extraction trials. This parameter also showed a significant increment with the increase of re-processing delay and the increase of malaxing temperature but did not show a significant increment with the increase of malaxing time. TAA increased 5 to 10 times in second extraction trials and all second extraction values fell outside IOC maximum limits for olive oil.

WAX content of the oils significantly increased from first to second extraction in all trials, and showed a significant increment with the increase of malaxing temperature. This parameter increased 6 to 10 times in second extraction trials. Nonetheless, only WAX values for the malaxing temperature treatments fell outside IOC limits for olive oil.

FAAE only had a significant increase from first to second extraction in the case of the malaxing temperature trials. It did not seem to be affected during the re-processing delay and malaxing time trials and the values of all second extraction treatments remained well below the IOC maximum limit for EVOO.

**Organoleptic assessment**

All second extraction treatments showed defect intensities between 1.0 and 2.5. The identified defects could be classified by panellists as fusty, musty, rancid and overcooked. There was also a significant loss of fruitiness intensity, as well as a decrease in the intensity of bitterness and pungency with increases in re-process delay, malaxing time and temperature. Based on these results, the oils failed to meet IOC limits for extra virgin but were classified as virgin.

## Economic analysis

The economic evaluation of the second extraction process was divided in the following case situations:

1) **Large plant with spare processing capacity (Table 7):** A large processing plant with 2 decanters of 5 tonne per hour working capacity processing 4 500 000 kg of fruit per year, where one of those decanters is not needed for all or part of the season. The only investment required in this case involves the set up of new piping to take the pomace from one line to the next one for re-processing.

2) **Large plant with a purpose set up for second extraction (Table 8):** A plant processing 4 500 000 kg of fruit per year that sets up a 5 tonne per hour working capacity line specifically to re-process all the pomace produced by a first line. The investment required involves the purchase of a full internal processing line (from malaxer to vertical centrifuge) and the piping required for the transfer of pomace between processing lines.

3) **Small plant (Table 9):** A small plant processing 200 000 kg of fruit per year using a 1 tonne per hour working capacity decanter to carry out both first and second extractions. The investment required in this case involves purchasing a 10 000 litre capacity stainless steel tank to store the pomace until it can be re-processed, as well as a transfer pump and the piping required to take the pomace to and from the storage tank.

It is important to highlight that the second extraction oil produced during the trials could not be classified as olive oil under any recognised national or international standard. As any of those oils could have been converted to olive oil by refining or blending them with a certain quantity of virgin oil, the second extraction oils for the purpose of this analysis were considered lampante oils and the current international price for this grade (AU$2.00 per litre) from www.poolred.com was adopted.

Based on the paste extractability results obtained in this project, it was assumed that both large and small plants would be able to achieve 85 per cent oil extractability in first extraction (industry benchmark for good processing practices) and that one-third of the oil lost in the pomace would be recovered during second extraction (average of our results and in line with industry benchmarks). The equipment running costs and wage costs considered in this evaluation were obtained as a combination of the actual running costs from the small and large processing plants that were used to carry out these trials and average industry standards.

Return on direct costs was evaluated both including and not including the labour wages associated with operation of a second extraction line in the case of the large plant scenario as large plant operations working with two processing lines should be able to operate both the first and second extraction at no additional labour cost.

Finally, a price sensitivity analysis with and without labour wages (Tables 10 and 11 respectively) was carried out due to the significant impact that the price of the oil has on the final economic result.

**Table 7. Evaluation of the return on direct costs (AU$) for a large processing plant using spare capacity for second extraction**

| | | | |
|---|---|---|---|
| Piping set up required for SE | $ | 5,000.00 | |
| Equipment Running Cost (w/o wages) | $ | 48.00 | /hour.unit |
| Equipment Running Cost (with wages) | $ | 78.87 | /hour.unit |
| Season period | | 50 | days |
| Running time | | 20 | hours/day |
| Oil recovery | | 35.0% | |
| Lampante Oil Value | $ | 2.00 | /litre |
| Decanter in FE | | 1 | unit |
| Decanter in SE | | 1 | unit |
| Total fruit per season | | 4,500,000 | kg/season |
| Oil accumulation | | 20.6% | |
| Oil extractability | | 17.5% | |
| Industrial efficiency FE | | 85% | |
| Oil loss | | 3.1% | |
| Oil produced FE | | 787,950 | kg/season |
| Oil recovery SE | | 40,146 | kg/season |
| Total direct costs (with wages) | $ | 79,720.33 | |
| Total direct costs (w/o wages) | $ | 48,850.00 | |
| Total income | $ | 87,750.43 | |
| **Net income/Loss (with wages)** | **$** | **8,030.10** | |
| **Net income/Loss (w/o wages)** | **$** | **38,900.43** | |
| **Return/direct costs (with wages):** | | **10%** | |
| **Return/direct costs (w/o wages):** | | **80%** | |

References: FE = first extraction, SE = second extraction, w/o wages = without wages

At current oil prices, the economic analysis for the large processing plant using spare capacity provided a positive return on direct costs considering additional wages for second extraction (10 per cent), and an even better result when wages are not considered (80 per cent) (Table 7). In the case of

the large processing plant with a purpose set up for second extraction, both the return on direct and total costs considering additional labour wages gave a negative result (–34 per cent and –23 per cent respectively) (Table 8). However, when labour wages were not considered as a cost the result became positive (9 per cent on direct costs and 5 per cent on total costs) (Table 8). The small plant analysis provides a negative return on direct costs (–82 per cent) (Table 9).

**Table 8. Evaluation of the return on direct and total costs (AU$) for a large processing plant using a purpose set up for second extraction**

| | | |
|---|---|---|
| Piping set up required for SE | $ 5,000.00 | |
| Processing equipment for SE | $294,000.00 | |
| Depreciation (20 years) | $ 14,950.00 | |
| Interest (7.0%) | $ 20,583.36 | |
| **Total indirect costs (IC)** | **$ 35,533.36** | |
| Equipment Running Cost (w/o wages) | $ 48.00 | /hour.unit |
| Equipment Running Cost (with wages) | $ 78.87 | /hour.unit |
| Season period | 50 | days |
| Running time | 20 | hours/day |
| Oil recovery | 35.0% | |
| Lampante Oil Value | $ 2.00 | /litre |
| Decanter in FE | 1 | unit |
| Decanter in SE | 1 | unit |
| Total fruit per season | 4,500,000 | kg/season |
| Oil accumulation | 20.6% | |
| Oil extractability | 17.5% | |
| Industrial efficiency FE | 85% | |
| Oil loss | 3.1% | |
| Oil produced FE | 787,950 | kg/season |
| Oil recovery SE | 40,146 | kg/season |
| Total direct costs (DC) (with wages) | $ 78,870.00 | |
| Total direct costs (DC) (w/o wages) | $ 48,000.00 | |
| Total IC+DC costs (with wages) | $114,403.36 | |
| Total IC+DC costs (w/o wages) | $ 83,533.36 | |
| Total income | $ 87,750.43 | |
| **Net income/Loss (with wages)** | **-$ 26,652.93** | |
| **Net income/Loss (w/o wages)** | **$ 4,217.07** | |
| **Return/direct costs (with wages):** | **-34%** | |
| **Return/direct costs (w/o wages):** | **9%** | |
| **Return/total costs (with wages):** | **-23%** | |
| **Return/total costs (w/o wages):** | **5%** | |

References: FE = first extraction, SE = second extraction, w/o wages = without wages

The price sensitivity analysis (Tables 10 and 11) shows a significant variation of the return on direct costs results in both of the large plant scenarios but presents no significant variation in the case of the small plant. When considering additional wages costs, the breakeven price point for the large plant– spare capacity scenario is AU$1.82 per litre and AU$2.60 per litre for the large plant–purpose set up scenario. If no additional wages are considered, breakeven price points drop to AU$1.12 per litre and AU$1.90 per litre respectively. The small plant scenario shows a negative return on direct costs for all lampante oil prices studied.

**Table 9. Evaluation of the return on direct costs (AU$) for second extraction in a small processing plant**

| | | | |
|---|---|---|---|
| Piston pump for pomace re-processing | $ | 12,000.00 | |
| Piping set up for pomace re-processing | $ | 2,000.00 | |
| Stainless steel tank (10kl) | $ | 10,000.00 | |
| Wages | $ | 30.00 | /hour |
| Processing time FE | | 12 | hour/day |
| Processing time SE | | 10 | hour/day |
| Equipment Running Cost | $ | 92.00 | /hour.unit |
| Season period | | 30 | days |
| Running time | | 10 | hours/day |
| Oil recovery | | 35.0% | |
| Lampante Oil Value | $ | 2.00 | /litre |
| Decanter in FE+SE | | 1 | unit |
| Total fruit per season | | 200,000 | kg/season |
| Oil accumulation | | 20.6% | |
| Oil extractability | | 17.5% | |
| Industrial efficiency FE | | 85% | |
| Oil loss | | 3.1% | |
| Oil produced FE | | 35,020 | kg/season |
| Oil recovery SE | | 1,784 | kg/season |
| Total direct costs | $ | 31,680.00 | |
| Total income | $ | 3,900.02 | |
| **Net income/Loss** | **-$** | **27,779.98** | |
| **Return/total costs:** | | **-88%** | |

References: FE = first extraction, SE = second extraction

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**Table 10. Price sensitivity analysis for the return on directs costs result (AU$) of the second extraction process including labour wages**

| | Lampante oil price (AU$/Lt) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $ 1.50 | $ 1.75 | $ 2.00 | $ 2.25 | $ 2.50 | $ 2.75 | $ 3.00 |
| Large plant - spare capacity | -17% | -4% | 10% | 24% | 38% | 51% | 65% |
| Large plant - purpose set up | -62% | -48% | -34% | -20% | -6% | 8% | 22% |
| Small plant | -91% | -89% | -88% | -86% | -85% | -83% | -82% |

**Table 11. Price sensitivity analysis for the return on directs costs result (AU$) of the second extraction process not including labour wages**

| | Lampante oil price (AU$/Lt) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $ 1.50 | $ 1.75 | $ 2.00 | $ 2.25 | $ 2.50 | $ 2.75 | $ 3.00 |
| Large plant - spare capacity | 35% | 57% | 80% | 102% | 125% | 147% | 169% |
| Large plant - purpose set up | -37% | -14% | 9% | 32% | 54% | 77% | 100% |
| Small plant | -91% | -89% | -88% | -86% | -85% | -83% | -82% |

# Discussion

Second extraction trials carried out at the small plant with cultivar Barnea reached an oil extraction efficiency of 82.5 per cent for first extraction and 37.4 per cent, 40.2 per cent and 37.1 per cent for second extraction carried out 2 hours, 24 hours and 48 hours after first extraction, respectively (Table 2). It is possible that a certain percentage of oil occluded in pulp cells that is not recovered during first extraction is freed up through further enzymatic processes occurring in the paste immediately after that first extraction process. However, the extent to which that occluded oil can be recovered seems to be defined immediately after first extraction, with no more significant oil quantities being freed up as the delay is extended. While no significant oil recovery increments were observed from delaying the second extraction operation, this delay had a significant negative impact on some of the chemical parameters of the oil that could compromise its value for the refining process.

Trials carried out at the large processing plant with cultivar Picual to evaluate malaxing time and those carried out with cultivar Arbequina to evaluate malaxing temperature in the second extraction showed significant extraction efficiency differences only in the first case (Table 3). This would indicate that increasing malaxing time would be more effective than higher malaxing temperatures for maximising oil recovery in a second extraction within the range of malaxing times and temperatures studied. Alba Mendoza et al. (1996) also reported no significant increments in oil recovery by increasing malaxing temperature during second and third centrifugations of the pomace. Longer malaxing times and higher malaxing temperatures had a negative impact on some of the chemical parameters of the oil.

Second extraction oil recovery ranged between 37 per cent and 41.2 per cent for the re-process delay and malaxing temperature trials while the malaxing time trials provided lower values, possibly due to the difficulty encountered in processing cultivar Picual fruit with high fruit moisture levels. Considering all oil recovery results, it seems that by carrying out standard practices for second extraction it is possible to recover up to one-third of the oil lost in the first extraction. This result is in line with those obtained by Hermoso et al. (1999) and by Alba Mendoza et al. (1996) working with Picual, Arbequina and other cultivars in Spain.

Based on the oil chemical results, FFA, K232, K270, PPP, DAG, UNSAP, stigmasterol, Δ-7-stigmastenol, total sterols, E+U, TAA, WAX and organoleptic parameters are more or less significantly affected by second extraction, regardless of olive cultivar or how the second extraction was carried out.

The FFA was negatively affected from first to second extraction, affected by re-process delay and by malaxing time. The increase of the FFA parameter is possibly related to the excessively long time that the oil was in contact with the paste, increasing its fermentation rate and separation of fatty acids from the main triglycerol chain. Alba Mendoza et al. (1996) found that the FFA of second extraction oil is directly related to the initial FFA of the oil obtained in the first extraction. Based on this, it seems that it would be possible to produce second extraction oils with FFA values within specifications for extra virgin (0.8 per cent) if dealing with sound, healthy fruit as occurred in the re-processing delay and malaxing time trials of this project. Alba Mendoza et al. (1996) concluded that malaxing temperature does not affect oil FFA, which is in agreement with this work.

K270 was negatively affected by longer re-processing delays, longer malaxing times and higher malaxing temperatures. It would seem possible that the increase of the K270 parameter in second extraction oils could be due to a combination of hydrolytic reactions that increase the FFA and malaxing temperatures that allow for the formation of dienes and trienes (Frankel 2005). All K270 values for second extraction oils fell outside IOC/AS maximum limits for extra virgin.

The DAG parameter is closely related to fruit quality at the time of crushing and it suffers a significant decrease with second extraction. It is likely that the high malaxing temperature used in second

extraction gives way to the formation of additional 1,3 DAGs that eventually result in a decrease of the DAG ratio.

UNSAP values showed a significant increase with all values for second extraction falling outside IOC maximum limits for extra virgin. This situation could be a consequence of the transfer of minor components from paste to oil due to the increases in malaxing temperature and time.

Regarding sterol composition of the oils, only stigmasterol (in agreement with Alba Mendoza et al. 1996) , Δ-7-stimgastenol and total sterols seem to be significantly affected from first to second extraction. Both stigmasterol and Δ-7-stimgastenol suffered a significant increment with the increase in malaxing time. These results are in line with those obtained by Guillaume et al. (2011). Total sterols experienced a significant increase from first to second extraction. This is in line with results found by Hermoso et al. (1999). This parameter also increased with the rise of re-processing delay, malaxing time and temperature. The increase is possibly due to the solubilization of sterols found in the olive seed and the olive skin and their eventual transfer from paste to oil due to the excessive contact of paste and oil during the first/second extraction process. Campesterol decreased from first to second extraction in re-processing delay trials but showed no change in malaxing time and temperature trials. This is in disagreement with Alba Mendoza et al. (1996), who reported an increase in campesterol under the same circumstances; but, it is in agreement with Guillaume et al. (2011) who concluded that campesterol is not affected by processing practices. E+U also experienced a significant increase from first to second extraction, which is in agreement with Hermoso et al. (1999) and Alba Mendoza et al. (1996). It also showed an increment with the increase of malaxing time. E+U are compounds found in the skin of the olive fruit (Guillaume et al. 2011) and the extended contact of oil with paste due to a longer malaxing time seems to increase the transfer rate of these compounds into the oil.

TAA – compounds found mainly in the fruit skin – increased 5 to 10 times from first to second extraction, with all values falling outside IOC limits for olive oil. TAA also increased with the rise in re-processing delay and malaxing temperature. Waxes are compounds found in the olive fruit skin and their content increased 6 to 10 times in the second extraction trials, increasing significantly with the increase in malaxing temperature. This WAX increase in second extraction oil is in line with those results obtained by Hermoso et al. (1999) and Alba Mendoza et al. (1996). However, WAX values fell outside IOC limits for olive oil only in the malaxing temperature trials, possibly due to the fact that the Barnea and Picual fruit used for the re-processing delay and malaxing time trials had lower-than-average initial WAX values.

All second extraction oils showed defect intensities between 1.0 and 2.5, and the most common defects found could be classified as fusty, musty, rancid and overcooked. For this reason, none of the second extraction oils could be classified as extra virgin from the organoleptic viewpoint (in agreement with Alba Mendoza et al. 1996). Fermentative defects such as fusty and musty were possibly present due to the fermentation suffered by the oil as a result of its excessive contact time with the pomace. On the other hand, defects such as rancid and overcooked possibly appeared in the oils due to oxidation and thermo- oxidation suffered by the pomace during the malaxation step of the second extraction process.

Based on the obtained results, it seems clear that the most significant impact on oil quality occurs at the time of doing the second extraction of the pomace, regardless of the olive cultivar and the treatment that the pomace undergoes during the second extraction.

Finally, based on these findings, Australian growers should be advised about the advantages, disadvantages, opportunities and limitations of carrying out a second extraction process as well as the financial feasibility of this practice depending on the size of operations.

# Implications

Based on expected production figures for the Australian olive industry in 2013 of 20 million litres of olive oil, the generalised adoption of second extraction technology could produce an additional 1 million litres of virgin and/or lampante oil for an estimated value of AU$2M.

It is possible that not all Australian producers would be able to cost-effectively adopt this technology but it is reasonable to expect that all medium and large-scale plants would be in the position of doing so. Based on recent estimates from the AOA, these medium and large-scale plants combined would represent at least 90 per cent of Australian olive oil production.

RIRDC and AOA need to disseminate the details of this study to the industry in order to allow growers and processors to consider their own situation in the context of this technology. The AOA has access to a large portion of the industry through its members and the well-utilised AOA web page and this data can quickly be made available to those who may be willing to improve their processing efficiencies by recovering oil lost in first extraction and generating an additional revenue stream.

# Recommendations

Currently available technology for mechanical oil extraction would have a capability of recovering up to one-third of the oil lost in the first extraction. However, according to most national and international legislation, the quality of oil obtained during the second extraction process may fall outside any recognised categories. This is caused by certain chemical parameters (E+U, TAA, WAX) that tend to fall outside the maximum limits for olive oil. It is common practice in the industry to blend and/or refine these second extraction oils in order to reduce the levels of the above chemical parameters so they fall within accepted limits. Final economic return depends on the scale of the operation, the total tonnage of fruit/paste available for re-processing, the need to conduct specific investment, the more or less efficient use of manual labour and the price of virgin and/or lampante oil.

Consequently, the cost effectiveness of second extraction will have to be assessed on a case-by-case basis taking into consideration the overall situation of the processor and the most-likely price scenarios. In any case, there seems to be enough evidence to show that small-scale operations will find it more difficult to benefit from the second extraction process since the limitations in processing throughput will not allow for the production of sufficient oil volumes to cover the direct costs involved in the operation. Furthermore, the lack of large volumes will most likely pose an additional hurdle at the time of trading the product.

A large-scale operation with no spare processing capacity is likely to be placed in a situation where it will have to carefully consider achievable oil prices, manual labour efficiency and the total tonnage to re-process in order to justify or not the set up of a specific second extraction processing line. Finally, it would seem as if large-scale operations with spare processing capacity can more easily justify the adoption of a second extraction process within their premises.

Australian olive processors need to note that, in the case of carrying out a cost-effective second extraction process, there is not a beneficial impact on delaying the pomace re-processing as no significant oil recovery improvements are obtained from this practice. On the contrary, the quality of the oil produced – as well as its value as a product for refining – tends to decrease. Processors should note that excessive delays between first and second extraction generate a significant increase in FFA, which in turn reduces the throughtput and efficiency of the refining process.

Finally, it is worth noting that, depending on the quality of the oil obtained after a second extraction process, an additional option to consider at the time of adding trading value to the product would be the possibility of using extra virgin or virgin oils as blending tools in order to adjust the chemistry of second extraction oil and produce an overall final product that would comply with the virgin category. In this particular case, particular attention should be paid to malaxing time and temperature conditions in order to minimise the impact that the use of prolonged malaxing periods and/or high malaxing temperatures have on the quality of second extraction oils.

Considering the results obtained in this study, processors that can economically justify this process are advised to carry out a malaxation process not exceeding both 120 minutes and 35°C in order to reach the best possible compromise between extraction efficiency and oil quality.

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# Evaluation of Second Extraction of Olive Oil in Australia

By Pablo Canamasas and Leandro Ravetti

Pub. No. 12/109

The objective of this project was to evaluate the technical and economic feasibility of re-processing olive pomace in order to obtain second extraction oils in both small and large-scale processing plants.

The information to be generated from this project aimed to increase both extraction efficiency and profitability for olive growers and processors in the Australian industry without negatively affecting or even allowing an improvement of the quality of the oils produced in the first extraction.

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RURAL INDUSTRIES
Research & Development Corporation

Phone: 02 6923 6900
Publications: publications@agrifutures.com.au
Email: info@agrifutures.com.au
Postal Address: Locked Bag 588,
Wagga Wagga NSW 2650
Street Address: Building 007, Tooma Way
Charles Sturt University,
Wagga Wagga NSW 2650