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Literature Review on Avocado Oil for SROS technological purposes

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Abstract

Avocado fruit is one valuable tropical produce which is highly underutilized in Samoa. It has been proven by many human nutrition studies to have positive effects on lowering total blood cholesterol, controlling weight and providing humans with essential nutrients and vitamins. It has a healthy fatty acid composition and contains abundant amounts of certain valuable plant compounds which have important functional properties. The quality of fruits are determined by various factors like variety or cultivar, growth conditions and harvesting time.

Avocado oil has been produced for many years and used mainly as a cosmetic product and raw material due to its nutrient rich unsaponifiable fraction. The recent development in technology however has lead to oil that is highly suitable for the consumer market in terms of quality and health benefits. Virgin oil contains all the healthy components of avocado like β-sitosterol, α-tocopherol, lutein and chlorophyll which are well known for their anti-cholesterol and antioxidant effects. Refined oil produces oil that is more stable but is stripped of all its healthy phenolic compounds. Avocado oil is currently servicing a niche market for cooking oil and also as a raw material for the cosmetic and pharmaceutical industries.

The most suitable methods for processing avocado oil are cold process and supercritical CO_2. They are not only cheaper to setup but also require minimal processing which help retain all the healthful properties of avocado oil. The usual methods like hydrodistillation and solvent extraction have negative impacts on the quality of the oil. The cold process method is now used at the industrial level to produce oil for a niche market while the supercritical CO_2 has only been trialed in the laboratory.

Introduction

The avocado is a tropical tree which grows well and abundantly in Samoa. It is one of the many agricultural produce which is highly under-utilised in the country. The unpopularity of the fruit amongst consumers results in a lot of fruits going to waste every time it is in season. This makes the need for value added products using such local agricultural produce very important not only to reduce food waste but also for the economic benefit of the country.

The avocado fruit is rich in nutrients, high in proteins, antioxidants and dietary fiber is perhaps the most poorly conceived and misunderstood fruit of all times. This is mainly attributed to its high fat and calorie content and so most nutritionists and dieticians either advise against it or to use it “sparingly” (Bergh, 1992). Many studies and research however have proven avocado to be highly advantageous for human health due to its healthy fat composition. All this goodness of avocado is well preserved in avocado oil and thus presents an excellent alternative for utilization of the fruit.

Avocado oil has been produced and used by South Americans for centuries but only as a skin ointment. A new niche market has sprung up in New Zealand and a few other countries for avocado oil destined for food preparation and other oil based products. The oil and its products are considered up-market products and this is highly attributed to the healthy composition of the oil. It is comparable to olive oil in that it is high in monounsaturated fat, high in functional micronutrients (beta-sitosterol) and vitamins and has unique cooking properties. The unsaponifiable fraction of the oil is highly valued in the cosmetic and pharmaceutical industry for its desirable properties and this is another lucrative market.

This literature review covers broad areas from the historical background of avocado, the tree, the fruit and finally avocado oil and how it is processed. Its main focus however is the production of avocado oil as a possible value added product for the utilization of this locally abundant fruit.

Historical Origin of the Plant

The avocado (alligator pear or aguacate as commonly known) is scientifically known as *Persea americana* of the family Lauraceae and is a native plant of Southern Mexico and Central America (Human, 1987). The word avocado comes from the Aztec word *ahuacatl* which is translated by the Spaniards as aguacate meaning "testicle" due to its shape. Historical records of the usage of the plant exist from 7000 B.C. of its cultivation from 6000 B.C. and continuous use in all the well known archeological sites of Mexico.

Agronomy

Growth Requirements

The avocado plant grows well in warm areas with tropical to subtropical climates. The plant at various stages does not tolerate climate that is too cold, too wet, too hot or too dry. Its flowers are very sensitive to very low temperatures and freezing temperatures tend to kill the plants. Frost and very hot weather results in a substantial loss of fruits and too much wind is also highly unfavourable (http://botgard.ucla.edu/htlm/botanytextbooks/economicbotany/Persea/index.html). The plant is tolerant to a wide range of soil types (acidic and alkaline) with the exception of saline conditions. It does require well aerated soils and will not survive in areas with poor drainage due to excess water (http://wikipedia.org/wiki/Avocado). It tends to grow well on hillsides but should never be grown near stream beds. The use of phosphorous (P) fertilizers after one year of growth for young plants and nitrogen (N) and potassium (K) for the older trees is very favourable for growth and fruit yields.

The plant can be grown in the shade but is productive only in full sun. Woolf *et al.* (1999) reported that fruits continuously exposed to the sun were more hardy and tolerant to conditions like high and low temperatures, had a slower rate of ripening, and more resistant to pathogen invasion than those growing in the shade. The sun exposed fruits were also higher in oil, dry matter and minerals. This supports the importance of sunlight and temperature on avocado fruit development and qualities.

Fertilization

Avocado flowers bloom from January to March and these flowers open twice on two consecutive days. The pollination of avocado when it flowers is a classic example of protogyny. This means the females mature before the males, so the flower cannot self pollinate but requires pollen from another flower or another plant. Type A flowers are receptive to pollen in the morning of Day 1 but reopen in the afternoon of Day 2 with stamens shedding pollens. Type B on the other hand bear flowers that are receptive to pollen in the afternoon of Day 1 and shed pollen in the morning of Day two. Growing plants bearing the two differrent types of flowers together will allow cross pollination to occur and increase the chances of production. A typical tree produces around a million flowers a year but only produces a dozen to a few hundreds of fruits (http://botgard.ucla.edu/htlm/botanytextbooks/economicbotany/Persea/index.html).

Varieties & Cultivars

There are three known varieties or horticultural races of avocado and these are the Mexican, Guatemalan and the West Indian Types. The Mexican types thrive in Mediterranean climate and are native to dry subtropical plateaus. The Guatemalan types are native to cool, high altitude tropics while the West Indian variety thrive in humid, tropical climates (http://www.crfg.org/pubs/ff/avocado). There are now many hybrids resulting from cross-breeding of these three varieties and also from the selection of certain favourable attributes. The three varieties can be differentiated from each other using various attributes as provided in Table 1.

Table 1 : Properties of the Three avocado varieties

		Properties by Varieties		
Main Attribute	Specific Attribute	Mexican	Guatemala	West Indian
Oil	scent	nice	none	none
Leaf	size	Small	various	various
	skin	thin	warty	leathery
Seed	size	Big	small	big
	cavity	loose	tight	loose
Tolerance	cold	yes	no	no
	salt	no	no	no
Fruits	Oil content	high	medium	low
	Maturity (months)	6	9	6

http://www.formatkenya.org/ormbook/Chapters/chapter16.htm).

Growers however tend to identify the fruits by cultivars rather than varieties. A list of various existing cultivars is provided on http://www.crfg.org/pubs/ff/avocado and only a few of the most popular cultivars are listed and noted below.

Haas – Guatemalan race and regarded as the industry standard fruit. Tree and fruit are medium sized, thick skin, roundish and purple at full maturity. Has a good shelf life, wide consumer acceptance and oil content is around 19 – 30%. It produces from April to September and is the most popular cultivar used around the world. It bears well only in alternate years and is an “A” cultivar (http://en.wikipedia.org/wiki/Avocado).

Fuerte –This tall tree is a hybrid and produces a shiny green, round pear shaped, large to very large fruits. Oil content around 18-26%, good flesh but also tends to bear fruits in alternate years. Season is December and is a “B” cultivar.

Gwen – The most popular and productive dwarf tree. Fruits are small, elongated and remain green when ripe. Season is February to October and is an “A” cultivar.

Pinkerton – A dense productive tree and is an “A” cultivar. Fruits look like long pears with pebbly green skin. The fruits darken when ripe, has small seeds and is in season in November.

Reed – Known as the summertime variety avocado. Is an “A” cultivar and produces a large fruit with thick green skin which stays green when ripe. Its season is August and its flesh becomes buttery yellow when ripe.

Zutano – A hybrid and is a columnar tree bearing medium to large fruits. Fruit has a shiny yellow skin and is pear shaped. It is similar to a Fuerte but is inferior and has fibres. Is a “B” cultivar and its colour remain the same when ripe.
(http://wikipedia.org/wiki/Avocado, http://foodreference/Avocado/varieties).

It is very interesting to note that starting from early January this year in Samoa avocado fruits have been seen sold in the market and in many local stores. As of now many stores and even the market are well stocked with fruits but very few people actually buy it.

Propagation

Growing avocado directly from the seeds is not favourable because it bears fruits only after 4-6 years of growth and it rarely resembles the parent cultivar. The avocado has hypogeal germination meaning the shoot grows directly from the epicotyl in the soil. Commercial orchards are thus usually propagated by either grafted trees or rootstocks (http://wikipedia.org/wiki/Avocado). Rootstocks are propagated by seeds (seedling rootstocks) and layering (clonal rootstocks). One common method is the etiolation technique used for propagating the desired clonal rootstocks specific for disease and soil conditions (http://www.crfg.org/pubs/ff/avocado). Lateral and terminal grafting is normally used and carried out for young plants after one year of growth in greenhouses.

Pests & Diseases

A soil borne fungus known as *Phytophthora cinnamomi* is a very severe disease which causes root rot of the trees. The disease is easily transported by equipment, tools and shoes from infected soil and farmers are highly encouraged to use disease free and certified plants or rootstocks. Once a tree is infected it is difficult to treat except to cut back on water supply. Dothiorella (*Botryosphaeria ribis*) canker is another fungus which infects the trunk and results in dead patches which spread to maturing fruits causing rancid smelling, darkened spots on the flesh. This disease which starts upon harvest cannot be detected on the outside and has no means of control. A viral disease known as sun blotch causes crinkling of new leaves, yellowed streaking of young stems, cracking of the trunk and occasional fruit deformation. It is spread by the use of contaminated tools and scions and so using virus-free propagating wood is a must. Pests include rats, leaf caterpillars, avocado brown mite, six spotted mite and also snails (http://www.crfg.org/pubs/ff/avocado, http://www.formatkenya.org/ormbook/Chapters/chapter16.htm).

Harvest and postharvest

Avocado fruits are strange in that they only start to ripen and turn soft when they are picked. They remain hard and continue to grow when mature on the tree until they fall off. The fruits can be left on the tree (4-6 months) after being fully developed and will ripen very quickly once picked. The taste of the fruits at the time of harvest depends on their oil content which in turn is dependant on their stage of maturity. Avocados can ripen quickly when stored together with other fruits like bananas and apples due to the production of ethylene gas (http://wikipedia.org/wiki/Avocado, http://botgard.ucla.edu/htlm/botanytextbooks/economicbotany/Persea/index.html).

The fruits must be handled with care when harvested to minimize physical damage and bruising which results in undesirable discolouration and softening of the pulp. The fruit ripening process like many is slowed considerably by low temperatures. Platt-Aloia & Thomson (1992) reported that it is high activities of wall hydrolytic enzymes during ripening that result in ultrastructural changes in the cell walls of ripened avocado fruits. Extended cold storage results in chilling injury which is marked by improper softening, off flavour development and discoloration of the mesocarp. The major storage component of the avocado fruit is the oil contained in its mesocarp. It is the breakdown of the structure of these specialized oil cells during prolonged cold storage that results in chilling injury (Platt-Aloia & Thomson, 1992).

A study conducted and reported by Arpaia *et a.l* (2006) noted that differences in postharvest quality (oil, dry matter, α-tocopherol, β-sitosterol, lutein & total chlorophyll) were attributed to differences in cultivars, growing conditions, location and fruit maturity.

Avocado Fruit & Human Health

Avocado Benefits

Bergh (1992) described the avocado fruit to be nutrition-rich while others in the industry call it a functional food due to its additional health benefits from certain phytochemicals (http://www.avocado-oil.co.nz/nutritionanalysis.html). It contains high amounts of vitamins A ,B, C, E, and other nutrients like folacin, niacin, iron (Fe), magnesium (Mg), folate, pantothenic acid and contains 60% more potassium than bananas. (http://wikipedia.org/wiki/Avocado). Most of these nutrients are deficient in most typical diets and are all abundantly present in avocado. In its unmodified natural state the avocado represents a more balanced and wholesome diet than most food or even concentrated supplement pills.

Vitamins E, C and beta carotene (vitamin A precursor) are natural antioxidants which protect against dangerous “free radicals” which are by-products of life processes due to oxygen (Bergh, 1992). These free radicals result in cataracts from eye tenses, cancer due to cell mutation, arthritis, advanced aging process, and heart disease due to cholesterol buildup. These antioxidants are specifically effective in reducing the oxidation of the low density lipoprotein (LDL) which lead to plaque deposits in arteries. The role of Vitamin E's role in slowing down the aging process makes avocado very important in the cosmetic industry.

Avocado protein has also been proven to contain all the essential amino acids for human nutrition attributes not provided by any other plant source (Bergh, 1992). Its fiber content was also noted to be high in both the soluble and insoluble forms and this is considered very advantageous due to fiber's lowering effects on cardiovascular disease, hypertension, diabetes, and obesity. Pectin in particular a water-soluble fiber is known to be most effective in maintaining heart health.

The avocado fruit contains more calories per gram than most other foods and thus people tend to avoid it because of the well known adverse effects of cholesterol on humans. The fat content of avocado which is the cause for much misconceptions however is another valuable aspect of the fruit. More than 70% of its fat is monounsaturated fat with low levels of polyunsaturated and saturated fat with slight variations according to cultivars and fruit maturity stage (Arpaia *et al*., 2006). Monounsaturated fat in particular has been noted by Bergh (1992) in two of his papers to be highly beneficial in that it not only lowers the level of the harmful cholesterol (LDL) but also maintains the level of the beneficial high-density lipoprotein (HDL) or good cholesterol which protects the heart (Eyres *et al*., 2006; http://avocado-oil.co.nz/nutritionanalysis.html; http://www.olivado.com/avocado_oil.htm). The desirable HDL is lowered with diets low in fat, or high in complex carbohydrates which is usually used by many people wanting to lose weight. A diet high in polyunsaturated fat on the other hand not only reduces HDL but is highly prone to oxidation at the site of unsaturation in its structure (Arpaia *et al*., 2006)

The use of avocado in human nutrition controlled experiments have either proven or claimed the following findings:

- Subjects on avocado enriched diets had a decrease in total cholesterol level

- A reduction in body weights and;
- A reduction in stroke incidencess due to high K content

(Bergh, 1992).

Avocados are also highly recommended food for infants. The smooth, delicate flavour, creamy consistency make it an excellent food choice. More importantly it provides them with essential nutrients and monounsaturated fat which is beneficial for baby's development. The more traditional uses of the fruit in particular for the South American people is its use as a sexual stimulant (http://wikipedia.org/wiki/Avocado)

Avocado Disadvantage

There is documented evidence that feeding any part of the avocado tree including its fruit to any non-human animal is life threatening and lethal for some animals. Thus total avoidance of any part of the tree is recommended by most animal organizations (http://wikipedia.org/wiki/Avocado)

Avocado Oil

Avocado oil is the major avocado product which utilizes this otherwise not very popular fruit in Samoa. Only a few countries are actually involved in the production of oil namely Mexico (34%), USA (8%), Israel (4%), South Africa (<2%) and New Zealand (<1%) and these are also the countries involved in growing and trading of the fruit (Eyres *et* al., 2006; Cutting, 2004). Avocado oil was predominantly processed by the traditional producing countries and sold to the cosmetics and pharmaceutical industry to be used in cosmetic and healthcare products and as a lubricant. The methods of extraction used resulted in oil that was not suitable for consumption until now. A new method has recently been developed in New Zealand which produces avocado oil that is comparable in quality to olive oil the industry's finest or premium cooking oil.

The fatty acid make up of avocado oil which is of great health importance, coupled with the presence of many essential nutrients and phytochemicals make it a very valuable product. The emerging market for it should be acknowledged and taken advantage of as it presents many opportunities for using surplus fruits and producing a value added product (Eyres *et al*., 2006).

Factors Influencing the Oil Content of Avocado

Avocado fruits with high oil content must be used in the production of oil. Various factors however are known to affect the oil content of fruits and they are:

Cultivar - Different cultivars vary in oil content upon maturity and only those with high oil content should be considered. Because the oil is contained in the pulp or flesh, cultivars with high proportion of flesh and minimum seed and peel should also be selected (Human, 1987; http://www.crfg.org/pubs/ff/avocado). Many studies have confirmed the Hass cultivar to be superior in quality with all the favourable attributes (Human, 1987; http://www.olivado.com/avocado_capsules.htm).

Maturity stage – The time at which the fruits of any given cultivar is harvested was noted by Arpaia *et al*. (2006) to have the greatest impact on the oil content of the fruits. Maturity is when the fruit is most suitable for human consumption and not for processing. Some cultivars mature early while others mature much later and understanding this becomes very important for choosing when to harvest. However it is understood that when avocado fruits mature their moisture content lower while their oil increases and leaving the fruits on the trees much longer after maturity tend to increase oil content (Human, 1987).

Location and growth conditions - The same study of avocado postharvest quality by Arpaia *et al*. (2006) also noted differences in oil content for the same cultivar due to different locations and growth conditions such as soil fertility. Sun exposed fruits were also found by Woolf *et al.* (1999) to yield higher levels of oil than those fruits in the shade.

Biochemical Composition & Physiochemical Properties of Oil

Understanding the biochemical composition and physiochemical properties of the oil help explain its functional properties and uses. Most of the beneficial attributes associated with eating avocados are mostly preserved in the oil and for this reason is very valuable. The composition and in particular properties of the oil varies according to how it is produced whether it be crude, virgin or refined according to the method and number of successive operations involved in its production (Simental & Escalona, 2004)

Various analysis have been done on the composition of avocado oil and Table 2 lists typical results according to Eyres *et al.* (2006). A major difference in colour or chlorophyll content of the oil is noted when it is refined, bleached and deodorized (RBD) compared to virgin oil.

Table 2: Typical analysis results of Avocado oil and Olive oil Composition

Parameter	**Avocado Oil**	**Olive Oil**
Acidity Value (as oleic) (%)	2.0 – 0.08	0.15-0.25
Peroxide value (meq/kg fat)	3.3-0.1	1.0-2.0
Iodine value (from GLC)	87-75	75-82
Colour (chlorophyll)(ppm)	40-70 virgin, 1-10 RBD	4-6
Specific Gravity (25^0C)	0.912- 0.916	0.914 - 0.918
Beta-sistosterol (%)	0.45 -1.0	0.1- 0.2
Total Vitamin E (mg/kg)	112 -200	100 – 150
Alpha-tocopherol (mg/kg)	130	100
Beta/Gamma-tocopherol	15	10
Delta-tocopherol	5	10

Flash Point	150 – 255^{0}C	-
Unsaponifiables	1.0 – 12%	-
Cholesterol	0	-
Sodium	0	-
Carbohydrate	0	-

(Eyres *et al*., 2006; Botha, 2004; http://avocado-oil.co.nz/nutritionanalysis.html; Human, 1987)

The comparison of the compositional make up of avocado and olive oil shows very similar results for most parameters. The Vitamin E, Beta-sistosterol and alpha-tocopherol levels however are much higher in avocado oil, the micronutrients with significant proof of health benefits. The flash or smoke point of avocado oil is another noticeable feature. This makes the oil highly applicable for high temperature cooking as it will not burn until it reaches temperatures well above 150^{0}C. The acidity value and peroxide values indicate stability in terms of minimal hydrolysis and lipase activities. The oil is also free of cholesterol and carbohydrate. Table 3 shows a Vitamin analysis of avocado oil as reported by Human (2004)

Table 3: Vitamin content of avocado oil (seasonal range) per 100g

Vitamins	**Result**
Vitamin A (carotene)	370 -870 IU
Vitamin B2 (Riboflavin)	0.08 – 0.16
Pyrodixine	0.19 – 0.26 mg
Pantothenic acid	0.78 – 1.2 mg
Folic Acid	0.022- 0.105 mg
Thiamine Hcl	0.08 – 0.125 mg
Ascorbic acid	4.0 - 13.0 mg
Niacin	1.05 – 2.42 mg
Choline	12.0 – 22.2 mg
Biotin	2.3 – 4.2 mg
Vitamin E	0.8 -4.2 IU

As seen in the above table, the vitamin content of oil varies within a range for the various parameters and the usual influential factors of cultivar, maturity and processing method is likely to impact on these values. The list is extensive and most of the vitamins is lacking in most diets. The presence of most of these vitamins in avocado oil gives it the properties which makes the oil highly valuable in the cosmetic industry.

Fatty Acid Composition

As seen in Table 2 the iodine value is high indicating a high degree of unsaturation. A typical avocado oil is comprised mostly of monounsaturated fatty acids (74%), 11% polyunsaturated fatty acids and about 13% saturated (Arpaia *et al.*, 2006). These percentages vary slightly with cultivars and other influential factors but the oil is very similar to olive oil. It is this high level of monounsaturated fat which gives the desirable effect of being “anticholesterol” as it prevents the formation of clots the major cause of coronary heart disease.

Table 4: A Typical analysis of the Fatty Acid composition of Avocado Oil as compared to Olive Oil

Fatty Acids	**Fatty Acids**	**Africa Oil Analysis (%)**	**New Zealand Oil Analysis (%)**	
		Avocado Oil	Avocado Oil	Olive Oil
Palmetic Acid	C16:1	11.85	12.5-14.0	8.6-12.9
Palmitoleic Acid	C16:1	3.98	4.0-5.0	0.3-0.7
Stearic Acid	C18:0	0.87	0.2-0.4	2.1-2.8
Oleic Acid	C18:1	70.54	70-74	77-82.6
Linoleic Acid	C18:2	9.45	9.0-10.0	4.6-7.5
Linolenic Acid	C18:3	0.87	0.3-0.6	0.5-0.7
Arachidic Acid	C20:0	0.50	0.1	0.0-0.6
Gadoleic Acid	C20:1	-	0.1	0.0-1.4
Eliosenoic Acid	C20:1	0.39	-	-

(Eyres *et al*. 2006; Human, 1987).

Table 4 lists results from two different countries and their analysis of avocado oil confirms the healthy composition of the oil in terms of fatty acid composition. It also indicates the comparability of avocado oil to olive oil due to very similar fatty acid composition. The analysis reported in Table 4 was done using the Fatty Acid Methyl Ester (FAME) analysis on a Gas Chromatograph.

Phytochemicals

The naturally occurring phenolic compounds found in vegetables and fruits have been proven to have equal or greater cholesterol lowering properties than unsaturated fatty acids (Nicolosi & Orthoefer, 2004). Beta-sitosterol (a phytosterol) is one of the healthy plant compounds found to be most abundant in avocado. It is widely proven to be responsible for the non-absorption of the bad cholesterol (LDL) and maintaining the good HDL cholesterol in the intestine which then lowers total plasma cholesterol (Arpaia *et al*., 2006). This compound was also reported by the British Medical Journal the Lancet to be very effective in offering relief to men above 50 years who suffered from benign prostatic hyperplasia resulting in significant improvements in urinary difficulties (http://www.olivado.com/avocado_capsules.htm). The phytosterol content has the same skin penetrating abilities of lanolin and for this reason avocado oil is highly valuable in the cosmetic industry. Lutein or carotenoid is also highly abundant in avocado oil. This phytochemical is effective in providing protection against prostate cancer, eye diseases and macular degeneration (http://www.avocado-oil.co.nz/nutritionanalysis.html).

Lozano *et al.* (1993) noted that the unsaponifiable fraction from immature fruits contained a much higher level for both total sterol (1.1 – 6.2%) and tocopherol (20.1-45.6 mg/100 g of oil) compared to matured fruits (sterol 0.8-2.0% & tocopherols 5.7-10.3 mg/100 g oil). This is very significant for the extraction of enriched amounts of these compounds as they are of high health significance.

Antioxidants

Phytochemicals in plants is reported to have greater antioxidant effects than minerals and vitamins (http://www.betterhealth.vic.gov.au). Lutein for example is one very effective antioxidant. Vitamin E represents a mixture of chemicals known as tocopherols and tocotrienols and is another well known vitamin with antioxidant effects (http://www.olivado.com/studies3.htm). α – tocopherol is one powerful antioxidant which neutralizes the free radicals produced under the normal metabolism of lipid compounds (Arpaia *et al*., 2006). As noted in table 2 this is also abundant in avocado oil. All these antioxidants found in high levels in avocado oil neutralize the free radicals which would otherwise result in the following:

- eye deterioration;
- inflammation of the joints;
- damage to nerve cells in the brain;
- accelerating the ageing process and;
- certain cancers.

(http://www.betterhealth.vic.gov.au)

Chlorophyll & Carotenoids

Crude and virgin oils have high chlorophyll and amounts of other soluble pigments (carotenoids) which give it their distinctive brown – green or emerald green colour. The virgin oil with high chlorophyll content is highly desired by consumers due to the health benefits associated with the presence of these micronutrients. The high chlorophyll content makes the oil highly prone to oxidative effects upon exposure to light and for this reason must be packed in dark bottles. Other carotenoids like lutein are also present in high amounts while others like neoxanthin, violaxanthin, antheraxanthin are present in very minute amounts (Arpaia *et al*. 2006). Further processing and refining removes the chlorophyll and other pigments giving oil that is pale yellow in colour and also more stable (Botha, 2004; Eyres *et al*. 2006).

Unsaponifiable Fraction

The healthy plant micronutrients which have anti-oxidant, anti-inflammatory, and cholesterol lowering properties are mostly contained in this portion of the oil. This part of avocado oil is highly valued in the pharmaceutical and cosmetic industries for the high skin penetration coefficient and the specific biological actions of its sterols (Botha, 2004). Human (1987) also reported this fraction to contain an unknown factor known as the H-factor which has healing properties. Eyres *et a.l* (2006) reports that the healing properties may be linked with lysyl oxidase which initiates cross linking in collagen and inhibits enzyme activity. This would be very important for the treatment of wounds and burns. The unsaponifiable fraction is also high in nutrients which is another reason why it is highly sought after by the cosmetic industry. The French pharmaceutical industry filed two separate patents No 17/245 and No 102888 for the extraction of this fraction indicating its high value (Human, 1987).

Lozano *et al*. (1993) reported that the unsaponifiable matter in oil from immature fruits (15-40%) was always higher than the matured fruits (4-9%). This fraction of the oil is where most of the healthy plant sterols are concentrated. This is interesting as it presents another valuable option for farmers in using immature fruits for extracting this highly valuable unsaponifiable matter from oil.

Oil Utilization

Cosmetic Industry – Avocado oil is well known for its anti-bacterial, anti-wrinkle and healing properties. The multiple properties of avocado oil namely stability, emolliency, skin penetration, softening and moisturizing results in its wide applicability for cosmetic products. The high penetration ability of the oil in particular makes it very successful in its use as a natural and effective beauty aid. It is used in a wide variety of creams and oils for skin application as it acts as an effective carrier of other supplements incapable of permeating the skin (Human, 1987). The high content of lecithin and phytosterols facilitates its spreadability. It is easy to emulsify as its low surface tension makes smoother creams and soaps. Vitamin A help prevent dry skin while Vitamins E and D are effective against skin wrinkling and slow the process of ageing. A few New Zealand and US companies now manufacture various skin care products using avocado oil, like body moisturizer, replenishing facial crème, skin repair crème and natural oil for everyday use (http://www.olivado.com/avocado_cosmetics.htm; http://www.elysianisle.com/avocado_oil.html; http://mountainroseherbs.com/learn/oilprofile/avocado.htm) .

The oil is an ingredient for up-market skin care cosmetics, shampoos and baby products. The oil is highly priced to those with skin problems and is used as a base for ointments used for treating dermatitis, acne, lacerations and other skin conditions. It is also used as a post-operative dressing to prevent adhesions to wounds and skin burns while accelerating the healing process. (http://www.avocado-oil.co.nz/skincare.html). It also has strong UV absorption properties making it a very good effective sunscreen.

Food –The oil is highly applicable for food preparation and because of its high quality (similar to olive oil) it provides another healthy alternative for consumers. It is marketed as a healthy oil due to its high content of monounsaturated fat, presence of essential amino acids and high vitamin content. The high sterol content in particular and its cholesterol lowering effect is what makes this oil a must for modern society. It has a high smoke point making it suitable for high temperature cooking. It also has a bland flavour which does not disguise the natural flavour of food. It is also used as a dressing for salads and vegetables and also as a dip for hot food like bread. There are naturally infused oil available with different flavours like garlic, chilli, lemon and orange which provide consumers more choices to choose from (http://www.avocado-oil.co.nz/nutritionanalysis.html; http://www.olivado.com/avocado_oil_uses.htm; http://www.jopling.co.uk/news_avocado.html; http://elysianisle.com/avocado_oil.html; http://www.oliveoilsource.com/olivenews.htm).

Dietary supplement – One of the most exciting products produced by New Zealand based Olivado and Elysian Isle companies is the avocado oil capsule. It simply takes all the beneficial attributes found in avocado oil and seal it in a health capsule which can be taken daily. It contains all the healthy micronutrients and vitamins available in the oil which can help fight bad cholesterol, inflammatory, osteoarthritis and prostate problems (http://www.olivado.com/avocado_capsules.htm; http://elysianisle.com/avocado_oil.html).

Processing of Avocado Oil

To produce a quality product requires high quality raw materials. For this reason it is imperative that the fruits used are of high grade in particular must contain high proportion of pulp, have high oil content, free of diseases and must not be physically damaged as evident in pulp discoloration and/or off-flavors. The fruits have to be carefully matured and ripened to allow for maximum oil development before they are used.

Various methods have been used in the extraction of oil from avocado fruits. The methods vary in their degree of effectiveness for oil extraction and also subsequent effect on the resultant oil quality. Heating and chemical extraction have been the traditional methods used and now a new method has been developed in New Zealand which allows oil to be expressed from the fruits with very minimal processing.

Human (1987) lists various methods used in the past for the extraction of avocado oil involving steam pressure, hydraulic pressing, solvent extraction, centrifugation, freeze-drying, rendering process and the use of a tube press plant. However the specific application of the oil should determine the process and method chosen. Only the most practical and suitable methods are discussed below.

Pre-Process Treatment

Avocado fruits destined for oil production must be firstly inspected for physical damage and other abnormalities. They are then washed before being processed to remove the skin and seed. The means used for washing, de-stoning and de-skinning of the fruits vary but all processes involve this first critical step (http://elysianisle.com/avocado_oil,html; http://www.olivado.com/avocado_oil.htm).

Rendering process - This method involves heating of the avocado pulp in avocado oil. The moisture evaporates off leaving the oil and the dry matter behind. The oil can then be decanted off while the remaining slurry is subjected to hydraulic pressure to press out more or the remaining oil. It is reported that laboratory experiments resulted in 94% recovery of the oil using this method (Human, 1987).

Tube Press Plant – This consist of either one or two tubes. The tubes are filled with avocado pulp and then subjected to hydraulic pressure to press out the oil through perforations within the inner tubes. This method was developed my Messrs Alfa Laval and aims at extracting out most of the oil with minimal damage to the oil quality (Human, 1987).

Solvent Extraction – This is one of the traditional methods commonly used. Various solvents could be used and organic solvents have mostly been utilised. Botha (2004) reported experimental solvent extractions using hexane and a Soxhlet extractor on a 10g dried sample for 8 hours. Subsequent removal of the solvent followed by vacuum evaporation and drying until constant mass. The resultant oil has a high chlorophyll content meaning the chlorophyll is co-extracted along with the oil. Chlorophyll levels as high as 192.9 ppm was reported by Werman & Neeman (1986) to have been extracted in the laboratory by ethanolic extraction.

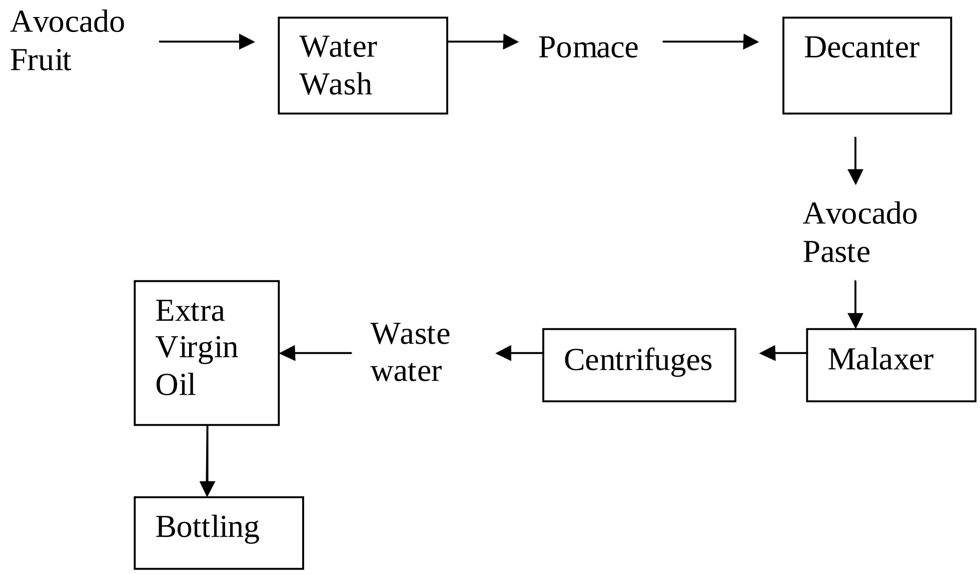
Human (1987) reported this method to have the highest yield but industrial equipment is very expensive to install plus the highly flammable solvents used are very dangerous. The recovery and total removal of the solvent is also an issue which requires a highly sophisticated plant. Thus because the raw material is an expensive fruit and the oil yield is at maximum around 22% of the whole fruit it is not economical to extract avocado oil in this way. Xiao *et al.* (2006) reported the method does have other disadvantages like loss of volatile compounds, long extraction times, toxic solvent residues and degradation of valuable oil compounds.

Centrifugation – After the pre-processing treatment, the fruits are fed into a mill where it takes the form of a guacamole. The malaxation takes up to several hours until the release of the fine emulsion of oil. The paste is then fed to a centrifugal decanter where the oil is separated from the guacamole (http://oliveoilsource.com/olivenews.htm). Werman & Neeman (1986) and Bizimana *et al*. (1992) reported that extraction of oil was most efficient using centrifugal force 12,300 xg, a 5:1 water to avocado ratio, temperature 75^{o}C, with a pH 5.5 and a 5% concentration of either NaCl, $CaCO_3$ or $CaSO_4$.

Cold Press- This relatively new method of extracting oil makes use of the modern Alfa Laval centrifugal extraction method so is a variation of the above method. The fruit flesh is firstly macerated by high speed grinders before the mixture is mixed in malaxers. When this process is complete, a three phase decanter then separates the mixture into oil, water and solids before polishing takes place with a multi-cone centrifuge. Extra virgin oil is produced after the first press. The extraction efficiency is dependant on such things like pH, centrifugation rate, salt, mixing temperature ($<50^{0}$C) and duration of pressing (Eyres *et al*., 2006; Sionek, 1997). At no time along the whole process is the oil subjected to light or oxygen as this has a deteriorating effect on the quality of the oil.

The extraction rates vary from 10-22% of the whole fruit and also tend to vary during the season.

Cold Press Extraction Process



(Wong *et al.*, 2006)

The above method involves low temperatures, and minimal processing and as a result the oil retains all its natural flavour, nutrients and healthy properties. Thus the resultant oil is of high quality and is considered a "virgin oil" because of very minimal processes involved (http://www.olivado.com/avocado_oil.htm; http://www.avocado-oil.co.nz/nutritionanalysis.html). This virgin oil however has high chlorophyll content and is thus more unstable. This makes packaging in dark bottles or tins and total avoidance of oxygen a must for a longer shelf life for the product. This oil must be stored in a dark, cool cupboard where the temperature never rises above 30^{o}C, but should never be refrigerated or it will solidify. Virgin oil only has a shelf life of two years if stored correctly. More stable refined cold processed oil can also be produced after it has undergone further processes of refining, bleaching and deodorized (RBD).

The virgin oil is excellent for salad dressing, a marinade on fish and chicken and also for baked goods. It can also be used as a simple drizzle on vegetables and potatoes and also for shallow pan-frying of poultry and fish (http://www.oliveoilsource.com/olivenews.htm).

The production of cold pressed oil requires little investment and the process itself is simple. However the process has inefficiencies in that around 6-15% of the oil remains in the pressed residue (Uzytku & Higieny, 1997).

Supercritical CO_2 – Botha (2004) reported extraction results for avocado oil extracted using supercritical carbon dioxide under four different extraction conditions.

Table 5 : Spectroscopic quantification of the colour of avocado oil extracted with supercritical carbon dioxide at four different conditions

Extraction Condition	**Absorption Value**	**Visual Quantification**
37^{o}C/350 atm	0.325	Straw-yellow
37^{o}C/532 atm	0.410	Straw-yellow greenish tint
81^{o}C/350 atm	0.526	Straw-yellow with strong greenish tint
81^{o}C/532 atm	0.765	Green with yellow tint

The above Table 5 indicates that at higher temperatures and pressures, chlorophyll can be co-extracted along with the oil. Xiao *et al.* (2006) reported that the power of solubilisation for supercritical CO_2 can be achieved with higher densities which is achieved at higher pressures. This allows large amounts of organic compounds to be dissolved which can later be separated from the fluid by means of reducing the temperatures or pressures. Thus the extraction of the phytochemicals was only possible at higher pressures and temperatures only due to the solubilisation of the organic compounds. Lower temperatures and pressures will extract only the oil without chlorophyll. This method is very important as it basically proves that more stable oil without chlorophyll can be extracted this way which eliminates the need to refine the oil of its colour pigments. The oil however does not contain the healthy plant compounds which is highly attributed for its health benefits.

Before analysing the free fatty acid of the oil the CO_2 must be totally removed as it increases the acidity level. This can be done by subjecting the oil to vacuum evaporation (Botha, 2004). The degree of oxidation of the oil in the dried material used for extraction is also important as volatile acids are also co-extracted by this method. The free fatty acid content however of the oil extracted by this method was not different to the FFA of the oil extracted by hexane indicating no effect of either pressure, temperature or supercritical CO_2 on the hydrolysis of the parent glycerides.

An important outcome of extracting with supercritical fluid as reported by Botha (2004) was that the unsaponifiable fraction of the oil was found to be higher for the first fractional extraction (20 minute intervals) and tend to decrease with subsequent extractions. Thus the unsaponifiable fraction of the oil can be enriched by extracting at time intervals.

The use of supercritical fluid is proven to be a cost-effective technique for laboratory scale while large scale units still require experimentation for accurate economic valuations. This method has advantages such as low operating temperatures, shorter extraction periods, high selectivity in the extraction of compounds and no undesirable solvent residue (Xiao *et a*l., 2006). It also uses a safe, readily available gas.

Refining of Avocado Oil

Virgin and crude oil can be further processed when it does not meet the virgin oil quality standards. The crude oil with high chlorophyll content is a dark green transparent oil with brown or yellow tints. This highly unstable oil could be refined using the following steps.

Bleaching

Bleaching removes colour pigments like chlorophyll and lutein using acidified activated earth at an elevated temperature. This is followed by filtration and a spectrophotometer may be used to monitor the bleaching process by measuring the optical density of the oil. Losses as high as 5% may be encountered here.

Deodorising

Deodorising is required to remove objectionable flavours/odours which may develop during bleaching by using steam distillation. This is done under vacuum at elevated temperatures. Again losses as high as 7% may be incurred here.

Winterising

The presence of high melting components in the oil makes it cloudy at low temperatures. These components tend to crystallize at low temperatures and must be removed. Winterising aid like oxystearin is used to help the formation of larger crystals which could then be removed via decanting and filtration.

Alkali Refining

The refining process involves the use of a strong alkali (eg. NaOH) to remove free fatty acids and peroxides. Both compounds tend to reduce the shelf life of the oil and also give it a rancid smell. This tedious process may result in losses as high as 7% - 8% (Human, 1987; Eyres *et al*., 2006). Nicolisi & Orthoefer (2004) reported that a patent (6, 197, 357) was awarded for the replacement of NaOH with Na_2CO3 or NaHCO3 which resulted in a refining process that retained more that 85% of the phenolic compounds. These healthy compounds are usually lost with the unsaponifiable fraction of the oil during the refining process when NaOH is used.

Another method for refining is by heating the oil under vacuum at elevated temperatures, and sparged with live steam causing the free fatty acids to be distilled off

Refined oil is pale yellow, bland, and highly stable. It is highly suitable for general purpose cooking because of its high smoke point and has a healthy fatty acid composition. It is most suited for barbeques as most common vegetable oil polymerize and oxidize readily on hot surfaces.

Effect of Processing on the Quality of Oil

The phenolic compounds which are well publicized for their health benefits are lost or destroyed by most processing methods. Extra virgin oil loses its highly beneficial micro-nutrients during the refining process and the cholesterol lowering and anti-oxidant properties are significantly reduced as a result (Nicolisi & Orthoefer, 2004). The colour or chlorophyll content of the oil is noticeably lower than that of virgin oil due to the removal of these plant compounds (Eyres *et al*., 2006).

Xiao *et al.* (2006) noted that the usual methods of hydrodistillation and organic solvent extractions present problems like toxic solvent residues, degradation of the unsaturated compounds and vitamins, and giving objectionable off-flavours due to heat. The change from NaOH to Na_2CO3 or NaHCO3 when refining is reported to achieve the same results when refining with the extra benefit of retaining the phenolic compounds. Thus a more stable and healthy oil can still be achieved after refining if Na_2CO3 or NaHCO3 is used.

The cold pressing and supercritical fluid methods appear to be the most suitable and beneficial methods to extract the avocado oil. Both utilise low temperatures which help retain the healthful composition of the oil, involves minimal processing and requires less capital investment.

Analysis Methods for Oil Components

The analysis of the various biochemical and physiochemical composition of the oil can be analysed using the following equipment given in table 6.

Table 6: Lab analysis equipment used for avocado oil compositional analysis

Equipment	**Components**	**Extraction Method**	**Reference**
Gas Chromatography - FAME analysis	for fatty acid composition	Cold Press – Centrifuge	Eyres *et al.* (2006)
Gas Chromatography – Mass Spectrometric	Major compounds	Supercritical CO_2	Xiao *et al.* (2006)
High Performance Liquid Chromatography	-tiacylglycerols - sitosterol & tocopherol - lutein - total chlorophyll		Eyres *et al.* 2006 Lozano *et al.* (1993)

Other detailed analysis as given in tables 2 & 3 do not specify the methods of analysis used. However the analysis equipment used for analysing other vegetable oils will undoubtedly be suitable for the analysis of avocado oil.

Conclusion & Recommendations

Avocado fruits are highly nutritious fruits which are abundant locally but has a very small local market. The avocado oil contains all the beneficial attributes of the fruit which makes it a very valuable product. It contains high amounts of the anti-cholesterol agent beta-sitosterol, a wide variety of vitamins and antioxidants, and other plant chemicals which impart beneficial functional properties on humans. The oil's fatty acid composition is composed mostly of the healthy monounsaturated fats particularly oleic acid which is similar to olive oil. The oil can be produced as a virgin oil or as a refined oil suited for various food preparation. The unsaponifiable fraction of the oil represents another major profitable market as used in the cosmetic and pharmaceutical industries, which has been the traditional end-user of avocado oil. The use of immature fruits to produce oil with higher unsaponifiable content and phytochemicals is an interesting area to pursue in particular for capsule production.

The cold press and supercritical CO_2 methods are the two best options to consider for processing avocado oil. They both utilize low temperatures to extract the oil while still retaining all the natural flavour, richness and healthful properties of the fruit. Supercritical CO_2 in particular has the extra benefit of being able to extract oil alone at low pressures and temperatures and also co-extract chlorophyll at higher pressures and temperatures. The cold process method is now widely used at the industry level while the supercritical CO_2 method has only been successfully trialed in the laboratory. Both methods however are known to be economical in terms of investment required due to the few processes involved.

Avocado oil is definitely a more productive use of the fruit. It can act as a local substitute for imported vegetable oil and as an export item both as a cooking oil or as a raw material for cosmetic and pharmaceutical products. The production of avocado oil is therefore an excellent option for making value added products from this wasted produce which has high economic value due to its highly healthy composition.

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