NSW GOVERNMENT | Department of Primary Industries

Variability of quality traits in canola seed, oil and meal - a review

Published by the NSW Department of Primary Industries

Variability of quality traits in canola seed, oil and meal – a review

First published May 2014

ISBN 978 1 74256 629 0

More information

Jamie Ayton/Horticulture, Wagga Wagga Agricultural Institute

www.dpi.nsw.gov.au

Acknowledgments

This work was co-funded by the Grains Research and Development Corporation (GRDC) and NSW DPI.

Cover image: Photo © NSW Department of Primary Industries

Jobtrack 12869

Contents

1 Introduction

Canola belongs to the botanical family Brassicaceae and includes the species *Brassica napus*, *B.rapa* and *B.juncea* (Daun, 2011). Canola is an altered form of rapeseed, a crop that has been used as a source of edible oil for thousands of years (Edwards and Hertel, 2011). During the 1980's, significant changes were made to rapeseed through breeding programs to produce canola. In order to be classified as canola, the oil in the seed must contain less than 2% erucic acid and the oil-free, air-dry meal must contain less than 30 µmoles/gram glucosinolates (CCC, 2009). Prior to the genetic changes, initially achieved by Canadian plant breeders such as Dr Baldur Stefansson and Dr Keith Downey, rapeseed oil contained 20%–45% erucic acid and 50–150 µmoles of glucosinolates (Bell, 1993; Daun, 2011).

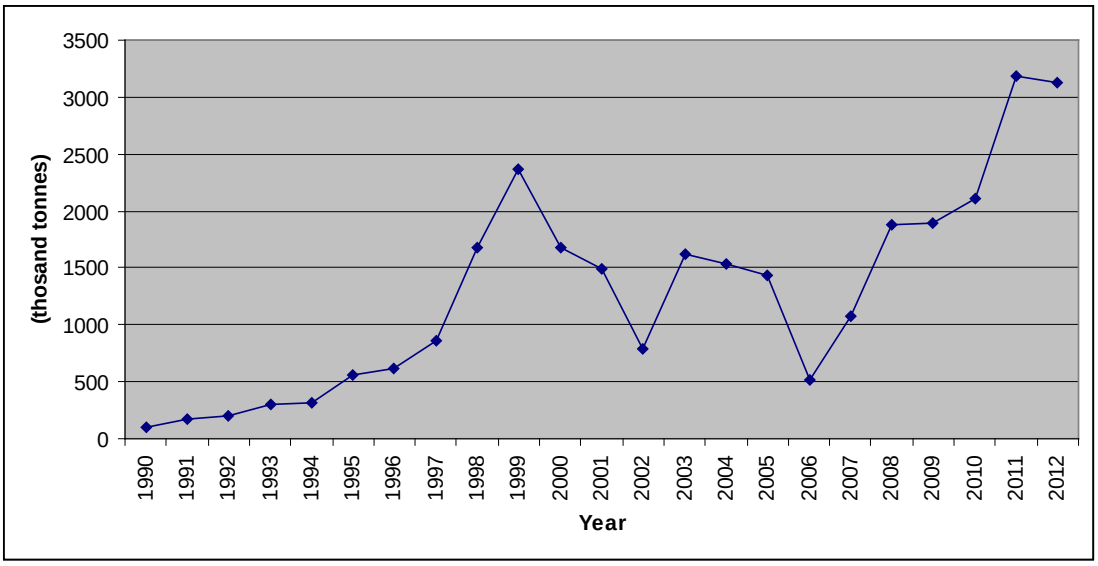
With a worldwide production of 62 million tonnes of canola produced in 2012, it ranks behind only soybeans in world oilseed crop production (USDA, 2012). Canola is grown principally as a source of edible oil, however it is being used more frequently in the production of biodiesel, especially in the European Union (EU) where almost nine million tonnes of biodiesel were produced in 2010, mainly from canola oil (EBB, 2010). Most common canola varieties typically contain between 35% and 50% oil (Zum Felde et al., 2007). The oil is the most valuable component of the seed, usually accounting for 65%–80% of the seed value, with the meal component accounting for the remainder.

The oil-free meal contains 35% to 50% protein and is a commonly used protein supplement in animal feed and aquaculture industries (Tan et al., 2011). While canola meal has an excellent balance of amino acids, some anti-nutritional components including glucosinolates, sinapine and comparatively higher levels of fibre limit its inclusion in animal rations (Matthäus, 1998). Approximately 36 million tonnes of rapeseed/canola meal was produced worldwide in 2012 compared to 180 million tonnes of soybean meal (from a crush of 240 million tonnes of soybean) (USDA, 2012). Canola meal generally has a higher fibre, lower protein and lower available energy content than soybean meal, which is its main commercial end-use competitor (Jia et al., 2012). Canola meal is usually priced at about 60% to 75% of the price of soybean meal, despite having a relative protein content of 70%–80% of soybean meal (Newkirk, 2002; Slee, 2012).

There is a growing trend towards the isolation of protein from canola meal for use in the production of food for humans due to its well balanced amino acid composition. However, the incorporation of canola meal into food for humans is also restricted by anti-nutritional factors such as sinapine, glucosinolates, phytic acid and tannins (Yoshie-Stark et al., 2008).

In Australia, canola is the third largest crop produced after wheat and barley and is widely grown in south east Australia and Western Australia. Generally, canola is grown in regions with >450 mm annual rain, however, successful breeding of drought tolerant lines has increased the area grown in low rainfall areas (Zhang et al., 2011) Production has increased from about 100 000 tonnes in the early 1990's to more than three million tonnes in 2012 (Figure 1).

Figure 1. Australian canola production 1990 to 2012 (adapted from data from www.indexmudni.com and www.australianoilseeds.com).



An estimated 2.1 million metric tonnes of canola seed was exported from Australia in 2012. While Australia is a relatively small producer of canola (accounting for approximately 5% of global production), it is the world's second largest exporter accounting for 17% of world trade in 2011/12. Most Australian canola exports are to the EU and Pakistan. In 2011, over 1.5 million tonnes of Australian canola were exported to the EU (Gowen, 2012).

2 Canola processing

Currently, approximately 750 000 tonnes of Australian canola seed is crushed domestically. A new plant at Wagga Wagga in New South Wales and another currently in development are expected to double Australia's oilseed crushing capacity. The new Wagga Wagga plant has started processing seed and is expected to crush 150 000 tonnes per annum (Gowen, 2012).

There are many different steps involved in the separation of oil from canola seed. There are also a number of different ways to extract the oil, including:

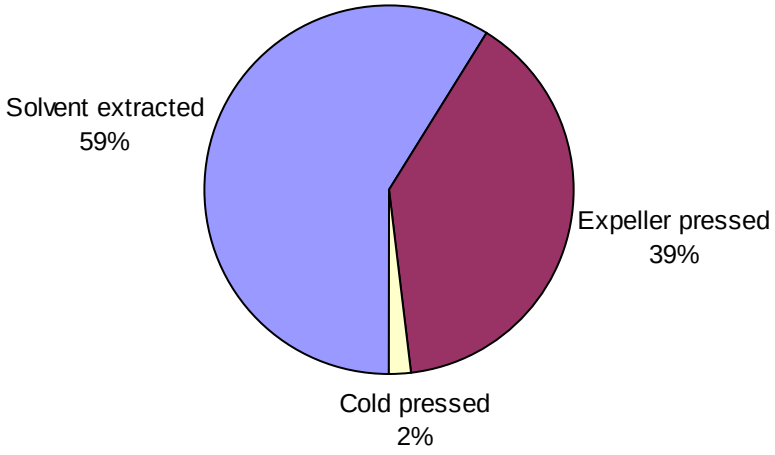
Cold press oil extraction - canola seed is not pre-conditioned prior to oil extraction. Mechanical separation is achieved with screw press expellers and temperatures up to 65°C generated within the expeller due to frictional forces.

Expeller oil extraction - canola seed is heat conditioned and the expeller is operated to optimise oil recovery. Temperatures up to 135°C are generated during the brief period the seed cake is passing through the expeller. In some plants, a double pass system operates where seed cake is reprocessed to increase oil recovery.

Solvent extraction - the seed is conditioned and then the oil is mechanically removed by screw press. The resulting 'seed cake' is then extracted using solvent (usually hexane) (Mailer, 2004).

The Australian canola processing sector is unique in that a significant proportion of the canola crush is achieved using cold pressed and expeller methods (Figure 2). Most other countries have a significantly higher proportion of the crush done using solvent extraction methods. Cold press and expeller plants are used due to lower capital costs than solvent extraction plants. However, because the oil is extracted by mechanical separation, the resulting meal is somewhat different to solvent extracted canola meal. Generally the nutritional composition of expeller and cold press canola meal is similar to solvent extracted meal except that it retains 8%–15% oil, leading to significantly higher energy values (Newkirk, 2011).

Figure 2. Canola processing methods used in Australia (Slee, 2012).



2.1 Solvent extraction

Solvent extraction is the most efficient method of extracting oil from the seed, generally leaving about 2% to 4% residual oil in the meal. The process usually includes:

Seed cleaning - foreign materials are removed.

Pre conditioning and flaking - the seed is heated to 35°C to prevent shattering when the seed enters the flaking unit. The seed is flaked by rollers, which rupture the cell walls. The thickness of the flake is important as thin flakes (<0.2 mm) are too fragile, while thick flakes (>0.4 mm) result in lower oil yields. The optimal flake size is approximately 0.3–0.35 mm.

Seed cooking - at the beginning of the cooking stage, the temperature is rapidly increased to between 80°C and 105°C (the actual temperature varies with different processors) for 15–20 minutes. The flakes are cooked to thermally rupture the cells that survived flaking as well as to reduce the oil viscosity and promote coalescence of the oil droplets. It also serves to inactivate endogenous myrosinase enzyme in the canola, thus preventing the breakdown of glucosinolates, which can produce undesirable products (such as isothiocyanates and nitriles) in the meal.

Pressing - high oil content oilseeds including sunflower, peanuts and canola are not suited for direct solvent extraction. Therefore, the flaked canola is passed through a series of screw presses or expellers, which usually remove 50%–60% of the oil. Excessive temperatures and pressures need to be avoided to prevent damage to the finished product. Generally the temperature used is about 100°C to 120°C. An important outcome from this step is producing a presscake that is ideal for solvent extraction.

Solvent extraction - the presscake is solvent extracted to remove most of the remaining oil. The solvent used is generally hexane, which is recovered and re-used following separation from the meal. At this stage the solvent laden meal (marc) retains 25%–35% hexane.

Desolventizing and toasting - The hexane is removed from the meal in a desolventizer-toaster where, in a series of compartments, the meal is heated on a number of steam-heated plates. The final removal of solvent from the meal is achieved by injecting steam through the meal (toasting). The meal is then dried at 100°C to 115°C. The final meal contains about 10% moisture. Some of the by-products of solvent extraction, including gums and soap, are added back to the meal. This process increases the meal quality and energy values (Mailer, 2004; Newkirk, 2009; Unger, 2011).

2.2 Canola oil refining

Once extracted, canola oil needs to be refined to remove some undesirable characteristics from the oil. This process usually includes:

Degumming - the phospholipids or 'gums' present in crude oil are removed by adding a mild organic acid (eg. citric acid) to the oil and mixing. The mixture is then passed through a centrifuge to separate the degummed oil from the gums and acid.

Refining - the crude degummed oil is treated using phosphoric acid, followed by the addition of just enough sodium hydroxide to neutralise the free fatty acids present. The oil and caustic solution is then heated to approximately 85°C to 90°C before being centrifuged, in order to remove neutralised fatty acids and soap. The oil is then washed with hot water and centrifuged again to further reduce soap content.

Bleaching - acid activated bleaching clay is used to adsorb colour pigments from the oil as well as soaps, metals (magnesium, calcium, iron) and peroxides. The oil-clay mixture is maintained at 95°C to 110°C and 3.6–3.9 kpa pressure, and mixed for 30–40 minutes before being passed through a filter to remove the bleaching clay.

Deodorisation - The final stage of processing removes odours, free fatty acids and other volatile compounds to produce a light coloured, neutral tasting oil. In simple terms, steam is sparged through the oil which is heated to between 250°C and 260°C, removing the undesirable components. The oil is cooled and transferred to storage under a nitrogen blanket to help prevent oxidation. Vapours from the deodoriser are passed through a scrubber, with the collected distillate a valuable resource for cosmetics and manufacturing industries (Unger, 2011).

3 Canola seed physical parameters

The physical properties of canola seed can have a significant effect both agronomically and during processing. Different varieties can vary widely in size, morphology and composition and are therefore important considerations for growers, bulk handlers and processors.

3.1 Seed size

Seed size plays an important role in crop establishment. Small seeds (<1.6 mm) tend to have lower survival rates upon germination, due to either a limited metabolic capacity to endure imposed stresses or the inability to switch metabolism to a dormant state during storage, or both (Gulden et al., 2004). There is also an interaction with sowing depth—larger seeds establish more seedlings, especially if sown at 3 cm or deeper (Edwards and Hertel, 2011; Scott et al., 1999).

Seed size can also have an effect on the suitability of canola seed for processing. During the flaking process (Section 2.1) rollers are positioned at a set distance to mechanically rupture cells. If the seed is too small, whole seed passes through the rollers; too big and they cause problems with blockages and incomplete oil extraction. Smaller seeds have also been shown to have lower mechanical resistance, probably due to low surface density of the seed coat fibre components (Tanska et al., 2008).

Hulls are largely fibre and all of it remains in the meal after oil extraction. This can lead to problems with digestibility when the meal is included in animal feeds (Bell, 1993).

Most canola seeds are between 1.5 and 2.5 mm in diameter (Calisir et al., 2005; Riethmuller et al., 2003). Seeds can be oblong, spherical or slightly flattened laterally (Barthet and Daun, 2011).

3.2 Seed weight

Canola seeds are smaller than most grains and oilseeds, therefore the seed weight and other physical parameters such as bulk density and porosity are affected more by the seed's moisture content than other species. Seed weight is generally determined using a thousand seed mass.

Experiments in the field have shown that heavier seed (>4 g/1000 seeds) increase yield by up to 0.45 t/ha (Clarke and Simpson, 1978; Riethmuller et al., 2003) Limited research has been done on the relationship between seed weight and other physical parameters such as oil content and the results are somewhat ambiguous. Tkachuk and Kuzina (1975) found that oil content was positively correlated with seed weight, whereas Daun et al. (1990) found there was no relationship between seed size and oil or protein content.

Thousand seed weight for canola typically range between 2.5 and 4.6 g/1000 seeds (Table 1).

Table 1. Typical thousand seed weights.

1000 seed weight (g)	Country	Source
3.1-4.1	Iran	(Razavi et al., 2006)
3.3-4.6	Iran	(Shahraki et al., 2012)
2.5-3.6	Canada	(Tkachuk and Kuzina, 1975)
2.9-3.6	Australia	(Zhang et al., 2011)

3.3 Moisture

The amount of moisture in canola seeds depends on a number of factors including relative humidity and temperature at each stage of production (in the field, at harvest, during storage and during processing). Moisture can have a significant effect during seed storage and processing. High temperature and moisture can quickly lead to seed spoilage during storage, and anecdotal evidence suggests maintaining moisture at or below 8% during long term storage is beneficial. High moisture contents also interfere with the flaking, pressing and extraction processes, therefore excessive moisture must be removed before those processes can begin. The tolerance levels for processing factories is surprisingly narrow, with a typical range of 7.0%–7.5% moisture required for seed feeding into the flaking system. Oil recovery, solvent recovery from the meal, and oil quality are all adversely affected by the seed moisture level outside the ideal range (Unger, 2011). At low seed moisture content (<5%), seed breakage during handling can occur (Stepniewski, 1999). Determining the moisture content of seed is important as it is used to determine the values of other components in the seed. For example, oil content is generally reported as a percentage of whole seed at 6% moisture, whereas protein is reported as a percentage of the oil-free meal at 10% moisture. The Australian Oilseeds Federation Grain Quality Standards sets the maximum acceptable level for moisture in seed on delivery at 8% (AOF, 2012).

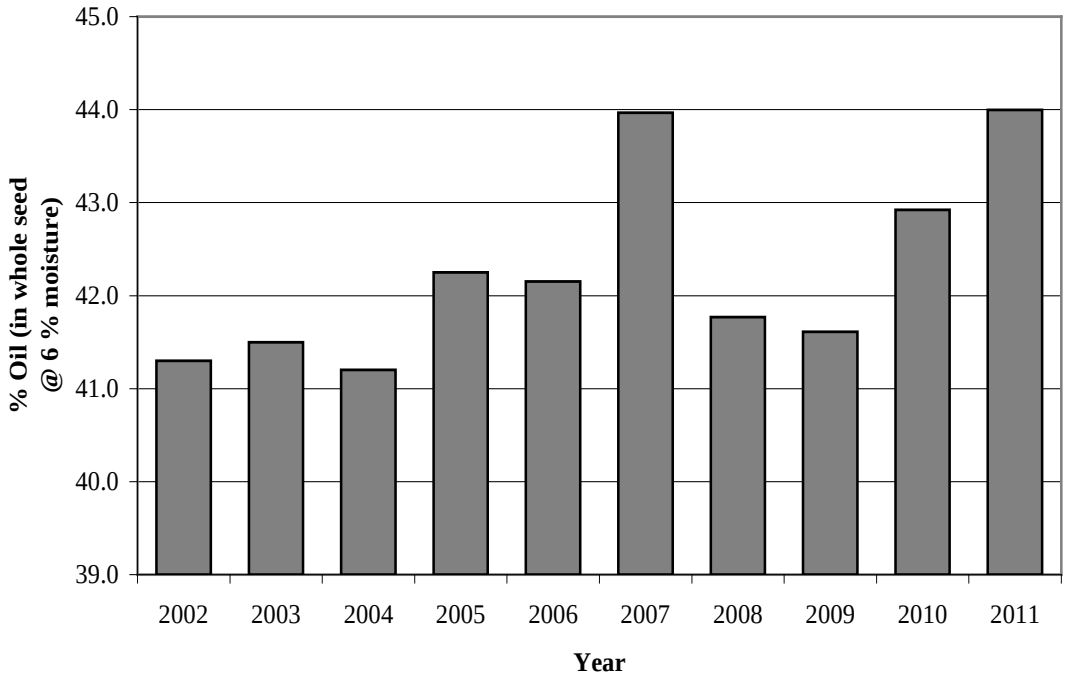
3.4 Oil content

Canola is grown primarily for oil, therefore oil content is the most important parameter when assessing canola quality. The oil is the most valuable component of the seed, usually accounting for 65%–80% of the seed value, with the meal accounting for the balance (Salisbury and Barbetti, 2011).

In Australia, oil content is usually expressed at 6% moisture, whereas in other canola producing countries, including Canada, 8.5% moisture represents average moisture content (Barthet and Daun, 2011). The oil content in canola varies significantly depending on the variety, agronomic conditions and the environment in which it is grown. Typically, oil content in canola seed ranges between 35% and 48%, while the annual average oil content of Australian canola has varied

between 41% and 44% in the last decade. When trading canola, a bonification system exists in Australia so that seeds with higher oil content receive a price premium, while those with lower oil content are given a deduction. Current Australian standards indicate that the base oil content is 42%, with a 1.5% price premium (or deduction) for each 1% above (or below) the 42% threshold (AOF, 2012).

Figure 3. Average oil content of Australian commercial canola 2002–2011 (adapted from Seberry et al., 2012).



3.5 Canola oil

Edible oils and fats are composed primarily of triacylglycerols (TAGs), which are comprised of three fatty acid molecules attached to a glycerol molecule. TAGs typically constitute between 94.5% and 99 % of canola oil (Przybylski et al., 2005). The non-triacylglycerol component of canola oil contains many different minor compounds such as tocopherols, phytosterols, phenolics and pigments. Each of these components are affected by the canola variety, the method of processing, and the method used in refining the oil.

Canola oil is used in a variety of retail, food service and manufacturing industries. Spreads and bottled oil make up the bulk of the usage in the retail sector. In the food service industry, spreads, salad dressings, cakes, pastry and frying are the main uses. The uses in food manufacturing are varied and include many products including biscuit, cereal, pet food and other processes. A great advantage of canola oil in these industries is the neutral colour and bland taste, which manufacturers require for many products.

3.6 Canola oil composition

3.6.1 Fatty acid profile

Since the mid-1980s, there has been a movement away from the use of oils with high saturated fatty acid contents, such as tallow and palm oil, in the food service and manufacturing sectors. The food industry turned to partially hydrogenated fats in which linoleic and linolenic acids were chemically modified to trans fatty acids to improve oil stability. This also had the benefit of increasing the viscosity of vegetable oils so that they can impart structure to baked goods similar to the animal fat and palm oil they displaced (DeBonte et al., 2012). However, trans fatty acids have since been shown to increase cholesterol in humans to a far greater degree than saturated fats (Mensink and Katan, 1990).

Traditional canola oils usually contain, on average: 7% saturated fats (palmitic acid (C16:0) and stearic acid (C18:0)), 60% oleic acid (C18:1), 20% linoleic acid (C18:2), 10% linolenic acid (C18:3) and <2% erucic acid (C22:1) (Bocianowski et al., 2012). This oil has many positive nutritional aspects such as low levels of saturated fatty acids, however the relatively high levels of polyunsaturated fatty acids make the oil somewhat unstable in comparison to other oils such as sunflower and olive oil.

Fatty acids are known to be affected by growing conditions, especially temperature, with cooler finishes to the season decreasing the amount of oleic acid (Pritchard et al., 2000), while warmer conditions increase the oleic acid content and decrease the level of unsaturation (Werteker et al., 2010).

As discussed in section 1, by definition the erucic acid content of canola cannot exceed 2% of the total fatty acids. Canola was developed to take advantage of the nutritional aspects of rapeseed oil (such as low saturated fatty acids) without the detrimental effects of erucic acid, which was higher than 40% in some varieties of rapeseed (Scarth and Tang, 2006). High levels of erucic acid were found to be responsible for producing fatty deposits in the heart (Christophersen and Bremer, 1972; Clandinin and Yamashiro, 1982), skeletal muscles and adrenal glands of rodents, as well as impeding growth (Sauer and Kramer, 1983), hence the need to reduce the levels of these fatty acids considerably.

3.6.2 Iodine value

Iodine value is a measure of the degree of unsaturation of an oil, which has a strong effect on the physical characteristics of the oil such as the solid fat index. The iodine value is defined as the number of grams of iodine absorbed by 100 g of fat. It gives an indication of the degree of unsaturation of a fat or oil. It is calculated from fatty acid composition using specific factors for each fatty acid (Kyriakidis and Katsiloulis, 2000). Canola oil usually has an iodine value of between 110 and 126. The more unsaturated the oil is, the higher the iodine value will be.

Manufacturers and food services providers use the iodine value as a quick indication of the suitability of an oil for their needs, therefore this is a very useful tool.

3.6.3 Tocopherols

Tocopherols, otherwise known as vitamin E, are comprised of the isomers alpha(α), beta(β), gamma(γ) and delta(δ)-tocopherol. Tocopherols are efficient natural antioxidants that act as singlet oxygen quenchers, with a single molecule of tocopherol able to react with up to 120 molecules of singlet oxygen (Bowry and Stocker, 1993). Therefore, tocopherols are a very important antioxidant in canola oil as they contribute to oil stability and hence the shelf life of the product. Thus, tocopherol content in seed oil is considered as a valuable compound (Zhang et al., 2006).

The variation in total tocopherol content in canola oil has been shown to range from 80 to 1000 mg/kg oil (Abidi et al., 1999; Dolde et al., 1999; Marwede et al., 2004) however the average total concentration is generally 400 to 700 mg/kg oil (Richards et al., 2008). Gamma(γ)-tocopherol is the predominant isomer, followed by alpha(α)-tocopherol. Beta(β)-tocopherol is present in trace amounts and delta(δ)-tocopherol is absent. The tocopherol content of canola oil has been shown to vary with variety (Abidi et al., 1999). In canola, the ratio of gamma-tocopherol to alpha-tocopherol is usually about 2:1.

3.7 Canola oil utilisation

3.7.1 Fatty acid profile

Each food industry sector (manufacturing, food service and retail) requires different fatty acid compositions depending on the requirements of their products. These include:

Oleic acid (C18:1) - some manufacturers require oils that contain high levels (>70%) of oleic acid. These oils can be used in applications where the oil is exposed to high temperatures for extended periods of time, while maintaining its resistance to oxidation (Aukema and Campbell, 2011). These oils generally have low levels of linolenic acid, which improves the frying properties of the oil. Canola oils with high levels of oleic acid and low levels of linolenic acid (<3%) have been shown to have superior frying qualities such as characteristic fried food flavour, texture and stability (Matthäus, 2006). High oleic oils used in manufactured food products have also been shown to significantly increase the shelf life of the products during storage (DeBonte et al., 2012).

Linoleic acid (C18:2) - researchers have shown that oils with linoleic acid ranging between 23% and 37% produced better flavour stability when used in manufacturing or frying than oils with higher or lower values for linoleic acid (Warner et al., 1997). However, high levels of linoleic acid also lead to lower storage stability and increased rancidity.

Although the exact compositions of retail spreads are difficult to find as they usually contain proprietary information, they generally require oils with relatively high linoleic and linolenic acid levels in order to meet standard requirements for these types of products. Industry experts have indicated that oils with >20% of linoleic acid and >20% linolenic acid would be ideal for the production of retail spreads (pers.comm).

Linolenic acid (C18:3) - lower levels of linolenic acid in canola oil are desirable for the food industry, for both frying and as an ingredient in manufactured foods. The storage stability of this type of oil shows improvement when compared to regular canola oil. Frying performance of the oil is also improved, as well as better storage stability of food cooked in it (Warner and Mounts, 1993).

Erucic acid (C22:1) - High erucic acid canola oil is a valuable and renewable raw material used in the manufacture of many industrial products. Erucamide, a derivative of erucic acid oils can be used as an anti-block and slip promoting agent in the production of plastic film, so high erucic acid oils are useful for this purpose (Przybylski et al., 2005). This oil can also be used in the manufacture of paints and coatings, inks, nylon and high pressure grease (Aukema and Campbell, 2011).

Biodiesel - Biodiesel production from vegetable oils is increasing in many countries, mainly due to government mandates aimed at reducing greenhouse gas emissions and reduced dependence on imported fossil fuels. Biodiesel is produced from oils and fats using a process called transesterification. Transesterification involves a reaction between an alcohol (usually methanol) and the oil in the presence of a catalyst. The fatty acids are transformed into fatty acid esters and glycerol (Walker, 2004). In the USA, the most common source of biodiesel is soybean oil, however in the EU, it is canola oil. Canola's high oil content means it is highly suited to biodiesel production as it has more oil per tonne of seed and produces less by-product. The low levels of saturated fatty acids found in canola oil also lead to better cold weather engine performance.

3.7.2 Iodine value

As detailed in section 3.6.2, iodine value is a useful tool for manufacturers and food services providers.

3.7.3 Tocopherols

It has been shown that tocopherols are especially important antioxidants in frying because of their low rate of evaporation and resistance to breakdown at usual frying temperatures (Matthäus, 2006; Przybylski et al., 2005).

As discussed in section 2.2, most canola oil is physically refined after extraction. The most widely used form of refining consists of vacuum steam distillation, also known as deodorisation,

after the oil has already been degummed and bleached. Deodorisation is used to remove free fatty acids and objectionable volatile compounds from the oil, and is therefore an important and necessary step. Unfortunately, some valuable components are also removed from the oil during this process, including tocopherols and sterols. Total losses are dependent on the processing temperature and pressure, as well as the deodorisor design (Cmolik et al., 2008). As such, the reported total losses of tocopherols in this processing step vary considerably (Table 2).

Table 2. Reported losses of tocopherols in canola oil during refining and deodorisation.

Losses (% of total tocopherols)	Source
15	(De Greyt, 2012)
25	(Kanematsu et al., 1983)
30	(Gogolewski et al., 2000)
40	(Prior et al., 1991)

The tocopherols stripped from the oil during the deodorisation process are concentrated in deodoriser distillate. The distillate is refined to remove other compounds such as free fatty acids and sterols. Yields of tocopherol depend on the type of refining used; however, tocopherol rich distillates (up to 20% tocopherol) have a commercial value of up to US$8000/MT (De Greyt, 2012).

Production of synthetic tocopherols is estimated to be 70 000 to 75 000 MT per year worldwide, while only a minor amount of natural origin is produced (<5000 MT). Synthetic tocopherol is used as an additive in animal feeds, while semi-synthetic and natural tocopherols are preferred for higher value added applications such as human food supplements and cosmetics (De Greyt, 2012).

4 Canola Meal

Canola meal, the solid component left after oil extraction, is the second most commonly used protein source for animal feed in the world after soybean meal. The high protein content (35%–45%) oil-free meal with a good balance of amino acids makes canola meal an attractive ingredient for feed formulations (Newkirk, 2009). Although canola meal contains about 70% to 80% of the protein content of soybean meal, it regularly sells at about 60% to 75% of its price. Factors that affect the value of canola meal include lower digestibility due to higher fibre content than soybean meal, amino acid degradation during processing and consistency of meal (Newkirk, 2002; Slee, 2012).

The increase in the Australian canola crush capacity in the last two decades has seen the amount of canola meal produced increase from 100 000 tonnes in 1995 to about 400 000 tonnes in 2012 (Figure 4). This will increase further with the new crushing plant in Wagga Wagga, New South Wales, beginning production in 2013 and plans for further processing plants in the near future. The annual canola meal production could reach 1 million tonnes by 2020 (Slee, 2012).

At the same time that the canola meal production has been increasing, the importation of soybean meal and other meals into Australia has also increased (Table 3). With improved canola meal, these imports could decrease and be replaced by the canola meal produced domestically.

Figure 4. Australian canola meal production 1995–2012 (data sourced from www.indexmundi.com.au).

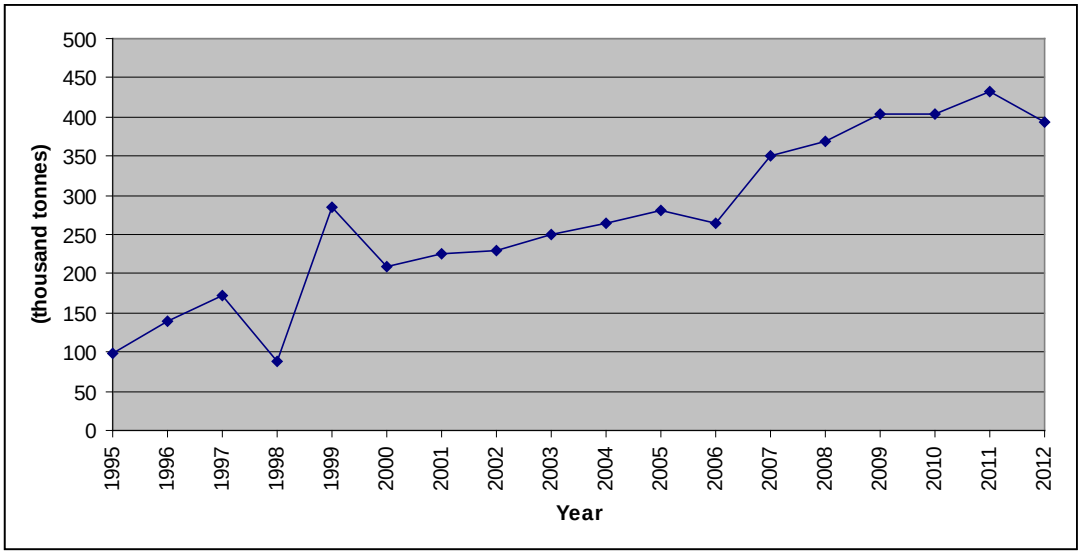


Table 3. Annual imports of vegetable protein meal into Australia (kilotonnes) (ABARES, 2013).

	2007/8	2008/09	2009/10	2010/11	2011/12
Soybean meal	528	482	513	521	607
Other*	230	129	98	32	22

***includes palm kernel meal, peanut meal.**

4.1Types of canola meal

As discussed in section 2, there are different methods used to extract oil from canola: cold press, expeller press and solvent extraction. Extraction of oil using solvents result in a meal with less than 5% residual oil, while expeller meals can contain between 8% and 15 % oil due to less efficient extraction (Seneviratne et al., 2010; Spragg and Mailer, 2007). Solvent processing removes more than 96% of the oil from the seed, however, most processors add gums back into the meal at a rate of up to 2%. This results in a slightly higher finished meal fat content and energy value. The addition also reduces the level of dust within dry meals (Spragg and Mailer, 2007). The residual oil can also affect the fatty acid content of the meal, which needs to be monitored because if the residual oil is high in unsaturated fatty acids, there may be an undesirable softening of animal carcass fat in meat destined for human consumption (Rowghani et al., 2007). Solvent-extracted canola meal is subjected to more moisture during the extraction process due to steam sparging and lower temperatures (115°C), whereas expeller extracted canola is exposed to less moisture but greater temperatures (up to 135°C). Greater extraction temperatures are known to affect the nutritive value of the meal especially the availability of protein (Woyengo et al., 2010).

4.2 Canola meal composition

4.2.1 Protein

Crude protein content in whole canola seed is variable, and is dependent on variety and growing conditions (Table 4). There is an inverse relationship between the oil content and protein content of canola, with breeding for higher oil content tending to lower protein content.

Crushers can have an influence on the amount of protein in canola meal depending on the amount of gums added back to the meal. Excessive heat applied during processing can also lead to denaturing of proteins and possibly reduces the availability of amino acids, particularly lysine (Bell, 1993).

Table 4 Typical protein content of canola meal (at 10% moisture in oil free meal). Adapted from (Spragg and Mailer, 2007) and (Bell and Keith, 1991).

	Solvent extracted meal		Expeller meal	
	Mean	**Range**	**Mean**	**Range**
Australia	39.1	34.9-44.5	39.9	34.8-45.9
Canada	39.2	35.6-40.5	-	-

In general, canola meal has a good amino acid profile for animal feed. Like many vegetable based protein sources, canola meal is limiting in lysine, however it is a good source of other amino acids such as methionine and cystine (Newkirk, 2009). The digestibility of amino acids varies between animals with digestibility of amino acids in canola meal generally about 10% lower in poultry and pigs than soybean meal (Newkirk, 2011). The digestibility of amino acids in ruminant diets is complex, however studies show that canola meal amino acids are readily digested in the rumen (Harris and Staples, 2003). Increased protein degradation post-rumen improves the performance of dairy cows and beef cattle, therefore, when using canola meal in ruminant diets it is important to formulate a diet that contains acceptable levels of rumen undegradable protein (RUP) (Newkirk, 2011).

4.2.2 Glucosinolates

Prior to the development of canola from rapeseed, the presence of glucosinolates was the major limiting factor in the use of rapeseed meal for livestock feed (Bell, 1984b). Canola glucosinolates are composed of two main types: aliphatic, which comprise about 85% of the glucosinolates in canola meal; and indolyl, which account for the remaining 15% (Newkirk et al., 2003). During commercial canola processing, heat applied during the cooking stage as well as the amount of thermal decomposition in the desolventising stage have an effect on the amounts of glucosinolates remaining in the meal (Bell, 1984a).

Glucosinolates as such are not toxic; however myrosinase (an endogenous enzyme that breaks down glucosinolates) present in the seed or in the microflora of an animals gut may hydrolyse them to yield toxic breakdown products. There are many different breakdown products from glucosinolates including thiocyanate, isothiocyanate, oxazolidinethione and nitriles, which can impair feed intake and growth performance (due to a bitter taste), and interfere with thyroid and liver function (Mullan et al., 2000). High glucosinolate levels have been shown to increase mortality in poultry, as well as lower egg production and egg weight, and are fatal to pigs, while ruminants are comparatively more tolerant (Tripathi and Mishra, 2007).

The mean glucosinolate content of whole canola seed grown in Australia ranged from 4 to 10 µmoles/gram whole seed (at 6% moisture) between 2002–2012, however some individual samples had much higher glucosinolate content (Seberry et al., 2012). During the same period, the average glucosinolate content in canola seed grown in Canada was shown to range between 8 and 12 µmoles/gram whole seed (Barthet, 2012). Interestingly, the current industry convention is to report glucosinolate levels in µmoles/gram whole seed, while both the Canadian and Australian standard set the limit for glucosinolates at 30 µmoles/gram oil-free meal. Hence, the reported values discussed above are actually increased by up to 60% once the results are recalculated as in oil-free meal.

Glucosinolate levels in seed can be affected by variety, agronomy and climate, with moisture availability during the growing season especially important. The processing method, as mentioned, also has an influence on the levels in meal. These influences are obvious in the reported values of glucosinolates in canola meals from different countries (Table 5). The maximum level of glucosinolates shown in Australian canola meal (Table 5) is important as it

shows the upper level is close to the maximum allowable level for canola (30 µmoles/gram in oil free meal). Some breeding efforts should be focussed on ensuring these levels remain as low as possible.

Table 5. Glucosinolate content of canola meal of different origin.

Country of Origin	Glucosinolate range	Reference
Australia	7.4–25.3	(Mullan et al., 2000)
Canada	11.4–21.7	(Slominski et al., 1999)
Belgium	13.8–33.0	(Derycke et al., 1999)
Denmark	10.7–18.3	(Jensen et al., 1995)

Note: Glucosinolates reported as µmoles/gram in oil free meal.

4.2.3 Sinapine

The main phenolic compounds found in canola are sinapate esters with sinapolycholine (sinapine) being the most prominent. They generally make up 1%–2% of the oil free meal and contribute to the bitter taste, astringency and the dark colour of canola products (Zum Felde et al., 2007). Also important is the effect sinapine has on production of 'off flavours' or 'fishy' eggs laid by susceptible hens that lack the liver enzyme to effectively handle the high yield of choline after hydrolysis of sinapine in the gut. This results in a build up of trimethylamine, which is transferred to the developing egg. Reduction in the sinapine content of canola meal through plant breeding can increase palatability and intake and help to avoid the problems with off flavours in the eggs (Bell, 1993). A genotype of B.napus with zero sinapine content has been produced using biotechnology (Wolfram et al., 2010). The fishy egg syndrome appears to be a mutation in Rhode Island Red laying hens that is not present in White Leghorns, hence, poultry breeders can correct this problem (Khajali and Slominski, 2012).

Phenolic levels in soybean meal are about one tenth of those found in canola seed. Sinapine levels have been shown to vary between 5 and 18 g/kg seed in European canola/rapeseed varieties (Velasco and Mollers, 1998), 10–25 g/kg in Canadian canola (McCurdy, 1990) and 7–16 g/kg in Australian varieties (Mailer et al., 2008).

4.2.4 Water soluble carbohydrates

Water soluble carbohydrates are the total soluble sugars present in a feed, including glucose, fructose, sucrose and fructans. Soluble carbohydrates are formed in the latter stages of seed development and climatic conditions may contribute to final amounts found in canola seed. The cotyledons appear to contain about one third of the water soluble carbohydrates, while the remainder is contained in the seed coat (Barthet and Daun, 2011)

Water soluble carbohydrates are usually readily digestible in the animal's gut, however they are sometimes protected in the stomach by cell's walls, therefore becoming less digestible. These compounds can make a significant difference to the metabolisable energy of meal due to their influence on the microflora in the gut of animals (Bell, 1993).

Water soluble carbohydrate contents of canola meals vary considerably, for example, 3% to 15% DM (dry matter) in Canadian cultivars (Bell, 1993) while others have reported levels between 7% and 12 % for expeller and solvent extracted meals (Feedipedia, 2012). Variability may be caused by several factors, including variety, environmental conditions during harvest and oil extraction method.

4.2.5 Starch

Starch is the most important storage carbohydrate in plants. Two types of polymers occur in starch: linear amylose and branched amylopectin. The two enzymes that are able to hydrolyse

starch are α- and β-amylase, which are usually found in the stomachs of animals. Alpha-amylase cleaves starch chains randomly and will degrade amylose and amylopectin, while β-amylase is able to degrade amylose only (Van Soest, 1992).

The starch content of canola seeds during early development approaches 50% of the total carbohydrates. However, the starch disappears as these 'energy stores' are converted into oil as the seed matures. As such, the level of starches is about 2.5% in oil-free meal and therefore contributes little to energy availability when fed in animal diets (Bell, 1993).

4.2.6 Neutral detergent fibre and acid detergent fibre

Dietary inclusion rates of canola meal are sometimes limited due to relatively high levels of fibre when compared to soybean meal, which lowers the available energy content of the meal (Jia et al., 2012). Unlike soybeans, canola seed is not dehulled prior to oil extraction. As a high proportion of fibre is contained in the seed coat, the fibre content of canola meal is usually significantly higher (Matthäus, 1998) (Table 6).

Neutral Detergent Fibre (NDF) is the amount of fibre in a sample that is not soluble in a neutral detergent solution. The major cell wall components constitute most of the NDF, including cellulose, hemicellulose, lignin, insoluble ash (silica) and cutin (Van Soest, 1992).

Acid Detergent Fibre (ADF) is defined as the amount of fibre in a sample that is insoluble in a weak acid. It consists mainly of cellulose, lignin, insoluble ash and cutin, which are the relatively undigestible components of the meal.

Efforts to lower the level of seed hull, and therefore the fibre content of canola meal, may help improve the adoption of canola meal in animal diets.

Table 6. Comparison of ADF and NDF values in solvent extracted canola meal, expeller extracted canola meal and soybean meal.

	NDF	ADF	Source
Canola meal – solvent extracted	26.2–37.9	15.9–25.6	(Feedipedia, 2012)
	23.7–25.7	18.8–22.2	(Bell and Keith, 1991)
	25.2–31.7	17.0–20.0	(Spragg and Mailer, 2007)
Canola meal – expeller extracted	24.5	19.9	(Bell, 1993)
	30.7–45.7	22.1–32.0	(Feedipedia, 2012)
	25.6–34.3	19.3–23.6	(Spragg and Mailer, 2007)
Soybean meal (dehulled)	7.9	5.6	(Bell, 1993)

Note: all results calculated as % of dry matter in oil free meal.

4.2.7 Ash

Ash content is determined by burning the sample at very high temperatures and measuring the remaining residue. The ash content of a feed is the inorganic portion, which consists of endogenous minerals normally contained in plants (calcium, potassium, magnesium etc.) as well as exogenous minerals due to soil contamination, such as silica. It is important to limit the amount of ash in feeds as excessive ash content leads to lower performance in animals (Hoffman, 2005).

Ash contents range from 7.8% to 10.1% (oil free dry matter) in solvent extracted canola meals, and 6.7 to 10.7% (oil-free dry matter) in expeller meals (Feedipedia, 2012; Getachew et al., 2004; Spragg and Mailer, 2007). Ash levels can be affected by agronomic conditions, harvest conditions and seed handling and storage.

4.2.8 Digestibility

The digestibility of an animal feed is expressed as the digestibility of dry matter (DMD) and digestibility of organic dry matter (DOMD). DMD is the percentage of the dry feed matter actually digested by ruminant livestock. It is calculated using a laboratory method standardised against DMD values from feed trials. High quality feeds have DMD over 65%, while feeds with DMD below 55% are of poor quality and will not maintain live weight even if stock have free access to it (Agrifood, 2012).

DOMD is calculated to represent the amount of organic matter that is digested by the animal. This value takes into account the inorganic matter (ash) and contaminants such as sand, dirt and clay present in the sample. DOMD is usually calculated from the regression equation relating DMD to DOMD. This is reported as a percentage (Agrifood, 2012).

DOMD is an important measure as it is a major component in the estimation of metabolisable energy in feeds for ruminants. The DOMD of canola meal is usually around 70% to 76% (Feedipedia, 2012).

4.2.9 Available energy

Canola meal is used as a protein supplement in animal feeds; however, its available energy content is an important factor in feed formulation. A single energy value cannot be applied because it is affected by species and the age of the animal being fed the meal and the techniques used in processing of the seed.

4.2.9.1 Metabolisable energy (Ruminants)

Metabolisable energy (ME) is the fraction of total energy that can be used by the animal for maintenance and production, expressed as megajoules per kilogram of dry matter (MJ/kg DM). It is the difference between the gross energy supplied by the feed and the sum of energy excreted in the faeces (undigested feed), in the urine and from the methane produced during digestion (AFIA, 2011).

Processing can have a significant effect on the ME of canola meal. Residual oil in the meal increases the available energy to the animal, with expeller meals generally 1.5 to 2.0 MJ/kg DM higher than solvent meals (Feedipedia, 2012; Spragg, 2007) (Table 7). The ME of soybean meal is generally higher (14.0–18.0 MJ/kg DM) than canola meal, due to the higher digestibility of the soybean meal (Feedipedia, 2012).

Table 7. Range of reported typical metabolisable energy values in canola meal.

	ME (MJ/kg, dry matter)	Source
Solvent meal	11.7–13.4[(a)]	(Bell, 1993)
	11.2–12.4[(b)]	(Spragg and Mailer, 2007)
Expeller meal	12.4–14.0[(c)]	(Spragg and Mailer, 2007)

(a) oil content: n/a (b) oil content:1.8-4.8%; (c) oil content 8.5-17.0%.

4.2.9.2 Apparent metabolisable energy (Poultry)

For poultry, apparent metabolisable energy, AME (defined as gross energy minus losses of energy in faeces, urine and gaseous products) is typically used to express the available-energy content of feed ingredients and complete diets (Sauvant et al., 2004). The energy requirements of the bird are determined by type (broiler or layer) and the age of the animal. Residual oil in the meal increases the available energy, as does starch and sugar content.

Typical AME content in canola meal ranges from 7.4 to 14 MJ/kg DM depending on the type of meal and the stage of growth of the bird (Table 8). This compares well with the AME of soybean meal, which is generally around 10 to 12 MJ/kg DM (Feedipedia, 2012).

Table 8. Range of reported apparent metabolisable energy (poultry) values in canola meal.

	AME (MJ/kg, dry matter)	Source
Solvent meal	7.4–10.9[(a)]	(Bell, 1993)
	9.2–9.6[(b)]	(Feedipedia, 2012)
	11.2–12.4[(c)]	(Spragg and Mailer, 2007)
Expeller meal	12.4–14.0[(d)]	(Spragg and Mailer, 2007)
	8.5–10.4[(e)]	(Feedipedia, 2012)

(a) oil content: n/a (b) oil content: 2.7–5.3%; (c) oil content: 1.8–4.8%; (d) oil content: 8.5–17.0%; (e) oil content: 7.4–24.0%.

4.2.9.3 Digestible energy (Pigs)

Digestible energy (DE) for pigs is the energy in feed after subtracting the energy lost in faeces. It is calculated using laboratory measurements including protein, starch, oil residue and fibre content of the meal. DE accounts for losses in digestion and is relatively unaffected by the pig's breed, age, weight or sex; the diet's amino acid balance; or the level of feeding. Therefore, DE values are generally characteristic of the ingredient and the value most used in diet formulation (Sauvant et al., 2004).

The digestible energy of canola meal for pigs ranges between 11.3 and 19 MJ/kg dry matter, depending on the type of meal (solvent or expeller) (Table 9). The digestible energy of soybean meal ranges between 16 and 21 MJ/kg dry matter.

Table 9. Range of reported digestible energy (pigs) values in canola meal.

	DE (MJ/kg, dry matter)	Source
Solvent meal	11.3–14.8[(a)]	(Bell, 1993)
	13.7[(b)]	(Feedipedia, 2012)
	12.1–12.7[(c)]	(Spragg, 2007)
Expeller meal	14.6–19.0[(d)]	(Feedipedia, 2012)
	13.4–15.1[(e)]	(Spragg, 2007)

(a) oil content: n/a; (b) oil content: 4.0% (c) oil content: 1.8–4.8%;(d) oil content: 7.4–24.0%; (e) oil content 8.5–17.0%.

4.2.9.4 Digestible energy (Fish)

Digestible energy (DE) in fish feed is an estimate of the energy supplied to the fish by the protein, carbohydrate and oil residue components of the feed, minus the estimated loss in faeces. Some energy is lost in urine and gill excretions, however these are difficult to estimate in aquatic systems (Sales, 2009).

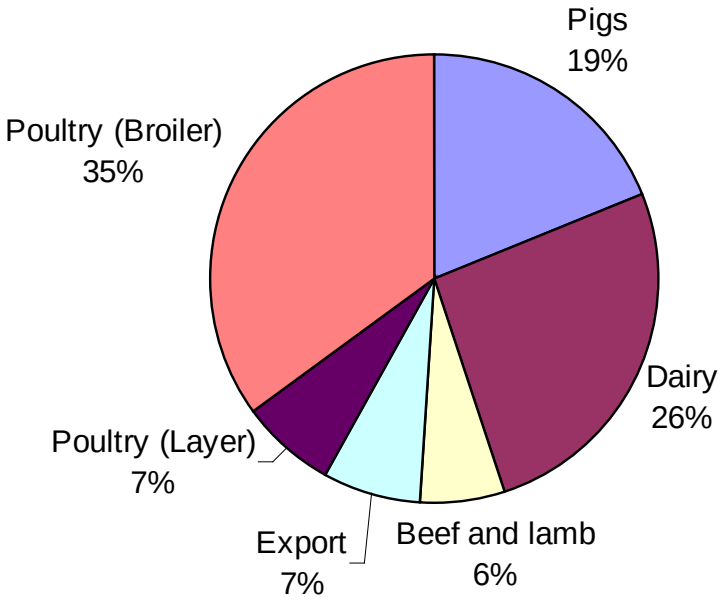
Reported digestible energy values for canola meal as fish feed range from 10.9 to 15.4 MJ/kg dry matter, while the DE for soybean meal is about 12 to 15 MJ/Kg dry matter (Feedipedia, 2012; Hajen et al., 1993).

4.3 Canola meal utilisation

The livestock industry in Australia requires approximately 11.5 million tonnes of feed annually. Of this, approximately one million tonnes is vegetable meal protein (Spragg, 2012).

In the livestock sector, canola meal is predominantly used in monogastric animals such as poultry and pigs; however the dairy sector is also gaining in importance as more intensive operations move to vegetable protein to supplement pasture feeding. About 370 000 tonnes of canola meal was used by the various livestock sectors in 2012, with about 30 000 tonnes exported (Figure 5) (Slee, 2012).

Figure 5. Australian canola meal usage in 2012. The total market was about 400 000 tonnes (Spragg, 2012).



4.3.1 Poultry

Canola meal is used in all types of poultry feeds, including broilers and layers, with inclusion rates depending on the growth stage—starter, grower, finisher or withdrawal rations. There has been some bias against canola meals within the poultry producing sector. In the past, producers have reported increased mortality, reduced growth rates, and high rates of leg problems with increasing levels of canola meal included in the diet. Researchers have shown that these problems have been caused to some degree by the levels of glucosinolates in the meal, with liver haemorrhage mortality and tibial dyschondroplasia the main effects (Campbell and Slominski, 1991; Summers et al., 1992). These effects are generally seen when the level of glucosinolates in the diet increase above 10 µmoles/gram of diet. While some of these problems have been alleviated due to low glucosinolate levels in canola varieties, lowering the glucosinolate level even further in canola should remain an industry priority to ensure that the incidence of these problems does not increase.

Feeding canola meal has no negative effects on the number of eggs produced, feed intake or egg size in laying hens (Perez-Maldonado and Barram, 2004). Some brown-shelled egg layers are unable to properly metabolize some compounds found in canola meal, namely sinapine and choline, therefore limiting inclusion rates in layer diets (Arntfield and Hickling, 2011).

Recent studies have shown that canola meal can be used in broiler diets up to 30% without any negative performance issues, as long as the diets are formulated on a digestible amino acid basis (Newkirk and Classen, 2002; Ramesh et al., 2006). Due to the high energy requirement of broiler meals, the inclusion rate of canola meal has its limitations as other protein sources such as soybean meal have higher energy content. Canola breeding efforts that increase the energy content of the meal would increase the potential of canola meal use in this sector.

The recommended maximum inclusion rates for poultry, based on appropriate feed formulation techniques, are shown in Table 10. These are cautious recommendations and higher inclusion levels may be warranted if economically attractive (Newkirk, 2009).

Table 10. Recommended maximum inclusion rates of canola meal in poultry diets (Newkirk, 2009).

Animal diet type	Maximum inclusion level
Chick starter	10
Broiler grower	20
Layer	10
Breeder	5

Due to the elevated oil content of expeller meal, it is seen as an excellent protein source for poultry diets and can be used as a sole source of protein in the diet without the need for additional fat. Expeller meal also contains essential fatty acids, which means supplemental fat containing these compounds does not need to be added to the diet (Newkirk, 2009).

4.3.2 Pigs

Canola meal is a commonly used protein source in pig diets worldwide. There are some constraints on the use of canola meal in pig diets, especially because of its relatively low energy value; therefore, it is currently included mainly to provide amino acids. Diets in feeding trials with varying levels of canola meal have found lower pig growth rate when compared to soybean meal fed pigs (Baidoo et al., 1987; Bell and Keith, 1991). This was because levels of digestible lysine decreased as canola meal inclusion rates increased. Since then, feeding trials with canola meal in pig diets where the diets were balanced to the same digestible lysine level resulted in a growth similar to soybean meal (King et al., 2001; Mullan et al., 2000).

Glucosinolates are the main anti-nutritional compounds for pigs in canola meal. Studies have shown that a maximum glucosinolate level of 2 µmoles/g of diet is recommended. Higher levels than this lead to reduced feed intake, growth rate and thyroid function (Schone et al., 1997). Australian expeller meal was found to have an average of 5 µmoles/g meal, while solvent meal was found to have about 2 µmoles/g meal (Spragg and Mailer, 2007), therefore relatively high inclusion rates in pig diets can be used before any detrimental effects are observed. The maximum level of glucosinolates in pig diets remain of interest and breeding efforts should remain focussed on further reduction to ensure that glucosinolates are not a limiting factor on the inclusion rates of canola meal in pig diets.

Sinapine has also been shown to have a negative effect on feed uptake by pigs, probably due to the bitter taste it imparts (Bourdon and Aumaitre, 1990). Efforts to lower the levels of sinapine in canola could lead to greater inclusion rates of canola meal in the future.

Canola expeller meal is an excellent source of protein and energy in pig diets. Feeding trials have shown that inclusion rates of up to 29% expeller meal can be added to the diet with no effects on feed intake, feed conversion or live weight gain (Brand et al., 2001).

4.3.3 Dairy

Canola meal is used in feeds for dairy cattle due to its high palatability and increased milk production. Mean milk production has been shown to increase by up to one kg/day when compared to diets containing cottonseed meal or soybean meal. The percentage of by-pass protein and digestible protein is important in ruminants. A good ruminant meal requires a balance of by-pass protein and digestible protein to support the rumen microflora. Canola meal has relatively high levels of rumen-degradable protein (RDP) that stimulates microbial protein production in the rumen. This can increase the amount of absorbable amino acids for the lactating cow (Newkirk, 2009).

Usually the limiting factor on the use of canola meal in dairy cattle diets is price. The dairy industry has very slight profit margins; therefore cheaper feed sources with similar nutritional

value are usually included. Inclusion rates also depend on the other components of the animals' diet. Pastures, corn and grains have varying levels of important components such as amino acids, so the inclusion rate of canola meal is dependent on the level of these found in the diet.

Canola meal has been shown to be highly palatable to ruminants. In cattle fed a mash diet, heifers have been shown to consume more than twice as much canola meal than soybean meal. This is probably due to relatively high sugar content in the canola meal (Sporndly and Asberg, 2006).

4.3.4 Beef and lambs

Canola meal is commonly used as a protein supplement in beef cattle and sheep. Glucosinolates can cause a problem with palatability and toxicity; therefore levels need to be monitored. Research has shown that calves (Claypool et al., 1985), growers and finishers (Petit and Veira, 1994) perform well on rations including canola meal. Expeller meal can cause problems with ruminants as the fat remaining in the meal can cause issues with rumen degradability. Other low cost, alternative protein sources are available to these industries, therefore canola meal is sometimes not an economically viable feed source (Newkirk, 2009).

4.3.5 Aquaculture

Canola meal is increasingly being used in aquaculture diets for species such as catfish, carp, tilapia, bass, perch, bream and shrimp. Inclusion rates in diets vary with species, from 10% in juvenile tilapia diets to 20% in salmon and trout feed (Newkirk, 2009).

High quality fish meal is recognized as the best source of protein for aquaculture, however it is also the most expensive as well as being non-sustainable due to the practice of using wild fish to produce the fish meal. Partial replacement of fish meal protein sources with cheaper alternatives is a considerable economic advantage to the industry (Hajen et al., 1993).

The amino acid profile of canola meal is limiting in lysine, however methionine and cystine are available in high levels. The relatively high levels of fibre in canola meal tend to lower the digestible energy of canola meal in most fish species. The presence of glucosinolates can also have an effect of the uptake of canola meal in some fish species (Enami, 2011).

Canola meal can be converted into canola protein concentrate (CPC) by aqueous extraction of the protein (Mwachireya et al., 1999). CPC contains approximately the same crude protein levels as fish meal and high levels of some amino acids (lysine and methionine) compared to soybean meal. The process used to concentrate the protein removes most of the glucosinolates. This technology allows a higher level of fish meal replacement in aquafeeds without affecting fish growth performance (Enami, 2011).

4.3.6 Human consumption

There is increasing interest in the use of canola meal as an alternative source of protein for human consumption due to its high protein efficiency ratio and well balanced amino acid profile. The incorporation of canola meal into human food is restricted by anti-nutritional factors such as glucosinolates, sinapine and tannins (Yoshie-Stark et al., 2008). The alternative to this is the production of canola protein isolates. Research currently underway is aimed at producing stable protein isolates for inclusion into food products, with huge value placed on the proprietary information surrounding these processes (Tan et al., 2011).

5 Conclusion

Opportunities exist to increase the value of canola seed and meal, and improve returns to growers. Current breeding programs are aimed at improving oil content, yield, and disease resistance. However, if some effort was aimed at reducing anti-nutritional components and increasing nutritive components, the quality of Australian canola has the potential to improve.

Segregation of seed, oil and meal is an important consideration in the value adding chain. Usually seed is handled in bulk through the harvest, transport and processing stages. Some consideration needs to be given to the segregation of specialised oil and meal types in order to market specific types of product to individual industries, in a similar way to the high-oleic acid canola oils currently being utilised by some of the fast food chains.

Opportunities exist to develop oil types for specific applications. High oleic acid oils with very low levels of linolenic acid are useful for frying; however totally different fatty acid profiles are useful for baking. Increasing the tocopherol content in canola oil would increase the stability of the oil. During processing, the tocopherols stripped during steam distillation can be collected and sold to the cosmetic, animal feed and human supplement industries, increasing the value of the product.

The amount of canola meal produced in Australia will increase in the future, with new processing plants currently starting production and others well into the planning stages. This will result in an increasing amount of canola meal available for the feed industry in Australia. Each type of animal has different feed requirements, but there are some common anti-nutritional factors in canola meal that need to be decreased through breeding, such as glucosinolates and fibre. Other nutritive components such as digestibility and protein could be targeted for increase. The monetary value of canola meal will increase as the quality of meal increases. As the quality of meal improves, demand will increase and the animal feed sector will be less reliant on soy meal imports. The extraction of protein isolates from canola meal for use in animal and human nutrition is an important development and should also lead to an increase in the value of canola meal.

5.1 Opportunities and recommendations

The quality of Australian canola can be improved, thereby increasing its market value. To achieve this, further research is required to identify cultivars that show traits that will improve the quality of Australian canola oil and meal, and the G x E interaction on these cultivars. Some areas of focus should include:

Glucosinolates - levels in Australian canola are reaching relatively high levels in some cultivars. Some effort should be focussed on reducing and maintaining low glucosinolate levels.

Tocopherols - these are important compounds in edible oils and contribute to the oxidative stability of oil. Increasing tocopherol levels in canola will increase the shelf life of the oil.

Fibre - lowering the level of seed hull and therefore the fibre content of canola meal will increase the use of canola meal into animal diets.

Energy - the animal feed sector, especially the poultry industry, is interested in increased energy content in canola meal. Increasing the energy content of the meal will increase the potential of canola meal use in these sectors.

Sinapine - efforts to reduce sinapine levels in canola meal may lead to greater inclusion rates in animal feeds.

Education - programs targeted at end-users would increase the awareness of canola products and potentially increase canola oil and meal usage.

Bonification - some consideration should be given to bonification systems for components other than oil content. High protein, low fibre, low glucosinolate and high energy in meal are all important components for the feed industry, and may attract a price premium.

6 Acknowledgements

This work was funded by the Grains Research and Development Corporation (GRDC) and NSW Department of Primary Industries. The author would like to thank Kerrie Graham, Rod Mailer, David Luckett, Trent Potter and Phil Salisbury for their contributions.

7 References

ABARES (2013). Australian Commodity Report. www.DAFF.gov.au/ABARES.

Abidi, S., List, G., and Rennick, K. (1999). Effect of genetic modification on the distribution of minor constituents in canola oil. *Journal of the American Oil Chemists' Society* **76**, 463-467.

AFIA (2011). "AFIA Laboratory methods manual," 7th/Ed. Australian Fodder Industry Association, Melbourne, Australia.

Agrifood (2012). Understanding your feed test report. Vol. 2013, www.feedtest.com.au/feedtest_report_explanation.htm.

AOF (2012). Quality standards, technical information and typical analysis. *In* "AOF 1-1 Grain Quality Standards". Australian Oilseeds Federation, Sydney.

Arntfield, S. D., and Hickling, D. (2011). Meal nutrition and utilization. *In* "Canola: Chemistry, production, processing and utilization" (J. Daun, N. Eskin and D. Hickling, eds.). AOCS Press, Urbana, Illinois.

Aukema, H., and Campbell, L., eds. (2011). "Oil nutrition and utilization." AOCS Press, Urbana, Illinois.

Baidoo, S. K., Mitaru, B. N., Aherne, F. X., and Blair, R. (1987). The nutritive value of canola meal for early-weaned pigs. *Animal Feed Science and Technology* **18**, 45-53.

Barthet, V. (2012). "Quality of Western Canadian canola." Canadian Grains Commission, Winnipeg, Manitoba.

Barthet, V., and Daun, J. (2011). Seed Morphology, composition and quality. *In* "Canola: Chemistry, production, processing and utilization." (J. Daun, N. Eskin and D. Hickling, eds.). AOCS Press, Urbana, Illinois.

Bell, J. M. (1984a). Nutrients and toxicants in rapeseed meal. *Journal of Animal Science* **73**, 679-697.

Bell, J. M. (1984b). Toxic factors in rapeseed meal and progress toward overcoming their effects. *Journal of Animal Science* **58**, 996-1010.

Bell, J. M. (1993). Factors affecting the nutritional value of canola meal: A review. *Canadian Journal of Animal Science* **73**, 689-697.

Bell, J. M., and Keith, M. O. (1991). A survey of variation in the chemical composition of commercial canola meal produced in Western Canadian crushing plants. *Canadian Journal of Animal Science* **71**, 469-480.

Bocianowski, J., Mikołajczyk, K., and Bartkowiak-Broda, I. (2012). Determination of fatty acid composition in seed oil of rapeseed (*Brassica napus L.*) by mutated alleles of the FAD3 desaturase genes. *Journal of Applied Genetics* **53**, 27-30.

Bourdon, D., and Aumaitre, A. (1990). Low glucosinolate rapeseed and rapeseed meals - effect of technological treatments on chemical composition, digestible energy content and feeding value for growing pigs. *Animal Feed Science and Technology* **30**, 175-191.

Bowry, V., and Stocker, R. (1993). Tocopherol mediated peroxidation: The prooxidant effect of vitamin E on the radical initiated oxidation of human low density lipoprotein. Journal *of the American Oil Chemists' Society* **115**, 6029-6044.

Brand, T. S., Brandt, D. A., and Cruywagen, C. W. (2001). Utilisation of growing-finishing pig diets containing high levels of solvent or expeller oil extracted canola meal. *New Zealand Journal of Agricultural Research* **44**, 31-35.

Calisir, S., Marakoglu, T., Ogut, H., and Ozturk, O. (2005). Physical properties of rapeseed (*Brassica napus oleifera* L.). *Journal of Food Engineering* **69**, 61-66.

Campbell, L., and Slominski, B. A. (1991). Feeding quality of very low glucosinolate canola. *In* "Twelfth Western Nutrition Conference", Winnipeg, Manitoba.

CCC (2009). Canola Standards and regulations. Vol. 2013. Canola Council of Canada, http://www.canola-council.org/ind_definition.aspx.

Christophersen, B. O., and Bremer, J. (1972). Erucic acid—an inhibitor of fatty acid oxidation in the heart. *Biochimica et Biophysica Acta (BBA) - Lipids and Lipid Metabolism* **280**, 506-514.

Clandinin, M. T., and Yamashiro, S. (1982). Dietary Factors Affecting the Incidence of Dietary Fat-Induced Myocardial Lesions. *The Journal of Nutrition* **112**, 825-828.

Clarke, J. M., and Simpson, G. M. (1978). Influence of irrigation and seeding rates on yield and yield components of *Brassica napus* cv. Tower. *Canadian Journal of Plant Science* **58**, 731-737.

Claypool, D. W., Hoffman, L. C., Oldfield, J. E., and Adams, H. P. (1985). Canola meal, cottonseed and soybean meals as protein supplements for calves. *Journal of Dairy Science* **68**, 67-70.

Cmolik, J., Pokorny, J., Reblova, Z., and Svoboda, Z. (2008). Tocopherol retention in physically refined rapeseed oil as a function of deodorization temperature. *European Jounal of Lipid Science and Technology* **110**, 754-759.

Daun, J. (2011). Origin, distribution and production. *In* "Canola: Chemistry, production, processing and utilization" (J. Daun, N. Eskin and D. Hickling, eds.), pp. 1-27. AOCS Press, Urbana, Illinois.

Daun, J., Symons, S., and Misener, B. (1990). Relationships between seed size and quality parameters in canola and rapeseed varieties. *In* "80th American Oil Chemists Society Annual Meeting", Baltimore, U.S.A.

De Greyt, W. (2012). Efficient recovery of tocopherols from vegetable oils. *Inform* **23**, 557-561.

DeBonte, L., Iassonova, D., Liu, L., and Loh, W. (2012). Commercialization of high oleic canola oils. *Lipid Technology* **24**, 175-177.

Derycke, G., Mabon, N., Mandiki, S. N., Bister, J. L., Wathelet, J. P., Marlier, M., and Paquay, R. (1999). Chemical changes and influence of rapeseed antinutrtional factors on lamb physiology and performance. Part 1 Animal performance and thyroid physiology. *Animal Feed Science and Technology* **81**, 81-91.

Dolde, D., Vlahakis, C., and Hazebroek, J. (1999). Tocopherols in breeding lines and effects of planting location, fatty acid composition and temperature during development. *Journal of the American Oil Chemists' Society* **76**, 349-355.

EBB (2010). European Biodiesel Board. Vol. 2013, http://www.ebb-eu.org/stats.php.

Edwards, J., and Hertel, K. (2011). Canola: Growth and Development. (J. Edwards, ed.). NSW Department of Primary Industries.

Enami, H. R. (2011). A review of using canola/rapeseed meal in aquaculture feeding. *Journal of Fisheries and Aquatic Science* **6**, 22-36.

Feedipedia (2012). Animal feed resources information system. Vol. 2013.

Getachew, G., Robinson, P. H., DePeters, E. J., and Taylor, S. J. (2004). Relationships between chemical composition, dry matter degradation and in vitro gas production of several ruminant feeds. *Animal Feed Science and Technology* **111**, 57-71.

Gogolewski, M., Nogala-Kalucka, M., and Szaliga, M. (2000). Changes of the tocopherol snd fatty acid contents in rapeseed oil during refining. *European Jounal of Lipid Science and Technology* **102**, 618-623.

Gowen, R. (2012). "Canola Voluntary Report December 2012." USDA Foreign Agricultural Service, Canberra.

Gulden, R. H., Thomas, A. G., and Shirtliffe, S. J. (2004). Relative contribution of genotype, seed size and environment to secondary seed dormancy potential in Canadian spring oilseed rape (Brassica napus). *Weed Research* **44**, 97-106.

Hajen, W. E., Higgs, D. A., Beames, R. M., and Dosanjh, B. S. (1993). Digestibility of various feedstuffs by post-juvenile chinook salmon (*Oncorhynchus-tshawytscha*) in sea water. 2. Measurement of digestibility. *Aquaculture* **112**, 333-348.

Harris, B., and Staples, C. R. (2003). Vegetable protein meal by-product feedstuffs for dairy catle. (U. o. Florida, ed.). IFAS Extension.

Hoffman, P. (2005). "Ash content of forages." Umiversity of Wisconsin, U.S.A.

Jensen, S. K., Liu, Y. G., and Eggum, B. O. (1995). The effect of heat treatment on glucosinolates a nutritive value of rapseed meal in rat. *Animal Feed Science and Technology* **53**, 17-28.

Jia, W., Mikulski, D., Rogiewicz, A., Zdunczyk, Z., Jankowski, J., and Slominski, B. A. (2012). Low-Fiber Canola. Part 2. Nutritive Value of the Meal. *Journal of Agricultural and Food Chemistry* **60**, 12231-12237.

Kanematsu, H., Ushigusa, T., Maruyama, T., Niiya, I., Fumoto, D., Toyoda, T., Kawaguchi, Y., and Matsumoto, T. (1983). Comparison of Tocopherol Contents in Crude and Refined Edible Vegetable Oils and Fats by High Performance Liquid Chromatography. *Journal of Japan Oil Chemists' Society* **32**, 122-126.

Khajali, F., and Slominski, B. A. (2012). Factors that affect the nutritive value of canola meal for poultry. *Poultry Science* **91**, 2564-2575.

King, R. H., Eason, P. E., Kerton, D. K., and Dinshea, F. R. (2001). Evaluation of solvent extracted canola meal for growing pigs and lactating sows. *Australian Journal of Agricultural Research* **52**, 1033-1041.

Kyriakidis, N., and Katsiloulis, T. (2000). Calculation of the iodine value from measurements of fatty acid methyl esters of some oils: Comparison with the relevant American Oil Chemists Society method. *Journal of the American Oil Chemists' Society* **77**, 1235-1238.

Mailer, R., McFadden, A., Ayton, J., and Redden, B. (2008). Anti-nutritional components, fibre, sinapine and glucosinolate content, in Australian canola (*Brassica napus* L.) meal. *Journal of the American Oil Chemists' Society* **85**, 937-944.

Mailer, R. J. (2004). "Canola Meal: Limitiations and opportunities." Australian Oilseeds Federation, NSW Department of Primary Industries, Wagga Wagga.

Marwede, V., Schierholt, A., Möllers, C., and Becker, H. C. (2004). Genotype × environment interactions and heritability of tocopherol contents in canola. *Crop Science* **44**, 728-731.

Matthäus, B. (1998). Effect of dehulling on the composition of antinutritive compounds in various cultivars of rapeseed. *Lipid / Fett* **100**, 295-301.

Matthäus, B. (2006). Utilization of high oleic rapeseed oil for deep fat frying of french fries compared to other commonly used edible oils. *European Jounal of Lipid Science and Technology* **108**, 200-211.

McCurdy, S. (1990). Effects of processing on the functional properties of canola/rapeseed protein. *Journal of the American Oil Chemists' Society* **67**, 281-284.

Mensink, R. P., and Katan, M. B. (1990). Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. *New England Journal of Medicine* **323**, 439-445.

Mullan, B. P., Pluske, J. R., Allen, J., and Harris, D. J. (2000). Evaluation of Western Australian canola meal for growing pigs. *Australian Journal of Agricultural Research* **51**, 547-553.

Mwachireya, S. A., Beames, R. M., Higgs, D. A., and Dosanjh, B. S. (1999). Digestibility of canola protein products derived from physical, enzymatic, and chemical processing of commercial canola meal in rainbow trout *Oncorhynchus mykiss* (Walbaum) held in fresh water. *Aquatic Nutrition* **5**, 73-82.

Newkirk, R. W. (2002). The effects of processing on the nutritional value of canola meal for broiler chickens, University of Saskatchewan, Saskatoon.

Newkirk, R. W., ed. (2009). "Canola Meal: Feed Industry Guide." Canadian Canola Council, Canada.

Newkirk, R. W. (2011). Meal nutrient compostion *In* "Canola: Chemistry, production, processing and utilization" (J. Daun, N. Eskin and D. Hickling, eds.). AOCS Press, Urbana, Illinois.

Newkirk, R. W., and Classen, H. L. (2002). The effects of toasting canola meal on body weight, feed conversion efficiency, and mortality in broiler chickens. *Poultry Science* **81**, 815-825.

Newkirk, R. W., Classen, H. L., Scott, T. A., and Edney, M. J. (2003). The digestibility and content of amino acids in toasted and non-toasted canola meals. *Canadian Journal of Animal Science* **83**, 131-139.

Perez-Maldonado, R. A., and Barram, K. M. (2004). Evaluation of Australian canola meal for production and egg quality in two layer strains. *In* "16th Australian Poultry Science Symposium, February 9-11", pp. 171-174, Sydney, Australia.

Petit, H. V., and Veira, D. M. (1994). Effect of post weaning protein supplementation of beef steers fed grass silage on performance during the finishing phase, and carcass quality. *Canadian Journal of Animal Science* **74**, 699-701.

Prior , E., Vadke, V., and Sosulski, F. (1991). Effect of heat treatments on canola press oils. I. Non- triglyceride components. *Journal of the American Oil Chemists' Society* **68**, 61-68.

Pritchard, F. M., Eagles, H. A., Norton, R. M., Salisbury, P. A., and Nicolas, M. (2000). Environmental effects on seed composition of Victorian canola. *Australian Journal of Experimental Agriculture* **40**, 679-685.

Przybylski, R., Mag, T., Eskin, N., and McDonald, B., eds. (2005). "Canola Oil." John Wiley and Sons, Winnipeg, Canada.

Ramesh, K. R., Devegowda, G., and Khosravinia, H. (2006). Effects of enzyme addition to broiler diets containing varying levels of double zero rapseed meal. *Asian-Australian Journal of Animal Science* **19**, 1354-1360.

Razavi, S., Yeghanehzad, S., Sadeghi, A., Ebrahimzadeh, S., and Niazmand, E. (2006). Some physical properties of Iranian varieties of canola seeds*. Iranian Journal of Food Science and Technological Research* **2**, 53-61.

Richards, A., Wijesundera, C., and Salisbury, P. (2008). Genotype and growing environment effects on the tocopherols and fatty acids of *Brassica napus* and *Brassica juncea*. *Journal of the American Oil Chemists' Society* **85**, 159-168.

Riethmuller, G., Carmody, P., and Walton, G. (2003). Improved canola establishment, yield and oil with large seed on sandplain soil in Western Australia. *In* "13th Biennial Australian Research Assembly on Brassicas", pp. 55-59, Tamworth, NSW.

Rowghani, E., Arab, M., Nazifi, S., and Bakhtiari, Z. (2007). Effect of canola oil on cholesterol and fatty acid composition of egg-yolk of laying hens. *International Journal of Poultry Science* **6**, 111-114.

Sales, J. (2009). Prediction of digestible energy content across feed ingredients and fish species by linear regression. *Fish Physiology and Biochemistry* **35**, 551-565.

Salisbury, P. A., and Barbetti, M. J. (2011). Breeding Oilseed Brassica for Climate Change. *In* "Crop Adaptation to Climate Change", pp. 448-463. Wiley-Blackwell.

Sauer, F., and Kramer, J. (1983). The problems associated with high erucic acid rapeseed oils and some fish oils on experimental animals. *In* "High and low erucic acid rapeseed oils: Production, usage, chemistry and toxilogical evaluation." (J. Kramer, F. Sauer and W. Pigden, eds.). Academic Press, Canada.

Sauvant, D., Perez, J. M., and Tran, G. (2004). "Tables of composition and nutritional value of feed materials," Second/Ed. Wageningen Academic Publishers, Netherlands.

Scarth, R., and Tang, J. (2006). Modification of brassica oil using conventional and transgenic approaches. *Crop Science* **46**, 1225-1236.

Schone, F., Rudolph, B., Kirchheim, U., and Knapp, G. (1997). Counteracting the negative effects of rapeseed and rapseed press cakes in pig diets. *British Journal of Nutrition* **78**, 947-962.

Scott, R. K., Stokes, D. T., McWilliam, S. C., Spink, J. H., and Clarke, R. W. (1999). Yield improvement through canopy management. *In* "International Rapeseed Conference", Canberra, Australia.

Seberry, D., Parker, P., and Ayton , J. (2012). Quality of Australian canola 2011. Australian Oilseeds Federation.

Seneviratne, R. W., Young, M. G., Beltranena, E., Goonewardene, L. A., Newkirk, R. W., and Zijlstra, R. T. (2010). The nutritional value of expeller-pressed canola meal for grower-finisher pigs. *Journal of Animal Science* **88**, 2073-2083.

Shahraki, M., Rasolov, S., Mohammad, G., and Fanae, H. (2012). Investigation of the correlation yield and yield components of 12 spring canola hybrids in Iranshahr climatic region*. African Journal of Agricultural Research* **7**, 3134-3138.

Slee, J. (2012). Australian canola meal outlook. Vol. 2013, http://www.ausgrainsconf.com/sites/default/files/file/2012/Presentations/Slee.pdf.

Slominski, B. A., Simbaya, J., Campbell, L., Rakow, G., and Guenter, W. (1999). Nutritive value for broilers of meals derived from newly developed varieties of yelow-seeded canola*. Animal Feed Science and Technology* **78**, 249-262.

Sporndly, E., and Asberg, T. (2006). Eating rate and preference of different concentrate components for cattle. *Journal of Dairy Science* **89**, 2188-2199.

Spragg, J. (2007). "Australian canola meal guide for the feed industry." Australian Oilseeds Federation, Sydney, New South Wales.

Spragg, J. (2012). "Feed grain 2011-2012 update report." JCS Solutions.

Spragg, J., and Mailer, R. (2007). "Canola meal value chain quality improvement: A final report prepared for AOF and Pork CRC. Project code :1B-103-0506."

Stepniewski, A. (1999). Formation of rapeseed postharvest quality and its resistance to external loads. *In* "10th International Rapeseed Conference", pp. http://www.regional.org.au/au/gcirc/1/503.htm. GCIRC, Canberra, Australia.

Summers, J. D., Spratt, D., and Bedford, M. (1992). Sulfur and calcium supplementation of soybean and canola meal diets. *Canadian Journal of Animal Science* **72**, 127-133.

Tan, S. H., Mailer, R. J., Blanchard, C. L., and Agboola, S. O. (2011). Extraction and characterization of protein fractions from Australian canola meals. *Food Research International* **44**, 1075-1082.

Tanska, M., Konopka, M., and Rotkiewicz, D. (2008). Relationships of rapeseed strength properties to seed size, colour and coat fibre composition. *Journal of the Science of Food and Agriculture* **88**, 2186-2193.

Tkachuk, R., and Kuzina, F. D. (1975). Rapeseed: Relations between some physical and chemical properties. *Canadian Journal of Plant Science* **56**, 169-174.

Tripathi, M. K., and Mishra, A. S. (2007). Glucosinolates in animal nutrition: A review. *Animal Feed Science and Technology* **132**, 1-27.

Unger, E. (2011). Processing. *In* "Canola: Chemistry, production, processing and utilization." (J. Daun, N. Eskin and D. Hickling, eds.). AOCS Press, Urbana, Illinois.

USDA (2012). Oilseeds: World markets and trades. Vol. 2013, http://usda01.library.cornell.edu/usda/fas/oilseed-trade//2010s/2012/oilseed-trade-12-11-2012.pdf.

Van Soest, P. J. (1992). "Nutritional ecology of the ruminant," Second/Ed. Cornell University Press, United States of America.

Velasco, L., and Mollers, C. (1998). Non-destructive assessment of sinapic acid esters in Brassica species:II. Evaluation of germplasm and identification of genotypes with reduced levels. *Crop Science* **38**, 1650-1654.

Walker, K. (2004). Non food uses. *In* "Rapeseed and canola oil: production, processing, properties and uses" (F. Gunstone, ed.). CRC Press, Boca Raton, U.S.A.

Warner, K., and Mounts, T. L. (1993). Frying stability of soybean and canola oils with modified fatty acid compositions. *Journal of the American Oil Chemists' Society* **70**, 983-988.

Warner, K., Orr, P., and Glynn, M. (1997). Effects of fatty acid composition of oils on flavour and stability of fried foods. *Journal of the American Oil Chemists' Society* **74**, 347-356.

Werteker, M., Lorenz, A., Johannes, H., Berghofer, E., and Findlay, C. S. (2010). Environmental and varietal influences on the fatty acid composition of rapeseed, soybeans and sunflowers. *Journal of Agronomy and Crop Science* **196**, 20-27.

Wolfram, K., Schmidt, J., Wray, V., Milkowski, C., Schliemann, W., and Strack, D. (2010). Profiling of phenylpropanoids in transgenic low-sinapine oilseed rape (*Brassica napus*). *Phytochemistry* **71**, 1076-1084.

Woyengo, T. A., Kiarie, E., and Nyachoti, C. M. (2010). Energy and amino acid utilization in expeller-extracted canola meal fed to growing pigs. *Journal of Animal Science* **88**, 1433-1441.

Yoshie-Stark, Y., Wada, Y., and Wäsche, A. (2008). Chemical composition, functional properties, and bioactivities of rapeseed protein isolates. *Food Chemistry* **107**, 32-39.

Zhang, H., Flottman, S., and Milroy, S. (2011). Yield formation of canola (*Brasssica napus* L) and associated traits in the high rainfall zone. *In* "17th Australian Research Assembly on Brassicas (ARAB)", pp. 93-98, Wagga Wagga, NSW.

Zhang, H., Vasanthan, T., and Wettasinghe, M. (2006). Enrichment of tocopherols and phytosterols in canola oil during seed germination. *Journal of Agricultural and Food Chemistry* **55**, 355-359.

Zum Felde, T., Baumert, A., Strack, D., Becker, H. C., and Möllers, C. (2007). Genetic variation for sinapate ester content in winter rapeseed (*Brassica napus* L.) and development of NIRS calibration equations. *Plant Breeding* **126**, 291-296.