# The Influence of Processing of Soyabeans and Sunflower Seed on their Energy and Amino Acid Availability for Poultry

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*Declaration*

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

# Abstract


## 1. The effect of heat-treatment and dehulling of full-fat soya (*Glycine max)* on $AME_n$, amino acid availability and broiler performance.

Heat treatment and dehulling of full-fat soya were evaluated in terms of their effect on $AME_n$, apparent amino acid availability and broiler performance. Four products were tested: raw whole soya (RWS), raw dehulled soya (RDS), extruded whole soya (EWS) and extruded dehulled soya (EDS). Trials were conducted to determine $AME_n$ values and apparent amino acid availability of the products. A 42-day broiler trial was conducted to measure the effect of extrusion and dehulling on broiler performance. Test products were added to the diets at levels up to 263.2 g/kg in the starter diet and 260.0 g/kg in the finisher diet. Results indicated that extrusion cooking improved $AME_n$ and apparent amino acid availability. This was reflected in the improved performance of broilers fed extruded soya as compared to raw soya. Increasing amounts of RWS and RDS led to decreases in mass and intake and poor feed conversion ratio (FCR) due to the presence of anti-nutritional factors. Broilers fed EWS were heavier, consumed more feed and had better FCR than those fed RWS or RDS. Dehulling improved $AME_n$ (EWS: 13.75 MJ/kg vs EDS: 15.09 MJ/kg) and rendered a product with slightly higher levels of total amino acids. Broiler performance did not reflect this as there was no difference in mass, intake or FCR between broilers fed increasing levels of EWS or EDS. Lysine and arginine were less available in EDS than EWS indicating the possible over-cooking of EDS. Levels of EWS and EDS of 263.2 g/kg in the starter and 260.0 g/kg in the finisher supported maximum broiler performance.

## 2. The effect of heat-treatment and dehulling of full-fat sunflower (*Helianthus annuus)* on $AME_n$, amino acid availability and broiler performance.

Heat treatment and dehulling of full-fat sunflower were evaluated in terms of their effect on $AME_n$, apparent amino acid availability and broiler performance. Four products were tested: raw whole sunflower (RWSF), raw dehulled sunflower (RDSF), extruded whole sunflower (EWSF) and extruded dehulled sunflower (EDSF). Trials were conducted to determine $AME_n$ values and apparent amino acid availability of the products. A 42-day broiler trial was conducted to measure the effect of expansion and dehulling on broiler performance. Test products were added to the diets at levels up to 115.0 g/kg in the starter diet and 181.5 g/kg in the finisher diet. Dehulling rendered a product with higher crude protein, ether extract, amino acid and $AME_n$ values. $AME_n$ was only slightly improved by expansion. The $AME_n$ values obtained were: RWSF: 16.03 MJ/kg, RDSF: 18.87 MJ/kg, EWSF: 16.22 MJ/kg, EDSF: 19.49 MJ/kg. Dehulling had no effect on apparent amino acid availability. Expansion did not affect apparent amino acid availability of dehulled full-fat sunflower but had a negative influence on apparent amino acid availability of whole sunflower seeds. This highlights the possible dangers of reduced protein quality as a result of over-processing. No differences were observed in terms of mass, intake and feed conversion ratio of broilers fed any of the products during the 42-day broiler growth trial. All products supported optimum broiler performance at levels up to 115.0 g/kg in the starter diet. For the finisher diets, optimum performance was maintained at levels of 181.5 g/kg, for RDSF and EDSF, while performance of broilers fed RWSF and EWSF was optimal up to 145.2 g/kg.

# Uittreksel

## 1. Die invloed van hitte-behandeling en ontdopping van volvetsojabone *(Glycine max)* op $SME_n$, skynbare aminosuur beskikbaarheid en braaikuikenprestasie.

Hitte-behandeling en ontdopping van volvetsojabone is ge-evalueer in terme van hul invloed op stikstof gekorrekteerde skynbare metaboliseerbare energie ($SME_n$) waardes, skynbare aminosuur beskikbaarheid en braaikuikenprestasie. Vier produkte is getoets: rou heel sojabone (RWS), rou ontdopte sojabone (RDS), geekstrueerde heel sojabone (EWS) en geekstrueerde ontdopte sojabone (EDS). Proewe is uitgevoer om die $SME_n$ waardes en skynbare aminosuur beskikbaarheid van die vier produkte te bepaal. Gedurende 'n braaikuikengroeitoets van 42 dae is die invloed van hitte-behandeling (ekstrusie) en ontdopping op braaikuikenprestasie gemeet. Die vier toetsprodukte is ingesluit in die aanvangsdieet teen peile van tot 263.2 g/kg en teen peile van tot 260.0 g/kg in die afrondingsdieet. Resultate het getoon dat ekstrusie die $SME_n$ waardes en skynbare aminosuur beskikbaarheid verbeter het. Braaikuikens wat geekstrueerde soja ontvang het, het beter gepresteer as braaikuikens wat rou soja ontvang het. Verhoogte insluitings van RWS en RDS het gelei tot verlagings in massa toename en voerinname en swak voeromsetverhoudings (VOV), as gevolg van die teenwoordigheid van anti-voedings faktore. Braaikuikens wat EWS ontvang het, was swaarder, het meer ingeneem en het beter VOV gehad as die wat RWS of RDS ontvang het. Ontdopping het $SME_n$ verhoog (EWS: 13.75 MJ/kg vs EDS: 15.09 MJ/kg) en ontdopte produkte het klein hoeveelhede meer aminosure bevat. Dit het egter nie in braaikuikenprestasie gewys nie. Daar was geen verskille in massa, voerinname en VOV tussen braaikuikens wat EWS of EDS ontvang het. Lisien en arginien was minder beskikbaar in EDS as EWS wat op die moontlike oor-prosessering van EDS dui. Vlakke van EWS en EDS van 263.2 g/kg in die aanvangsdieet en 260.0 g/kg in die afrondingsdieet het maksimale braaikuikenprestasie ondersteun.

## 2. Die invloed van hitte-behandeling en ontdopping van volvetsonneblosaad *(Helianthus annuus)* op $SME_n$, skynbare aminosuur beskikbaarheid en braaikuikenprestasie.

Hitte-behandeling en ontdopping van volvetsonneblomsaad is geevalueer in terme van hul invloed op stikstof gekorrekteerde skynbare metaboliseerbare energie ($SME_n$) waardes, skynbare aminosuur beskikbaarheid en braaikuikenprestasie. Vier produkte is getoets: rou heel sonneblomsaad (RWS), rou ontdopte sonneblomsaad (RDS), geekspandeerde heel sonneblomsaad (EWS) en geekspandeerde ontdopte sonneblomsaad (EDS). Proewe is uitgevoer om die $SME_n$ waardes en skynbare aminosuur beskikbaarheid van die vier produkte te bepaal. Gedurende 'n braaikuikengroeitoets van 42 dae is die invloed van hitte-behandeling (ekspansie) en ontdopping op braaikuikenprestasie gemeet. Die vier toetsprodukte is ingesluit in die aanvangsdieet teen peile van tot 115.0 g/kg en teen peile van tot 181.5 g/kg in die afrondingsdieet. Ontdopte sonneblomsaad het hoer peile van ruproteien, eter-ekstrak en aminosure as heel sonneblomsaad. $SME_n$ waardes is ook hoer vir ontdopte sonneblomsaad. Hitte-behandeling het $SME_n$ waardes effens verhoog. Die bepaalde $SME_n$ waardes is as volg: RWSF: 16.03 MJ/kg, RDSF: 18.87 MJ/kg, EWSF: 16.22 MJ/kg, EDSF: 19.49 MJ/kg. Ontdopping het geen invloed op skynbare aminosuur bekikbaarheid gehad nie. Skynbare aminosuur beskikbaarheid van ontdopte sonneblomsaad is nie deur hitte-behandeling beinvloed nie, terwyl die van heel sonneblomsaad negatief beinvloed is. Dit beklemtoon die gevare van verswakte proteien kwaliteit as gevolg van oor-prosessering. Geen verskille is opgemerk in terme van massa, voerinname en voeromset verhouding (VOV) tussen die vier produkte gedurende die braaikuikengroeitoets van 42 dae. Alle produkte het maksimale braaikuiken prestasie ondersteun in die aanvangsdieet teen vlakke van 115.0 g/kg. In die afrondingsdieet het RDSF en EDSF optimale braaikuikenprestasie onderhou teen vlakke van 181.5 g/kg, terwyl RWSF en EWSF net tot vlakke van 145.2 g/kg ingesluit kon word voor braaikuikenprestasie benadeel is.

This work is dedicated to my mom and dad, my brothers and my grandmother, and of course to the best companion in the world, Diesel.

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# Contents

# 1. Introduction to Oilseeds

The cultivation of oilseeds has been undertaken since ancient times. Oilseeds are those crops in which energy is stored mainly in the form of oil. Oilseeds provide an easily available and highly nutritious source of human and animal food (Weiss, 2000). The importance of oils and fats in both human and animal nutrition is well recognised (Salunkhe *et al.,* 1992). They are a vital component of many cell constituents, an excellent and important source of energy and they also act as a carrier for fat-soluble vitamins.

The oilcakes of soya and sunflower, as well as other high protein seeds have long been the major protein source used in poultry feeds (Kohlmeier, 1997). The extracted oil has been used mainly for human consumption. Increased production, competition and other factors have made the use of full-fat oilseeds within the range of economic possibility (Waldroup and Cotton, 1974). The need for protein for human and animal consumption is steadily growing while conventional protein sources are becoming less available and more expensive (Brand and Brundyn, 2001).

The production of oilseeds has grown substantially in recent times as a response to increasing world population and improved living standards. They are grown all over the world and fall into three major groups:

1. Those that are annual or biennial such as soya, sunflower, groundnut and rapeseed.
2. The perennial crops such as coconut and oil palms.
3. Crops such as cotton and maize germ, where the embryo, a rich source of oil, is a by-product.

Table 1.1 shows a list of the commercially important oil crops of the world. Not all are cultivated on a large scale in South Africa.

**Table 1.1** Commercially important oil crops of the world (Salunkhe *et al.,* 1992)

| **Name** | **Scientific name** |
|---|---|
| Soybean | *Glycine max* L. |
| Sunflower | *Helianthus annuus* L. |
| Peanut | *Arachis hypogaea* L. |
| Rapeseed | *Brassica napus* L. |
| | *Brassica juncea* L. (Zern and Cross) |
| | *Brassica campestris* L. |
| Safflower | *Carthamus tinctorius* L. |
| Sesame | *Sesamum indicum* L. |
| Cotton | *Gossypium hirsutum* L. |
| | *Gossypium barbadense* |
| Oil palm | *Elaeis guinensis* Jacq. |
| Coconut | *Cocos nucifera* L. |
| Maize | *Zea mays* L. |
| Rice | *Oryza sativa* L. |
| Castor | *Ricini communis* L. |
| Linseed or flax | *Linum usitatissimum* L. |
| Niger | *Guizotia abyssinica* Cass. |
| Jojoba | *Simmondsia chinensis* (Link) Schneider |
| Crambe | *Crambe abyssinica* Hochst. Ex. R. E. Fries |
| Olive | *Olea europaea* L. |
| Poppy | *Papaver somniferum* L. |

Among the oilseeds, soya is the greatest contributor to the world's oilseed output (Weiss, 2000). The major oilseed producing areas are in temperate regions of the world. The countries exporting the most oilseeds or oilseed products are U.S.A., Canada, Brazil, Argentina, Malaysia and the Philippines. Soya is the major export product and represents almost 80% of the total export (Salunkhe *et al.,* 1992). Canada is a major exporter of canola oil. Malaysia is the chief exporting country of palm oil. Sunflower exports have also increased as a result of large increases in production in Argentina and the U.S.A.

**Table 1.2** Calculated world production (million tons) of selected oilseeds (Weiss, 2000)

| | **1960** | **1970** | **1980** | **1990** | **2000** |
|---|---|---|---|---|---|
| Soya | 27.0 | 45.0 | 93.0 | 104.0 | 180.0 |
| Sunflower | 7.0 | 10.0 | 15.5 | 23.0 | 28.0 |
| Castor | 0.7 | 0.9 | 1.0 | 1.3 | 1.5 |
| Copra | 4.0 | 4.0 | 5.0 | 5.0 | 5.0 |
| Cottonseed | 20.0 | 21.0 | 24.0 | 34.0 | 35.0 |
| Groundnut | 12.0 | 12.0 | 14.0 | 17.0 | 20.0 |
| Linseed | 4.0 | 4.0 | 3.0 | 2.5 | 2.5 |
| Rape | 4.0 | 7.0 | 12.0 | 25.0 | 40.0 |
| Safflower | 0.5 | 0.6 | 1.0 | 1.0 | 0.5 |
| Sesame | 2.0 | 2.0 | 3.0 | 3.0 | 3.0 |
| **Total** | 81.2 | 106.5 | 171.5 | 215.8 | 315.5 |

From Table 1.2 it is clear that soya is already the oilseed that is produced in the largest quantity. It is also worth noting that both soya and sunflower are being produced on an ever-increasing scale.

The utilisation of oilseeds varies across the world. For example, in the western world groundnuts are used primarily for the preparation of salted nuts and paste (peanut butter), while in many developing countries of Asia a major part of groundnut production is utilised for the extraction of oil. Coconut oil is used for cooking in many parts of Asia while it is used mainly for non-food purposes in the west.

Oilseeds can be used as whole seeds or components can be isolated. The component most commonly isolated for use is oil. Once the oil has been extracted the remaining components are left in a more concentrated form. Perhaps the most important remaining component is protein. Oil can be extracted either by the traditional method (expeller pressing) or by solvent extraction. The processing method generally depends on the level of industrialisation in the country concerned. The cake or meal obtained after the extraction process is a rich source of protein. These high protein oilcakes are generally used in animal feeds. Another by-product obtained during the processing of oilseeds is lecithin. It is an excellent emulsifier and is used in the manufacture of margarine.

Many oils are used for non-food applications. Plant oils are used in the manufacture or preparation of soaps, paints, resins, varnishes, plastics, lubricants, thermoplastics and agro-chemicals. Coconut oil is mostly used in soaps and surfactants. Soya and linseed oils are used as a stabiliser in vinyl plastics. Castor oil based products are used in lubricants and pharmaceuticals, and even in cosmetics and flavourings.

## 1.1. Oilseeds in South Africa

Full-fat sunflower and full-fat soya both have great potential in South Africa. As compared to other oilseeds, production is high and can increase still further (Jurgens, 2001). The most important oilseeds in South African terms are sunflower, soya and canola. On an international scale soya is the oilseed produced in the greatest quantities (Zhang and Parsons, 1994). The situation in South Africa is slightly different where sunflower is the most common oilseed and the second highest production is that of soya. There is also potential for sunflower and soya production in South Africa to increase to a large degree. Canola production in South Africa is still relatively small but it is also something that is growing quite substantially (Ekermans, 2002).

**Table 1.3** Production estimates[1] of summer oilseed crops in South Africa: 2001/2002 season (SAGIS, 2002)

| **Crop** | **Area planted 2001/02 (HA)** | **Final estimate 2001/02 (tons)** |
|---|---|---|
| Sunflower seed | 645 510 | 840 040 |
| Soya beans | 124 150 | 202 398 |
| Groundnuts | 94 160 | 120 185 |

[1] Estimates are based on conditions as at 20 August 2002

Table 1.3 clearly shows that sunflower production is the highest of the summer oilseeds. Soya production is substantially less. The area planted and total yields of these products are growing from year to year.

**Table 1.4.** Production estimates[1] of canola and sweet lupin crops in South Africa: 2002/2003 season (SAGIS, 2002)

| Crop | Area planted 2002/03 (HA) | Second estimate 2002/03 (tons) |
|---|---|---|
| Canola | 32 800 | 42 590 |
| Sweet lupins | 11 000 | 12 000 |

[1] Estimates are based on conditions as at 19 September 2002

Canola and sweet lupines are the most important of the winter oilseeds crops (Table 1.4). Lupins are not produced in great quantities but canola production is growing substantially. On an international scale canola is an extremely important oilseed and in South African terms it is also becoming very important.

**Table 1.5.** Provincial production of oilseed crops in South Africa (SAGIS, 2002)

| Province | Sunflower: Final estimate 2001/02 (tons) | Soya: Final estimate 2001/02 (tons) |
|---|---|---|
| Northern Cape | 500 | - |
| Free State | 398 250 | 20 400 |
| Eastern Cape | 200 | 323 |
| KwaZulu Natal | 90 | 37 800 |
| Mpumalanga | 45 000 | 101 500 |
| Limpopo | 28 000 | 24 300 |
| Gauteng | 18 000 | 9 075 |
| North-West | 350 000 | 9 000 |
| **Total** | 840 040 | 202 398 |

Table 1.5 shows the production of these oilseeds by province in South Africa. Mpumalanga is the province that produces the most soya. The Free State and North-West provinces produce the most sunflower seed.

This study focuses primarily on the use of unextracted or "full-fat" soya and sunflower as part of broiler feeds. These are the two most important oilseeds in South Africa. It is intended to determine the nutritional value of these products for broiler chickens, and to investigate whether any processing of the products is necessary to maximise their value for broiler chickens. Each of these products is relatively high in energy and protein and as such could potentially play an important role in poultry feeding. Due to the scarcity and high cost of conventional protein sources, alternate sources are being sought. These alternate protein sources need to be evaluated carefully in terms of their nutritional value for poultry. While the nutritional value of full-fat soya has been well documented, the same cannot be said of full-fat sunflower seeds (Elzubeir & Ibrahim, 1991; Arija *et al.,* 1998; Ortiz *et al.,* 1998; Villamide & San Juan, 1998). This research aims to provide information regarding the nutritional composition of various full-fat soya and sunflower products.

The following chapters will serve to summarise relevant literature as well as to outline the reasons for conducting the experiments that were undertaken.

## 2. Nutritional Value of Full-fat Soya *(Glycine max)* for Broilers

Since the 1960's and early 1970's research has indicated that full-fat soya can be used efficiently and profitably in animal feeding (Monari, 1996). The full-fat seeds' potential value lies in their high oil and protein contents. Due to recognition of the product's value, the use of full-fat soya has increased dramatically in recent times.

Full-fat soya is recognized as an excellent protein source as well as a source of energy (Perilla *et al.*, 1997). It is well known though that soya contains anti-nutritional factors that need to be destroyed before the product is suitable for poultry rations (Leeson and Atteh, 1996). A number of varieties of soya exist and it is obvious that the precise nutritional value of each one may differ slightly. It is also known that new varieties have been developed to help combat some of the anti-nutritional factors present in soya beans. Lectin-free soyabeans have been developed (Douglas *et al.,* 1999) and Singh *et al.,* (1969) identified soya cultivars that are low in Kunitz trypsin inhibitor.

**Figure 2.1** Average composition of full-fat soya (Monari, 1996)

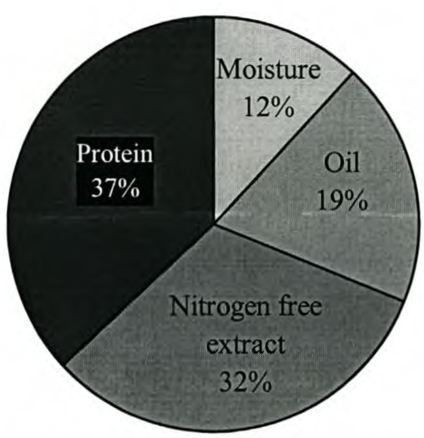


Figure 2.1 gives a basic idea of the nutrient composition of full-fat soya. It is immediately evident that it is high in both protein and oil. Much of its potential benefit for broiler chickens lies in these fractions.

Table 2.1 gives a summary of the nutrient composition of soyabean meals and full-fat soyabean meal. Values may vary somewhat depending on cultivar, area of production and many other factors but for the purpose of illustration these values are considered sufficient.

**Table 2.1** Soybean product composition[1]

| | SBM (44)[3] | SBM (47)[4] | FFSBM[5] |
|---|---|---|---|
| Dry matter, % | 89.0 | 90.0 | 90.0 |
| Protein, % | 44.0 | 48.5 | 37.0 |
| Met. Energy MJ/kg [2] | 9.37 | 10.59 | 14.69 |
| Fat % | 0.8 | 1.00 | 18.0 |
| Fibre, % | 7.0 | 3.9 | 5.5 |
| Calcium, % | 0.29 | 0.27 | 0.25 |
| Phosphorous, % | 0.65 | 0.62 | 0.58 |
| Avail. Phosphorus, % [2] | 0.29 | 0.24 | 0.25 |
| Methionine, % | 0.62 | 0.67 | 0.53 |
| TSAA, % | 1.28 | 1.39 | 1.07 |
| Lysine, % | 2.69 | 2.96 | 2.25 |
| Tryptophan, % | 0.74 | 0.74 | 0.51 |
| Threonine, % | 1.72 | 1.87 | 1.41 |
| Isoleucine, % | 1.92 | 2.12 | 1.56 |

[1] NRC, Poultry (1994), "as fed" basis

[2] Scott *et al.,* (1982), "as fed" basis as quoted by Kohlmeier, (1997)

[3] Soybean meal 44% protein

[4] Soybean meal 47% protein

[5] Full-fat soybean meal

Possibly the most important thing to note from Table 2.1 is the increased energy level of the full-fat soya as compared to the oil extracted meals. This is due to the higher fat levels that occur if the oil is not removed from the beans (Kohlmeier, 1997). In hot climates such as those that prevail over most of South Africa it may be very beneficial to be able to include a protein source that is also high in energy. Feeding raw materials high in energy as well as protein can counteract lower intakes, which are common during hot weather. Full-fat soya is high in both energy and protein. Full-fat soya is also an excellent source of fatty acids (Kohlmeier, 1997).

The main factor determining the metabolisable energy (ME) content of full-fat soya is the digestibility of the fat (Kan *et al.*, 1988). The same authors reported that the digestibility of fat in full-fat soya beans is mush lower than that of a combination of soya bean meal and free soya bean oil. They also showed, however, that pelleting significantly increased the fat digestibility and thus ME of the full-fat soya beans. It seems clear that the disruption of the cell walls is the mechanism responsible for making the fat more available and thus more digestible.

The reported nutritional value of full-fat soya varies from author to author. A summary of the various reported nutritional values is given in Table 2.2.

**Table 2.2** Summary of reported nutritional values of cooked full-fat soya

| *Nutrients* | Highest reported value | Lowest reported value | Average | Authors |
|---|---|---|---|---|
| Dry matter, % | 90.0 | 90.0 | 90.0 | |
| $AME_n$ MJ/kg | 15.5 | 13.6 | 14.3 | Douglas *et al., (*1999); Kan *et al.,* (1988); Waldroup (1982) |
| Crude Protein, % | 40.60 | 34.84 | 37.54 | Chohan *et al.,* (1993); Kan *et al.,* (1988); Zhang & Parsons (1993) |
| Fat, % | 23.81 | 16.20 | 19.89 | Diaa El-Din H. Farag (1998); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Fibre, % | 5.70 | 5.26 | 5.48 | Diaa El-Din H. Farag (1998); Kan *et al.,* (1988) |
| Methionine, % | 0.61 | 0.51 | 0.55 | Douglas *et al., (*1999); Waldroup (1982); Zhang & Parsons (1993) |
| Lysine, % | 2.53 | 2.18 | 2.32 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Cystine, % | 0.63 | 0.53 | 0.58 | Douglas *et al., (*1999); Rios Iriarte & Barnes (1966); Zhang & Parsons (1993) |
| Tryptophan, % | 0.55 | 0.51 | 0.53 | NRC, (1994); Waldroup (1982) |
| Threonine, % | 1.63 | 1.35 | 1.50 | Douglas *et al., (*1999); Rios Iriarte & Barnes (1966); Zhang & Parsons (1993) |
| Isoleucine, % | 1.84 | 1.59 | 1.73 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Leucine, % | 3.08 | 2.66 | 2.88 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |

| | | | | |
|---|---|---|---|---|
| Phenylalanine, % | 2.01 | 1.71 | 1.87 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Arginine, % | 3.18 | 2.37 | 2.77 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Histidine, % | 1.14 | 0.89 | 1.02 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Rios Iriarte & Barnes (1966) |
| Tyrosine, % | 1.52 | 1.07 | 1.35 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Rios Iriarte & Barnes (1966) |
| Valine, % | 1.94 | 1.62 | 1.81 | Douglas *et al., (*1999); Herkelman *et al.,* (1993); Zhang & Parsons (1993) |
| Calcium, % | 0.25 | 0.25 | 0.25 | NRC, (1994); Waldroup (1982) |
| Phosphorous, % | 0.58 | 0.58 | 0.58 | NRC, (1994); Waldroup (1982) |
| Avail. Phosphorus, % | - | - | 0.25 | NRC, (1994) |

Table 2.2 shows that reported $AME_n$ values vary from 13.6 MJ/kg to 15.5 MJ/kg. In fact some reported values are even higher (eg. 16.22 MJ/kg, Chohan et al., (1993)). All values reported in the table are for mash, but once pelleted the $AME_n$ value will be even higher. The pelleting process disrupts the fat containing cells and renders the fat more available. Generally however, the reported values fall between the levels indicated in Table 2.2. Protein and fat values also vary quite substantially. The fat content and the availability of the fat will determine, to a large extent, the energy value.

Table 2.3 shows a summary of reported amino acid availabilities of cooked full-fat soya. Table 2.4 shows a similar summary for raw soya. In comparing the two tables it is clearly evident that the amino acid availabilities of raw soya are substantially lower than those of cooked soya. This is due to the anti-nutritional factors present in raw soya. The most important is trypsin inhibitor. These factors are destroyed during heating and this ensures that the amino acids are more available to the birds. The highly folded structure of the proteins is also denatured to some extent, making the proteins more susceptible to breakdown by enzymes. Generally, it seems that the average amino acid availability is in the region of 80 to 85%. It is interesting to note that reports of tryptophan values in full-fat soya are seldom found. This may be due to practical difficulties during analysis. In the research to be undertaken as part of this study, tryptophan content and availability in full-fat soya will be analysed and reported.

**Table 2.3** Summary of reported amino acid availabilities (%) of cooked full-fat soya

| | Burgos *et al.*, (1973) | Zhang & Parsons (1993) | Anderson-Hafermann *et al.*, (1992) | Average |
|---|---|---|---|---|
| Methionine | 83.17 | 77.90 | 83.00 | 81.36 |
| Lysine | 82.82 | 88.00 | 87.00 | 85.94 |
| Cystine | 77.66 | 77.70 | 83.00 | 79.45 |
| Tryptophan | - | - | - | - |
| Threonine | 82.39 | 75.80 | 82.00 | 80.06 |
| Isoleucine | 82.07 | 85.70 | 85.00 | 84.26 |
| Leucine | 82.24 | 84.60 | 87.00 | 84.61 |
| Phenylalanine | 82.84 | 81.70 | 85.00 | 83.18 |
| Arginine | 86.02 | 89.80 | 91.00 | 88.94 |
| Histidine | 83.75 | 83.50 | 86.00 | 84.42 |
| Tyrosine | 83.06 | 82.70 | - | 82.88 |
| Valine | 81.13 | 83.20 | 83.00 | 82.44 |

In Table 2.4 it is clear that there is considerable variation in the amino acid availabilities of raw soya. This is due to variations in content of anti-nutritional factors as well as variations in amino acid content between cultivars, location etc. The average amino acid availability is lower for raw soya and is generally in the region of about 60 to 70%. Regardless of the total amino acid content, these lower availabilities will ensure that birds do not perform optimally unless anti-nutritional factors are destroyed prior to feeding.

**Table 2.4** Summary of reported amino acid availabilities (%) of raw full-fat soya

| | Douglas *et al.*, (1999) | Anderson-Hafermann *et al.*, (1992) | Average |
|---|---|---|---|
| Methionine | 50.40 | 65.00 | 57.70 |
| Lysine | 68.70 | 73.00 | 70.85 |
| Cystine | 63.00 | 67.00 | 65.00 |
| Tryptophan | - | - | - |
| Threonine | 64.00 | 64.00 | 64.00 |
| Isoleucine | 61.70 | 64.00 | 62.85 |
| Leucine | 66.00 | 68.00 | 67.00 |
| Phenylalanine | 78.20 | 68.00 | 73.10 |
| Arginine | 75.10 | 78.00 | 76.55 |
| Histidine | 68.40 | 72.00 | 70.20 |
| Tyrosine | 65.00 | - | 65.00 |
| Valine | 57.10 | 65.00 | 61.05 |

Although this study focuses on energy values and amino acid availability, there are two other fractions that should briefly be mentioned due to their contribution to the nutritive value of full-fat soya (Monari, 1996). These are:

- Lecithin complex (1.5-2.5%). These are phospholipids and are essential for the normal functioning of the nervous system and the brain. They also function during fat transfer and assimilation, and act as a choline precursor.
- Linoleic acid (C18:2). This is a polyunsaturated fatty acid with a vitamin-like action, essential for all animal species at all ages. Unlike animal fats and other vegetable oils, soybean oil contains high levels of linolenic acid. Enzymes in animal tissues can convert linolenic acid to linolenic acid (C18:3). This and other polyunsaturated fatty acids (omega-3) have received much attention in recent times due to their ability to reduce cholesterol levels and blood pressure in humans.

Waldroup and Cotton (1974) conducted broiler trials in order to determine the maximum inclusion rate of full-fat soya. Their results are shown in Table 2.5.

**Table 2.5** Performance of broilers fed all mash diets containing various quantities of cooked full-fat soya (Waldroup and Cotton, 1974)

| Full-fat soya (% of diet) | Liveweight (g)[1] | Feed Conversion Ratio |
|---|---|---|
| 0 | 569[a] | 1.75[a] |
| 5 | 543[abcd] | 1.63[a] |
| 10 | 559[ab] | 1.58[a] |
| 15 | 553[abc] | 1.66[a] |
| 20 | 541[abcd] | 1.63[a] |
| 25 | 550[abc] | 1.56[a] |
| 30 | 531[bcd] | 1.63[a] |
| 35 | 522[cd] | 1.72[a] |
| 40 | 516[d] | 1.66[a] |

[1] Means in the same column with the same superscript are not different (P>0.05)

Rates of up to 40% were used in their trials. With rates of inclusion of up to 25% they obtained growth rates as high as those of the control diet, which was based on soybean oil meal. They found no statistical difference in feed conversion ratio at any level of inclusion of full-fat soya.

### 2.1. Anti-nutritional Factors in Soya

It has been well documented that soya contains certain biologically active compounds with anti-nutritive action (Han and Parsons, 1991; Herkelman *et al.,* 1993; Leeson and Atteh, 1996). Protease inhibitors are the most important of these. The ability of a soybean extract to inhibit trypsin was first reported by Read and Haas (1938). The protein fractions responsible for this inhibition were subsequently purified by Bowman and Birk and by the crystallization of the so-called Kunitz trypsin inhibitor (Liener, 1994). If full-fat soya is not subjected to some form of heat treatment before feeding, its nutritional value is quite low (Monari, 1996).

Although the protease inhibitors are the most important of the anti-nutritional factors, it should be remembered that trypsin inhibitor is not the only anti-nutritional factor present in soya. A number of other Bowman-Birk type protease inhibitors have been identified by Stahlhut and Hymowitz (1983). Perilla *et al.,* (1997) reported that lectins and saponins are also present in soya beans and that these may reduce feed intake and the rate and efficiency of growth. It is also true that haemagglutinins/lectins and the high bulk density of full-fat cooked soya may cause nutritional problems for the broiler chicken. Table 2.6 shows the anti-nutritional factors present in soya and their resistance to heat-treatment.

**Table 2.6** Anti-nutritional factors in soya and their resistance to heat-treatment (Liener, 1994)

| *Heat stable* | *Heat-labile* |
|---|---|
| Saponins | Protease inhibitors |
| Tannins | Lectins |
| Estrogens | Goitrogens |
| Flatulence factors | Antivitamins |
| Lysinoalanine | |
| Allergens | |
| Phytate | |

Some of the anti-nutritional factors are discussed in more detail below.

- Protease (trypsin and chymotrypsin) inhibitors

It seems that the natural function of these factors is to protect the bean from birds and microbial invasions (Monari, 1996). Trypsin inhibitor may constitute up to 6% of soya bean protein (Herkelman *et al.,* 1993). When raw soya is fed to non-ruminants these factors bind to trypsin and chymotrypsin causing a drop in digestive efficiency. Trypsin and chymotrypsin are proteolytic enzymes secreted by the pancreas of the animal.

The physiological response of the animal to the ingestion of protease inhibitors is the secretion of greater amounts of digestive enzymes. This results in hypertrophy of the pancreas (Herkelman *et al.,* 1993). These enzymes contain a high proportion of sulphur amino acids (methionine and cystine). This added endogenous loss of amino acids exacerbates the relative deficiency of these amino acids in soya protein (Monari, 1996). McDonald *et al.* (1995) agreed that the pancreatic hyperactivity resulted in the increased production of trypsin and chymotrypsin, and the consequent loss of methionine and cystine. The concentrations of these amino acids are already sub-optimal in soya.

At least five trypsin inhibitors have been identified. The main protease inhibitors present in raw soya are the Kunitz factor and the Bowman-Birk factor (Herkelman *et al.,* 1993; Stahlhut and Hymowitz, 1983).

- Haemagglutinins/ lectins

These are proteinaceous compounds present in soya and believed to have an anti-nutritional action (Schulze *et al.,* 1995). Lectins are in fact glycoproteins that have the ability to bind to cellular surfaces. They have a relatively high binding affinity to the epithelium of the small intestine (Douglas *et al.,* 1999). This binding results in a disruption of the brush border and reduced nutrient absorption (McDonald *et al.,* 1995). These lectins can themselves resist the process of proteolysis in the gut (Monari, 1996). They can therefore cause reduced growth rates and appetite depression (Douglas *et al.,* 1999).

It seems that the effect of lectins is less significant than that of the protease inhibitors. The toxicity of lectins varies, but those found in soya are relatively mild (McDonald *et al.,* 1995). Soya varieties have been developed that are free of lectins. Douglas *et al.* (1999) concluded that lectins accounted for approximately 15% of the growth depression from raw soya in chicks. They found that raw lectin-free soya allowed for better chick growth that raw conventional soya. They attributed this to the higher energy levels and better amino acid digestibility of lectin-free soya as compared to conventional soya.

- Saponins

These are glycosides present in soya at relatively low concentrations. They are generally associated with a bitter taste. They also have the ability to haemolyse red blood cells. They are not really of great concern for monogastric animals as they occur at low levels and have very little nutritional significance (Monari, 1996).

- Goitrogenic factors

These are also glycosides, some of which have a goitrogenic activity. This causes an enlargement in the thyroid gland. This in turn can cause a reduction in the activity of the thyroxin secreted by the thyroid gland.

- Allergenic factors, Rachitogenic factors and Metal chelating factors

None of these appear to have any significant effect on broiler growth. They may at one time or another, affect other animals but this falls outside of the scope of this study.

- Urease

Raw soya has varying levels of urease activity. This however, is not really of any nutritional significance other than the fact that it is used as an indirect measure of the efficiency of processing (Araba &Dale, 1990; Monari, 1996).

## 2.2. Processing of Soya

The use of full-fat soya beans depends on the processing treatments that are used to reduce the activity of anti-nutritional factors (Leeson and Atteh, 1996). The two main anti-nutritional factors (Kunitz and Bowman-Birk protease inhibitors) are thermo-labile and their concentration in raw soya may be reduced to insignificant levels by heat treatments. There is evidence however that excessive heat may damage heat sensitive amino acids like lysine, arginine, methionine and cystine (McDonald *et al.*1995; Renner *et al.,* 1953; Warnick & Anderson, 1968). According to Renner *et al.*, (1953) the amino acids most affected by over-processing are lysine and arginine. McNaughton & Reece (1980) reported that destruction of trypsin inhibitor and urease during heat treatment immediately preceded lysine degradation. A further problem may be that oxidative stability is reduced (Kouzeh-Kanani *et al.,* 1981, as quoted by Leeson and Atteh, 1996).

Processing methods must be carefully controlled in order to ensure that the danger of under- or overprocessing can be averted (Liener and Kakade, 1980). Heating soya beans not only destroys heat-labile anti-nutritional factors but also improves nutritional value by denaturing the highly folded native protein structure and thus making protein more available (Herkelman *et al.,* 1993). It is also well documented that heat treatment of raw soya improves growth, feed utilization, Nitrogen retention and reduces hypertrophy of the pancreas.

There are a multitude of methods to treat soya so as to reduce the effect of anti-nutritional factors. Some of these methods include:

- Cooking (Soaked and then boiled)
- Wave emission treatments (Micro-wave treatment or Micronisation)
- Treatments with heated gasses (Flaking or Expansion)
- Roasting treatments (Dry roasting, Super-heated steam roasting or fluidised-bed roasting)
- Extrusion (Wet or dry extrusion)

It should also be noted that hydrolytic enzymes present another possibility to remove anti-nutritional factors from the ration and to improve digestion and absorption. Phytase addition can lead to an increase in growth and feed conversion efficiency (Simons and Versteegh, 1993, as quoted by Marsman *et al.,* 1995). Hemicellulolytic enzymes may show an improvement in weight gain and efficiency thereof in wheat or barley based diets (Brenes *et al.,* 1993). Pentosanases and glucanases are enzymes that degrade non-starch-polysaccharides. When added to wheat and rye diets they can decrease viscosity in the gastro-intestinal tract (Choct and Anison, 1992). Such enzyme preparations are now available on a commercial scale.

Irradiation of full-fat soya beans has been shown to effectively reduce trypsin inhibitor activity, haemagglutinating activity and urease activity while improving total protein efficiency (Diaa El-Din H. Farag, 1998).

The various processing treatments can affect the energy value of the final product. This is demonstrated in Table 2.7. It is important that the processing method is carefully chosen so as to optimise broiler performance.

**Table2.7** Influence of treatment on the apparent metabolisable energy (AME) of full-fat soya for chicks (Wiseman, 1984)

| Treatment | AME (MJ/kg) |
|---|---|
| Dry extrusion | 17.9 |
| Wet extrusion | 17.4 |
| Micronisation | 17.3 |
| Roasting | 15.8 |
| Raw soya | 13.5 |

These values indicate that the process used to destroy anti-nutritional factors may modify the nutritional value of the full-fat soya. According to these results the process of dry extrusion provides the product with the highest AME value.

In the studies conducted the process of wet extrusion was used. This is one of the more common methods of processing full-fat soya (Jurgens, 2001) and finds widespread application in the feed-manufacturing industry. For this reason the process and effects of extrusion will be examined more closely.

### 2.2.1. Extrusion of Soya

Extrusion cooking is a widely used processing technology for the heat treatment of soya (Marsman *et al.,* (1995). It is a processing method in which heat is created by the friction that arises when feed is forced through die holes at high pressure (Zhang and Parsons, 1993; Waldroup, 1982). It has been proved many times that extrusion can inactivate trypsin inhibitor and other anti-nutritional factors (Mustakas *et al.,* 1970; Bjorck and Asp, 1983). Temperatures can be controlled during the extrusion process and this clearly is an important factor when ensuring that the product is sufficiently processed to have destroyed the anti-nutritional factors but not over-processed so as to have compromised the availability of the heat-labile amino acids (Zhang and Parsons, 1993; Perilla *et al.,* 1997). Literature and data demonstrating the effect of different screw-configurations on the efficiency of extrusion and animal performance is scarce (Marsman *et al.,* 1995).

It has been reported by Zhang and Parsons (1993) that extrusion is more efficient than autoclaving. They concluded that the optimum protein quality is obtained when extrusion occurs at 138 $^0$C. Another interesting conclusion drawn by these authors is that Kunitz trypsin inhibitor-free soya beans can be extruded successfully at lower temperatures than conventional soya beans. The range of satisfactory extrusion temperatures is also greater for Kunitz trypsin inhibitor-free soya beans. The potential for economic benefits of such findings should not be missed. Herkelman *et al.,* (1993) stated that the nutritional value of low trypsin inhibitor soya beans is superior to conventional soya beans but that heat treatment is still needed to optimise their nutritional value.

Perilla *et al.,* (1997) showed, in their study, that the optimum temperature of wet extrusion lies somewhere between 122 $^0$C and 126 $^0$C. They also showed that trypsin inhibitor activity is the best *in vitro* predictor of anti-nutritional factor inactivation, and thus, the nutritional value of soya beans.

This is true unless they are overheated because the trypsin inhibitor activity is not indicative of overheating. Urease activity is an easier and cheaper analysis to perform and it also gives a relatively good indication of the nutritional value of soya beans (Herkelman *et al.,* 1993).

**Table 2.8** *In vitro* parameters of full-fat soya beans extruded at different temperatures using a wet extruder (Perilla *et al.,* 1997)

| *Treatment group* | **Extrusion temp. ($^0$C)** | **Urease activity (ΔpH)** | **Trypsin inhibitor (mg/g)** | **Protein solubility in 0.2% potassium hydroxide (%)** |
|---|---|---|---|---|
| 1 | Raw | 2.03 | 37.92 | 90 |
| 2 | 118 | 1.08 | 9.41 | 88 |
| 3 | 120 | 0.85 | 6.68 | 86 |
| 4 | 122 | 0.10 | 1.66 | 84 |
| 5 | 126 | 0.09 | 1.26 | 72 |
| 6 | 140 | 0.05 | ND[2] | 67 |
| 7 | SBM[1] | 0.25 | 4.20 | 77 |

[1]Soya bean meal

[2]None detected (<0.1 mg/g)

According to Perilla *et al.,* (1997), an acceptable range of urease activity is believed to be between 0.01 and 0.5. Some literature reports conflict with this statement. Table 2.8 shows that extrusion temperatures of 122-126 $^0$C can reduce urease activity to within these limits. At 140 $^0$C the urease and trypsin inhibitor activity is even less but the danger of adversely affecting the bio-availability of some amino acids must be taken into account (Perilla *et al.,* 1997). Herkelman *et al.,* (1993) suggested that urease activity alone might not be the best indicator of optimum heat treatment. Kohlmeier (1997) observed that optimum processing had occurred when protein solubility was between 80-85%.

Table 2.9 shows performance of broilers fed soya processed to different degrees. It is clear that effective processing is required to achieve optimum performance of broilers. Both weight gain and feed conversion ratio are affected by processing efficiency. It is not only anti-nutritional factors but also amino acid availability that need to be considered.

**Table 2.9** Average weight gains, feed conversion ratios and relative pancreas weights at 3 weeks of broilers fed processed full-fat soya (Oeltman *et al.*, 1986)

| | TSAA[1] (%) | Lysine (%) | Average weight gain (g) | FCR | Relative pancreas weight[2] |
|---|---|---|---|---|---|
| Under-cooked | 0.79 | 0.96 | 531 ± 13 | 1.68 | 0.37 |
| Normal | 0.79 | 0.96 | 548 ± 10 | 1.64 | 0.35 |
| Over-cooked | 0.79 | 0.92 | 532 ± 9 | 1.69 | 0.36 |
| Over-cooked + lysine | 0.79 | 0.96 | 524 ± 14 | 1.73 | 0.36 |

[1] Total sulphur amino acids

[2] Pancreas weight/body weight

Featherston and Rogler (1966), and White *et al.*, (1967) compiled reviews of processing methods for utilizing unextracted soya beans. Featherston and Rogler (1966) found that pelleting helped to rupture the fat cells and increased the availability of the oil in already extruded soya beans. White *et al.*, (1967) found that extrusion processing was sufficient to support maximum chick growth as compared to diets containing solvent-extracted meal. They also found that pelleting significantly improved feed utilization of extruded soya beans as well as improving rate of gain. The digestibility of the whole beans and particularly the fat was improved after pelleting. This is attributed to the rupture of the cells that occurs during extrusion. Pelleting helps to reduce problems associated with the light fluffy nature of the product. Pelleting controls the bulkiness of the diet and increases cell rupture to ensure greater nutrient release (Waldroup and Cotton, 1974).

If one were to feed all-mash rations to broilers it would be wise to consider what the maximum inclusion level should be. Waldroup and Cotton (1974) suggested that in all-mash broiler rations full-fat soya beans should not be included at levels of greater than 25%. The reduction in performance at higher levels of inclusion is attributed to the higher bulk-density of such feeds.

Other methods are also used to process soya. In South Africa dry extrusion accounts for about 56% of all cooked full-fat soya while wet extrusion accounts for about 7% of cooked full-fat soya (Jurgens, 2001). Roasting is no longer very popular and only produces 1% of all cooked full-fat soya. The second most popular method is expansion that is used to produce 36% of all full-fat soya. The potential for greater use of full-fat soya in South Africa is substantial.

### 2.3. Quality Control of Processed Soya

In order to ensure that processing has had the desired effect it is necessary to carry out tests to measure processing efficiency. The objectives of these tests are threefold. They are carried out in order to determine whether:

- Trypsin inhibitor content has been reduced to acceptable levels;
- Protein quality has been maintained;
- As much oil as possible has been released from the cells that contain it.

There are a number of techniques available to achieve these objectives. They include (Monari, 1996):

- Trypsin inhibitor activity (TIA) determination;
- Lectin level determination;
- Saponin determination;
- Urease test;
- Protein dispersibility index;
- Protein solubility in KOH;
- Cresol red test;
- Lysine availability;
- Colour comparison;
- Rapid colour test;
- Full-fat soybean oil content;
- Net protein utilisation and biological value.

McNaughton et al., (1981) reported that colour could be used equally well to determine both under- and over-processing. This is possible due to the Maillard browning reactions occurring during soya processing. In South Africa the most common of the quality control tests are the urease test and the protein solubility in 0.2% potassium hydroxide (Ekermans, 2002). There are conflicting reports as to the boundaries within which optimum processing has been achieved. Table 2.10 gives a summary of some reported ranges of acceptability of parameters used to determine quality of processed soya.

**Table 2.10** Acceptable ranges of protein solubility and urease activity to ensure optimum processing

| Solubility in 0.2% KOH | Urease activity (Δ pH) | Authors |
|---|---|---|
| 80-85% | 0.01-0.50 | Kohlmeier, (1997) |
| | 0.05-0.20 | Wright, (1981) |
| ± 50% | | Herkelman *et al.*, (1991) |
| 70-80% | | Araba & Dale, (1990) |
| | <0.15 | McNaughton *et al.*, (1981) |
| 67-85% | | Marsman *et al.*, (1995) |

Urease index and trypsin inhibitor content can be used as indicators of under-processed soya. It has been proved however, that the urease index as well as trypsin inhibitor is not an efficient indicator of overprocessing of soya (Araba & Dale, 1990; Herkelman *et al.,* 1991).

In contrast to urease activity, protein solubility in 0.2% KOH has the advantage that even in severely overheated soya, it does not reach zero. The protein solubility assay overcomes the basic shortcoming of the urease test in that it can be used to distinguish between degrees of over-processing (Araba & Dale, 1990). These authors, in fact showed that soya bean meal with a urease value of 0.00 units of pH change could still support maximum chick growth. They concluded that the protein solubility assay was superior to urease index in determining over-processing of soya.

While there is some debate as to the optimum ranges of protein solubility and urease activity, it appears safe to assume that a protein solubility of 70 to 80% and a urease activity of between 0.05 and 0.20 units of pH change are acceptable.

In the studies conducted it was decided to analyse all soya products for urease activity and protein solubility in KOH. This would give a clear indication as to the effectiveness of the heat-treatment that they were exposed to. They were also chosen due to the relative ease with which they can be performed and because they are relatively inexpensive.

## 3. Nutritional Value of Full-fat Sunflower Seed *(Helianthus anuus)* for Broilers

Sunflower is a widely found oilseed in many parts of the world (San Juan and Villamide, 2000; Zhang and Parsons, 1994) due to its great capability of adaptation to different climatic and soil conditions (Ravindran and Blair, 1992). Villamide & San Juan, (1998) reported that there exists a general lack of information regarding the nutritional value of sunflower seed and the products derived from them. The same was reported by a number of other researchers (Elzubeir and Ibrahim, 1991; Arija *et al.,* 1998; Ortiz *et al.,* 1998; Villamide and San Juan, 1998).

The available literature is somewhat contradictory and presents great variation in terms of the nutritional value of full-fat sunflower. The nutritional value of sunflower oilcake is documented far more thoroughly. No consensus has been reached as to the optimum and maximum inclusion levels of full-fat sunflower seed for poultry.

It seems that the use of sunflower seed has been fairly limited in the past due to its relatively high fibre content and a relatively low lysine content as compared to other oilseeds, especially soya beans (San Juan and Villamide, 2000). Sunflower seed does however, have a high energy content and a relatively low price (Ortiz *et al.,* 1998).

Sunflower oil has for some time been recognized as a good fat source for poultry, especially layers, due to its high linolenic acid content (San Juan and Villamide, 2000). It may provide a convenient method of adding additional energy to broiler diets, while avoiding well known technical difficulties and quality problems of animal fat addition (Rodriguez *et al.,* 1998). Ortiz *et al.,* (1998) reported that oil content of sunflower seed can vary from 40 to 55 %. San Juan and Villamide (2000) stated that the sunflower seed itself has a high oil content (up to 50%) and reasonable crude protein content (up to 23%), which may lead to an interest in using it as an ingredient in broiler feeds. They concluded that, while sunflower seed may be of lower nutritional value than oil and sunflower seed meal mixed, it was still a cheap and easy way to add energy and protein to poultry diets.

The major fatty acids of sunflower seed are linolenic and oleic acid (Ortiz *et al.,* 1998). In terms of amino acid content it has been reported that the levels of glutamic acid, arginine and aspartic acid were high, while methionine and cystine levels were low (Ortiz *et al.,* 1998). Daghir *et al.,* (1980) state that lysine is the first limiting amino acid in sunflower seed followed by threonine.

Table 3.1 shows a summary of the reported nutrient composition of full-fat sunflower seed. An average reported $AME_n$ value of 18.26 MJ/kg indicates that full-fat sunflower is an excellent source of energy for poultry. The high energy level is due, in the most part, to high oil levels (approximately 40%). The average reported crude protein value is 18.73%. This would imply that full-fat sunflower may be an important source of protein for poultry. A closer look at the amino acid values shows that methionine (0.42%), lysine (0.65%) and cystine (0.33%) are present in low quantities. This is in agreement with the reports of Daghir *et al.,* (1980) and Ortiz *et al.,* (1998). Another factor that may limit the maximum inclusion levels of full-fat sunflower is its relatively high fibre content. When included at high levels this will lead to an increase in the bulk density of the diet, which in turn will lead to reduced intakes. It is not desirable to limit broiler intake in this way.

**Table 3.1** Summary of reported nutritional values of full-fat sunflower seed

| ***Nutrients*** | Highest reported value | Lowest reported value | Average | Authors |
|---|---|---|---|---|
| Dry matter, % | 90.0 | 90.0 | 90.0 | |
| $AME_n$ MJ/kg | 20.93 | 15.16 | 18.26 | Elzubeir & Ibrahim, (1991); Kashani & Carlson, (1988); Rodriguez *et al.,* (1998) |
| Crude Protein, % | 22.40 | 15.99 | 18.73 | Daghir *et al.*, (1980); Elzubeir & Ibrahim, (1991); San Juan & Villamide, (2000) |
| Ether extract, % | 46.61 | 32.70 | 40.57 | Elzubeir & Ibrahim, (1991); Kashani & Carlson, (1988); San Juan & Villamide, (2000) |
| Fibre, % | 17.10 | 13.40 | 14.68 | Cheva-Isarakul & Tangtaweewipat, (1991); Elzubeir & Ibrahim, (1991); Rodriguez *et al.,* (1998) |
| Methionine, % | 0.47 | 0.38 | 0.42 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.,* (1998) |

| | | | | |
|---|---|---|---|---|
| ***Lysine, %*** | 0.79 | 0.56 | 0.65 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| ***Cystine, %*** | - | - | 0.33 | Cheva-Isarakul & Tangtaweewipat, (1991) |
| Threonine, % | 0.68 | 0.49 | 0.61 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| Isoleucine, % | 0.91 | 0.59 | 0.73 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| Leucine, % | 1.36 | 0.83 | 1.10 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| Phenylalanine, % | 0.98 | 0.53 | 0.75 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| ***Arginine, %*** | - | - | 2.08 | Rodriguez *et al.*, (1998) |
| ***Histidine, %*** | - | - | 0.62 | Rodriguez *et al.*, (1998) |
| Tyrosine, % | 0.85 | 0.36 | 0.61 | Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| Valine, % | 1.02 | 0.72 | 0.89 | Cheva-Isarakul & Tangtaweewipat, (1991); Kashani & Carlson, (1988); Rodriguez *et al.*, (1998) |
| Calcium, % | - | - | 0.15 | Daghir *et al.*, (1980) |
| Phosphorous, % | - | - | 0.35 | Daghir *et al.*, (1980) |

When dealing with products of such high fat content it is important to consider the ability of the birds to digest that fat. It seems that Nitrogen and amino acid digestibility is not affected as the chick gets older, but there is a significant effect on the digestibility of the dietary fat. Fat digestibility increases with age (Ortiz *et al.,* 1998). This has been attributed to the inability of the very young chick to secrete sufficient bile salts to replace those lost by excretion (Serafin and Nesheim, 1967 as quoted by Ortiz *et al.,* 1998). It seems that full-fat sunflower in the diet has a positive effect on fat digestibility. The dietary $AME_n$ values showed similar trends to those reported for the fat digestibility. This is in agreement with the generally accepted idea that $AME_n$ tends to increase with age (Fisher and McNab, 1987).

Ortiz *et al.,* (1998) concluded that the substitution of full-fat sunflower to a diet, for broilers, in place of maize, soya bean meal and sunflower oil had a positive effect on digestibility and $AME_n$.

**Table 3.2** Chemical composition of sunflower products (San Juan and Villamide, 2000)

| | Sunflower seed | Press-extracted sunflower seed | Defatted sunflower seed meal |
|---|---|---|---|
| Crude protein, % | 17.83 | 27.01 | 33.14 |
| Ether extract, % | 46.61 | 20.18 | 2.77 |
| Ash, % | 3.81 | 5.67 | 7.0 |
| Crude fibre, % | 14.46 | 21.0 | 25.21 |
| Neutral detergent fibre, g/kg DM | 235.9 | 341.8 | 389.1 |
| Acid detergent fibre, g/kg DM | 164.7 | 237.0 | 295.1 |
| Acid detergent lignin, g/kg DM | 50.1 | 74.1 | 85.5 |
| Gross energy (MJ/kg DM) | 26.33 | 22.20 | 19.38 |

The chemical composition of some sunflower products is shown in Table 3.2. The table compares full-fat sunflower seed and sunflower oilcakes. The seed itself is very high in fat while the processed forms of the seed have had most of that fat removed. As a consequence of the oil removal, the remaining part of the seed has a much higher protein concentration. The fibre concentration is increased at the same time. Perhaps one of the most important aspects to take note of is the reduction in the energy value. By feeding sunflower in its full-fat form one can take advantage of the high energy content as well as the relatively high protein content. At the same time the cost of oil extraction can be avoided.

The fat content of sunflower seed can vary quite dramatically depending on the variety used (Rodriguez *et al.,* 1998). In fact the entire composition is often very variable (Villamide and San Juan, 1998) and this is one of the problems associated with sunflower. Quality control is difficult when the composition of a product varies so dramatically depending on factors such as region, climate, soil conditions and of course processing conditions.

Sunflower seed does contain certain phenolic compounds, the most important of which is chlorogenic acid, which darkens upon oxidation and can impair the acceptability of sunflower products (Pomenta and Burns, 1971; Trevino *et al.,* 1998; Dorrell, 1976). The content of chlorogenic acid in sunflower tends to be variable (Dorrell, 1976). Its effect on broiler performance has not been fully quantified but it will be discussed in a later chapter.

In terms of maximum inclusion levels the reported research does not seem to find consensus. Rodriguez *et al.,* (1998) reported that inclusions of up to 25 % have no negative effect on weight gain and feed efficiency for broilers. Metabolisable energy and nutrient digestibility were not adversely affected in their study.

Cheva-Isarakul and Tangtaweewipat (1991) found that broilers fed full-fat sunflower exhibited lower intakes than birds fed on control diets. They attributed the lower feed intake of birds fed full-fat sunflower to the high energy and high fibre content of the seed. Birds consume feed according to their energy requirement. Also the bulkiness of the sunflower will depress feed intake. Birds still however, consumed more metabolizable energy when fed full-fat sunflower. These authors said that an increase in abdominal plus visceral fat was noticed and was probably due to increased energy levels in the diet while protein intake is limited by reduced overall intakes. They concluded that inclusions of up to 50% were possible and that lysine supplementation was beneficial to performance of birds fed high levels of full-fat sunflower seed.

Elzubeir and Ibrahim (1991) concluded in their study that levels of up to 22.5% could be included in broiler rations with no adverse effect on performance or carcass skin colour.

Daghir *et al.,* (1980) recommended that no more than 10% full-fat sunflower seed be added to the diet of broiler chickens. They reported however, that at up to 20% there was no harmful effect on the liver or pancreas of the birds. They found that up to 30% was acceptable in laying hen diets.

Arija *et al.,* (1998) found that the inclusion of sunflower kernels adversely affected growth and fat digestibility at levels up to 5%. They concluded however, that hulls added at 5% had no adverse effects on broiler performance.

It is clear from the preceding paragraphs that there is no consensus as to the maximum inclusion of full-fat sunflower in broiler rations. Authors state high fibre levels, low lysine levels and even anti-nutritional factors such as chlorogenic acid, as reasons to limit inclusion of full-fat sunflower in broiler rations. Research into the nutritional value of full-fat sunflower and the optimum inclusion in broiler diets is essential if advantage is to be taken of the immense potential for sunflower production in South Africa.

### 3.1. Anti-nutritional Factors in Sunflower Seed

The presence of phenolic compounds in sunflower seeds is well known (Trevino *et al.,* 1998). The most important of these is chlorogenic acid which is one of the most widely distributed phenolic substances in plants. This compound darkens upon oxidation and can impair the acceptability of sunflower products (Pomenta and Burns, 1971; Trevino *et al.,* 1998). There is very little available information on the nutritional consequences of dietary chlorogenic acid.

The content of chlorogenic acid in sunflower seeds may vary from 1.4 to 4.0% (Dorrell, 1976). The content seems to be affected by environmental conditions and plant maturity. According to Dorrell (1976) there exists sufficient genetic variation to justify future selection for lower levels of chlorogenic acid.

**Table 3.3** Chlorogenic acid content (G/kg ± SD) of hulls and kernels of different sunflower genotypes (Pedrosa *et al.*, 2000)

| Genotype | Chlorogenic acid in hull | Chlorogenic acid in kernel |
|---|---|---|
| Tesoro | 0.0322 ± 0.0007 | 0.9714 ± 0.0513 |
| Marko | 0.0185 ± 0.0012 | 0.8820 ± 0.0523 |
| Clip | 0.0895 ± 0.0170 | 0.7261 ± 0.0969 |
| Vyp | 0.0373 ± 0.0036 | 0.8484 ± 0.0798 |
| Nanta | 0.0882 ± 0.0057 | 0.6303 ± 0.1428 |

Table 3.3 shows the chlorogenic acid content of a variety of sunflower genotypes. It is clear from the table that the majority of the chlorogenic acid is within the kernel. Table 3.4 illustrates the distribution between hull and kernel of the entire polyphenol content of the seed.

**Table 3.4** Actual total polyphenol content of the whole sunflower seed (g/kg) and its distribution % in the kernel and hull (Pedrosa *et al.*, 2000)

| Genotype | Total polyphenols | Kernel | Hull |
|---|---|---|---|
| Tesoro | 1.06 | 98.3 | 1.7 |
| Marko | 1.24 | 99.3 | 0.7 |
| Clip | 1.04 | 94.6 | 5.4 |
| Vyp | 1.30 | 98.7 | 1.3 |
| Nanta | 1.16 | 96.3 | 3.7 |

The investigations of Milić *et al.*, (1968) show that chlorogenic acid has the ability to interact with proteins and also to inhibit *in vitro* activity of some digestive enzymes such as trypsin and lipase. They believed that these protein-binding and inhibitory effects could be of nutritional importance. Cater *et al.*, (1972) report that chlorogenic acid participates in enzymatic browning reactions and this may impair digestibility of dietary protein.

Trevino *et al.* (1998) reported that increasing levels of chlorogenic acid in the diet did not have a negative effect on digestibility and nutritional quality. They added chlorogenic acid at up to 6 g/kg (equivalent to approximately 300 g/kg of ground sunflower in the diet) and found no effect on digestibility of crude protein, crude fat and starch. They also found that the presence of chlorogenic acid in the diet at up to 6g/kg had no effect on $AME_n$ values. They concluded that chlorogenic acid or its derivative compounds were not absorbed across the gut wall, or if absorbed they did not affect the utilisation of dietary energy in broilers.

Daghir *et al.,* (1980) found that inclusion of raw full-fat sunflower in broiler diets caused mild discoloration of the horny layer of the gizzard, but no increase in gizzard erosion. They attributed the discoloration to chlorogenic acid.

Arija *et al.,* (1998) conducted a literature review and concluded that there is no real evidence of any significant anti-nutritional factors in sunflower kernels.
Arija *et al.,* (2000) found that the addition of 150g/kg full-fat sunflower kernels to broiler diets may cause some damage to epithelial lining of the gut. They did not however quantify the possible effect of this damage. They believe that chlorogenic acid may have a negative impact on growth but only at high levels.

Elzubeir and Ibrahim (1991) observed no significant differences in weight gain, feed intake, feed efficiency, mortality, skin colour, and liver and pancreas relative weight when sunflower seed was included at up to 225g/kg. Their data indicated that unprocessed sunflower seed does not contain any toxic substances that may cause growth depression in broilers.

From the available literature it is clear that phenolic compounds such as chlorogenic acid do have an impact on digestion of dietary nutrients. It is less clear however, whether this impact is nutritionally significant. It seems that if there is a nutritionally significant effect, it only occurs when chlorogenic acid is present at high levels.

### 3.2. Processing of Sunflower Seed

There is very little information available on the processing or heat treatment of full-fat sunflower. There is some information from the processing of sunflower seed meal that can be useful. In the experiments conducted as part of this thesis, sunflower was expanded in order to determine if there is any benefit in heat-treating full-fat sunflower seed prior to feeding.

The possible benefits of heat-treating sunflower may be the release of nutrients due to disruption of cell structures during processing. Kan *et al.,* (1988) showed for soya that the most important factor determining $AME_n$ values was the fat digestibility. By disrupting the cell structure during processing one can enhance fat digestibility. While energy would be the major nutrient supplied by full-fat sunflower, other nutrients may also become more available after processing.

There is a danger that if sunflower seed meal is overprocessed the availability of some amino acids may be reduced, especially lysine (Zhang and Parsons, 1994). This is extremely important to remember because sunflower seed is already deficient in lysine. Protein solubility in potassium hydroxide has been reported as a good indicator of reduced protein quality in overprocessed soybean meal and canola meal and now also in sunflower seed meal. Zhang and Parsons (1994) reported a large decrease in lysine digestibility after overprocessing and attributed it largely to Maillard reaction products. While this data was compiled using sunflower seed meal and not full-fat sunflower it may be wise to keep it in mind when processing full-fat sunflower if indeed one wants to do so.

In some of the available literature Daghir *et al.,* (1980) reported that steaming or dry heating had no effect on the utilization of full-fat sunflower by broilers. Brad (1967), as quoted by Daghir *et al.,* (1980) found that moderate thermal treatment of sunflower increased the speed of *in vitro* digestion by pepsin and trypsin. It seems, according to their results, that steam heating may be slightly more efficient than dry heating.

In the work conducted for this study full-fat sunflower seed was put through an expander to determine whether this type of heat-treatment would have any effect on its nutritional quality. Initially extrusion was tried but due to the extremely high oil content of full-fat sunflower, these attempts were unsuccessful. Expander processing of full-fat sunflower has not been widely researched. Expander processing is discussed further, in light of its potential effect on nutritional quality of full-fat sunflower. Due to the lack of information specifically from expansion of sunflower, relevant results of expansion of other products and whole diets have been used. It is hoped to give some idea of the possible outcomes of expansion of full-fat sunflower.

### 3.2.1. Expander Processing

Expander processing has been used in the poultry industry for some time (Kwakkel & van der Poel, 1997). In recent times the use of expanders as stand-alone equipment in animal feed manufacturing plants has grown rapidly (van Zuilichem *et al.,* 1997). It is a process in which steam- or liquidconditioned meal is fed into mixing and conveying screw. The exit gap at the end of the screw can be hydraulically or electrically controlled and in so doing can ensure that the expansion process can be adapted to obtain optimum processing conditions. In fact there are many variables that affect the nature of the final product. This means that end products are of a very diverse nature and ensures that the efficiency of the expansion process in difficult to evaluate (Bos *et al.,* 1997).

When the feed leaves the expander a sudden drop in pressure occurs and some of the added water evaporates spontaneously. This, along with the sudden increase in volume of the material as it leaves the expander, is known as "expansion". This process is generally somewhat cheaper than both single- and twin-screw extrusion (van Zuilichem *et al.,* 1997). Some of the other advantages, for the feed manufacturer, of using expander processing include (van Zuilichem *et al.,* 1997):

- Increased fat and molasses addition
- Gelatinisation of starch
- Inactivation of anti-nutritional factors
- Sterilisation of feed
- Improved pellet durability and reduced dust levels.

The expansion process affects many chemical properties of feed products but for the purpose of this study proteins and amino acids, as well as fat and cell walls are of importance. The effect of expansion on starch has been studied more thoroughly than any effects on other nutrients. Gelatinisation is the most important of the processes affecting starch. This will not be discussed in any detail however, as it is not considered important within the framework of this study.

- Effect on proteins and amino acids

According to the work of Peisker (1992), expander processing has no significant influence feed protein content. Table 3.5 shows the effect of expander treatment on the stability and availability of certain amino acids.

**Table 3.5** Stability of amino acids (% of feed) after expander processing of a pig feed (Peisker, 1992)

| **Amino Acid** | **Untreated** | **Expander processed** | |
|---|---|---|---|
| | | 120 $^0$C | 130 $^0$C |
| Lysine (total) | 0.84 | 0.83 | 0.78 |
| Reactive lysine | 0.80 | 0.79 | 0.74 |
| Lysine availability | 95% | 96% | 95% |
| | | | |
| Threonine | 0.61 | 0.59 | 0.57 |
| Methionine | 0.55 | 0.56 | 0.54 |

At a temperature of 120 $^0$C neither that total lysine nor the reactive lysine changed. Even at 130 $^0$C there were no significant differences found in the content or availability of any of the amino acids. Peisker (1992) also stated that synthetic lysine and methionine are "expander stable". This is extremely important considering their widespread use in modern broiler rations.

Feed protein may become physically bound in the matrix formed by starch gelatinisation (Thomas & van der Poel, 1997). The protein dispersibility index decreases in expanded feeds as compared to untreated feeds. The protein dispersibility index of legume seeds decreases with increasing temperatures during expansion, while in cereals the protein dispersibility index shows virtually no decrease (Peisker, 1992). This did not however, seem to impede the digestion of protein in the animal. This is due to the fact that the animal's digestive enzymes easily dissolve the starch matrix and make the protein available again. In fact, the breakdown of the tertiary protein structure during expansion can actually cause an increase in protein denaturation and digestibility (Thomas & van der Poel, 1997).

Expander processing may also be employed to reduce the levels of proteinaceous anti-nutritional factors (Bos *et al.,* 1997). Trypsin inhibitors and chymotrypsin inhibitors are heat labile, as are lectins. Expander processing is therefore an acceptable way to ensure these factors are sufficiently disrupted so as to have no effect on animal performance. In light of this, it is possible to use expansion rather that extrusion to destroy these anti-nutritional factors. There are however, many differences between the expansion process and the extrusion process so it is not possible to directly transfer results from extrusion to expansion.

- Effects on fat and fatty acids

Expander processing can influence the quality of fatty acids in feed (Peisker, 1992). Microbial lipase (from *Penicillium, Pseudomonas, Candida* etc) is most responsible for decomposition of fat in feeds and feedstuffs. These naturally occurring lipases are inactivated completely by expander processing (Peisker, 1992). This means that the free fatty acid content of stored, expanded feeds will not rise dramatically as is the case with stored feeds that have not been expanded.

Oxidation of fat in feeds and feedstuffs may also occur. The enzyme, lipoxidase, when present will cause fat in feeds to turn rancid (Bos *et al.,* 1997). The products formed during this oxidation give the feed a characteristic taste and smell, which causes lowered intakes. According to the work of Peisker (1992), expander processing reduces the incidence of fat oxidation by inactivation of the relative enzymes during treatment.

Due to the shear forces at work during expansion, fat and oil containing cells may be ruptured. If there is starch present when expansion takes place, gelatinisation will occur. This matrix will form an amylose-lipid complex. The significance of this is that it will reduce the amount of fat leaking out of feed at high temperatures (Thomas & van der Poel, 1997). After this, higher levels of fat can be added to the feed during pelleting.

- Effects on cell wall structures

Cell walls of older plants contain pectins, hemicelluloses, cellulose and even some lignin (Bos *et al.,* 1992). Cell walls of this nature have very low digestibility for monogastric animals like chickens. Milling and pelleting result in the disruption of cell walls due to the high shear forces that these processes excerpt on the feed. This same principle can be applied to expansion. Cell walls are broken down and digestibility is increased.

Milling and pelleting are fairly standard procedures in feed manufacturing but the expansion process may further improve digestibility of diet ingredients when employed in conjunction with these processes.

- Effects on micro-organisms

The high temperatures reached during expansion will lead to a reduction of the micro-organisms present in the feed (Beumer & van der Poel, 1997). The effects of expansion on the numbers of different micro-organisms present in different feeds are shown in Table 3.6.

**Table 3.6** Effect of expander treatment on the counts of micro-organisms in different feeds (Beumer & van der Poel, 1997)

| **Feed type** | **Conditions** | | **No. of micro-organisms per gram feed** | | | | ***Salmonella***[1] |
|---|---|---|---|---|---|---|---|
| | Temp ($^0$C) | Pressure (bar) | Aerobic germs | *Entero-bact.* | *E coli* | Moulds | |
| Broiler | untreated | untreated | 63 000 | 10 | <10 | 1 400 | - |
| | 125 | 10 | 900 | <10 | <10 | <10 | - |
| | 135 | 20 | 870 | <10 | <10 | <10 | - |
| Layer | untreated | untreated | 830 000 | 1 000 | - | 1 400 | + |
| | 125 | - | 39 000 | <10 | <10 | <10 | - |

[1] +/- *Salmonella* detected/ not detected on 25 g feed

The extent of the reduction in microbial numbers will be determined by the temperature, treatment time and moisture content (Beumer & van der Poel, 1997). The combinations of these three variables need to be controlled and understood in order to successfully reduce microbial numbers.

Considering the constant attention given to food and feed safety it is extremely important to note that expander treatment appears to provide an effective means of eliminating *Salmonella* from animal feeds. Expander treatment on its own is obviously not enough and the entire production and delivery process needs to be correctly managed and organised to ensure safe feeds.

- Effects on nutritional value and broiler performance

Most of the available research involves the expansion of complete feeds rather than single feed ingredients. It is nevertheless, worth reporting some of the results in order to get an idea of the results obtained when feeding expanded poultry rations.

The results of Kwakkel & van der Poel, (1997) are shown in Table 3.7. They compared three processes viz. pelleting, expansion and a combination of expansion followed by pelleting.

**Table 3.7** Effects of dietary treatments on broiler performance at 36 days of age (Kwakkel & van der Poel, 1997)

| | **Pelleting** | **Expander treated** | **Expanded and pelleted** |
|---|---|---|---|
| Body weight (g) | 1504[a] | 1432[b] | 1523[a] |
| Cumulative feed intake | 2551[a] | 2433[b] | 2592[c] |
| Feed conversion ratio | 1.74 | 1.75 | 1.75 |

[a,b,c] Values with different superscripts in the same row differ significantly ($P<0.05$)

Growth performance is best in the group fed expanded, pelleted feed. The group fed expanded feed performed the worst in terms of growth. This is due, most likely, to the increase in bulkiness of the diet. This bulkiness caused a reduction in feed intake. If the feed is pelleted, this problem is avoided. The feed conversion ratios were not affected by treatment.

Peisker (1992) emphasized that one of the main advantages of expander processing is that considerable amounts of free fat can be added to the diet. Fat is trapped within the starch matrix formed during gelatinisation, allowing for the addition of extra fat without the usual technical difficulties. This allows nutritionists to increase energy levels in the ration and can improve growth rates of broilers. If an ingredient such as sunflower is expanded on its own this will not be the case. The process of starch gelatinisation does not occur when expanding sunflower on its own.

In another trial Peisker (1992), compared three treatment methods in terms of nutrient digestibility. The three treatments were "pelleting", "expansion and pelleting" or "first expanding the maize portion and then pelleting the whole diet".

**Table 3.8** *In vitro* characteristics and digestibility coefficients of crude nutrients in differently treated broiler mixed feeds (Peisker, 1992)

| | **Processing** | | |
|---|---|---|---|
| | Standard pelleted | Expanded-pelleted | Maize expanded Mix pelleted |
| Starch hydrolysis | 22.6 | 31.0 | 34.2 |
| PDI[1] | 17.6 | 16.0 | 16.8 |
| | | | |
| *Digestibility coefficients* | | | |
| Organic matter | 68.6 ± 3.4 | 70.2 ± 1.2 | 67.7 ± 2.3 |
| Crude protein | 78.5 ± 1.9 | 77.2 ± 0.8 | 76.9 ± 0.8 |
| Crude fat | 70.6 ± 4.5[a] | 82.3 ± 6.1[b] | 67.7 ± 10.0[a] |
| Starch | 97.8 ± 0.7[a] | 98.9 ± 0.1[b] | 98.1 ± 0.7[ab] |

[1] Protein Dispersibility Index

[a,b] Values with different superscripts in the same row differ significantly ($P<0.05$)

No differences were found in organic matter or crude protein digestibilities. Expander-pelleting did however, increase starch and fat digestibility (Table 3.8). This is most likely due to the rupture of fat containing cells and starch gelatinisation.

Smith *et al.,* (1995) conducted experiments to determine the effects of expander processing prior to pelleting. They fed either pelleted or expanded-pelleted diets for a 41-day period. Their results showed that expanding treatment prior to pelleting improved body weight gain, feed conversion ratios and also pellet durability.

Plavnik & Sklan, (1995) reported that expansion of maize or wheat/barley based diets led to an increase in $AME_n$ values by 1.5 to 3.5 %. Their results are presented in Table 3.9.

**Table3.9** Effect of expansion on apparent digestibilities of nitrogen (N), fatty acids, starch (g/kg), gross energy (GE), apparent (AME) and N-corrected ($AME_n$) metabolisable energy (MJ/kg) of corn or wheat/barley based diets (Plavnik & Sklan, 1995)

| | **N** | **Fatty acids** | **Starch** | **GE** | **AME** | **$AME_n$** |
|---|---|---|---|---|---|---|
| *Maize-based diets* | | | | | | |
| -mash | 680 | $758^a$ | 969 | $794^a$ | $14.19^a$ | $13.04^a$ |
| -expanded | 661 | $798^b$ | 972 | $796^a$ | $14.33^b$ | $13.26^b$ |
| *Wheat/barley based diets* | | | | | | |
| -mash | 673 | 778 | 976 | $768^a$ | $13.57^a$ | $12.58^a$ |
| -expanded | 676 | 781 | 979 | $779^b$ | $13.96^b$ | $12.90^b$ |

$^{a,b}$ Means within the same column (per diet) with different superscripts are different ($P<0.05$)

From the research findings presented here it seems that expander processing is certainly a useful tool for any feed manufacturer. Apart from the fact that the process may be employed to destroy anti-nutritional factors, it also seems to have a positive effect on nutrient utilisation and energy values. It is clear that it helps to rupture fat containing cells and to break down cell walls. It also has a positive effect on pellet quality and durability.

In the experiments to be presented as part of this thesis expander treatment was carried out on sunflower seeds. The intention is to determine if the expansion treatment had any effect on the $AME_n$ values of sunflower seeds, and the subsequent performance of broilers fed diets containing full-fat sunflower treated in different ways. It is also intended to calculate apparent amino acid availability. This will give an indication as to whether the processing has affected the biological value of the protein in full-fat sunflower seed.

The following experiments were conducted to determine the nutritional value of full-fat soya and full-fat sunflower, and subsequently to quantify their effect on broiler performance. Full-fat soya is already a widely used raw material in the poultry feed manufacturing industry. Full-fat sunflower is less well utilised and less well understood. There is great potential for the use of full-fat sunflower in South Africa but information on its nutritive value is scarce. Without such information its use will remain limited and its potential may never be realised.

# 4. The effect of heat-treatment and dehulling of full-fat soya (*Glycine max)* on $AME_n$, amino acid availability and broiler performance.

## Introduction

The need for protein for human and animal consumption is steadily growing while conventional protein sources are becoming less available and more expensive (Brand & Brundyn, 2001). Increased production, competition and other factors such as their high energy content (Simovic *et al*., 1972) have made the use of full-fat oilseeds within the range of economic possibility (Waldroup & Cotton, 1974). The use of full-fat soya (*Glycine max*), which is high in both protein and energy, makes it possible to formulate higher density diets (Simovic *et al*., 1972). In hot climates such as those that prevail over most of South Africa it may be very beneficial to counteract lower intakes in this way. Waldroup (1982) added that full-fat soya can be handled in the mixing process at lower cost than conventional fat sources, can allow higher fat content feeds to be pelleted and is of better quality than most other fat sources. Full-fat soya is also an excellent source of lysine (Ekermans, 1988) and fatty acids (Kohlmeier, 1997).

It has been well documented that soya contains certain anti-nutritional factors (Han & Parsons, 1991; Herkelman *et al.,* 1993; Leeson & Atteh, 1996). Trypsin inhibitor is probably the most important of these. It should be remembered that protease inhibitors are not the only anti-nutritional factors present in soya. Perilla *et al.,* (1997) reported that lectins and saponins are also present in soya beans and that these may reduce feed intake and the rate and efficiency of growth. Heating soya beans not only destroys heat-labile anti-nutritional factors but also improves nutritional value by denaturing the highly folded native protein structure, making protein more available (Herkelman *et al.,* 1993). Research has confirmed that heat treatment of raw soya improves growth, feed utilization, nitrogen retention and reduces hypertrophy of the pancreas (Renner & Hill, 1960; Perilla *et al.,* 1997). Over-cooking damages heat-sensitive amino acids like lysine, arginine, methionine and cystine, and decreases their availability (McNaughton & Reece, 1980; Renner *et al.*, 1953; Savage *et al.,* 1995). The process of dehulling removes the fibrous pericarp from the seed leaving a slightly more nutrient dense product. At the same time, insoluble polysaccharides and tannins, that may reduce protein digestibility, are removed.

The aim of these experiments was to determine the $AME_n$ values and apparent amino acid availability of whole and dehulled raw full-fat soya, as well as whole and dehulled cooked full-fat soya. Experiments were then conducted to examine the effect of these products on broiler performance.

**Materials and Methods**

Raw whole soya beans were obtained from a local producer. Some of the beans were then dehulled using the facilities of a local soya bean crusher[1]. The removed hulls represented approximately 8% of the original mass of the beans. A part of each of the whole and dehulled soya was then extruded using a single screw extruder at a barrel jacket temperature of 120°C. This left four test products: raw whole soya (RWS), raw dehulled soya (RDS), extruded whole soya (EWS) and extruded dehulled soya (EDS).

Proximate composition of each of the various products was determined as well as urease activity and protein solubility in a 0.2% solution of potassium hydroxide (AOAC, 1995).
The apparent metabolizable energy values corrected to zero-nitrogen balance (AMEn) were determined according to the European reference method described by Bourdillon *et al.,* (1990) and were calculated as described by Hill and Anderson (1958). The products were not pelleted during this energy determination. Apparent amino acid availability was determined using the same samples as collected for the energy trial. Amino acid analyses were done using High Performance Liquid Chromatography (HPLC) techniques in a Beckman 6300 amino acid analyser.

A control starter diet and a test starter diet (containing high levels of RWS, EWS, RDS and EDS) were formulated. The two diets were then blended at the following levels:

100% Control: 0% Test
80% Control: 20% Test
60% Control: 40% Test
40% Control: 60% Test
20% Control: 80% Test
0% Control: 100% Test

The process was then repeated to produce the finisher diets. Each of the test products was used in a starter and finisher diet at the same levels as the EWS diet. The diets are presented in Table 1. The

[1] Nedan Oil Mills, Hereford Street, Potgietersrus, South Africa

nutrient composition of each of the test diets was calculated from analysis of each of the test materials.

**Table 1** Composition of starter and finisher diets (g/kg)

| ***Ingredient*** | **Starter Control** | **Starter Test** | **Finisher Control** | **Finisher Test** |
|---|---|---|---|---|
| Maize | 496.3 | 430.8 | 673.0 | 607.7 |
| Maize gluten 60 | - | 80.0 | - | - |
| Soybean 48 | 394.9 | 170.0 | 247.1 | 1.8 |
| Sunflower 37 | - | - | - | 72.8 |
| Fishmeal 65 | 18.0 | 8.1 | 20.0 | 20.0 |
| Oil - sunflower | 42.9 | - | 21.2 | - |
| DL methionine | 1.3 | - | 1.9 | 1.7 |
| Limestone | 14.2 | 14.8 | 12.1 | 11.8 |
| L-lysine HCL | - | - | 2.3 | 2.6 |
| Monocalcium phosphate | 24.3 | 24.8 | 15.6 | 15.1 |
| Salt | 1.6 | 2.0 | 1.8 | 2.0 |
| Sodium bicarbonate | 4.1 | 3.8 | 1.5 | 1.1 |
| Vit+min premix | 2.5 | 2.5 | 2.5 | 2.5 |
| Coccidiostat | 0.8 | 0.8 | 0.8 | 0.8 |
| **Test Ingredient** | **-** | **263.2** | **-** | **260.0** |

| Nutrients | **Starter** | | | | | **Finisher** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Control** | **RWS** | **EWS** | **RDS** | **EDS** | **Control** | **RWS** | **EWS** | **RDS** | **EDS** |
| $AME_n$ (MJ/kg) | 12.56 | 11.63 | 12.56 | 11.74 | 12.9 | 12.80 | 11.88 | 12.80 | 11.99 | 13.13 |
| Crude protein | 238.90 | 266.70 | 269.30 | 267.70 | 267.30 | 190.30 | 192.10 | 194.70 | 195.10 | 195.60 |
| Crude fibre | 29.70 | 33.80 | 32.80 | 31.64 | 31.41 | 25.80 | 40.55 | 39.60 | 38.65 | 38.30 |
| Ether extract | 70.00 | 71.20 | 71.70 | 75.91 | 74.60 | 53.60 | 75.00 | 75.55 | 79.66 | 78.36 |
| Lysine, (avail.) | 12.00 | 9.70 | 12.00 | 10.08 | 11.90 | 10.47 | 8.20 | 10.47 | 8.57 | 10.37 |
| Methionine, (avail.) | 4.70 | 3.80 | 4.20 | 3.79 | 4.08 | 4.81 | 4.30 | 4.76 | 4.36 | 4.64 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tryptophan, (avail.) | 2.44 | 2.00 | 2.50 | 2.18 | 2.53 | 1.78 | 1.30 | 1.85 | 1.73 | 1.97 |
| Arginine, (avail.) | 15.27 | 13.70 | 15.60 | 13.16 | 14.81 | 11.22 | 9.60 | 11.39 | 8.99 | 10.63 |
| Calcium | 11.00 | 11.00 | 11.00 | 11.06 | 11.06 | 8.50 | 8.50 | 8.50 | 8.55 | 8.55 |
| Available phosphorous | 6.00 | 6.00 | 6.00 | 6.03 | 6.03 | 4.20 | 4.20 | 4.20 | 4.23 | 4.23 |

Each of the blends was fed to three replicate groups of 80 "Ross 308" broilers. The birds were randomly allocated to cages within a completely closed, controlled environment house. They were fed *ad lib*. The starter diet was fed from week 1 to week 3 and the finisher diet from week 3 to week 6. The stocking density was 21 birds/$m^2$. The mass and feed intake of the birds were measured at the same time each week. Mortalities were recorded daily.

The performance data was statistically analysed according to the "growth curve model" as described by Kshirsagar & Smith (1995) and first introduced by Potthoff & Roy (1964). Third-degree polynomial regression lines were fitted to the data across levels of inclusion. The regressions were then statistically compared for differences between products using the "growth curve model". A "repeated measures analysis of variance" was also carried out according to the method described by Ferguson (1987). This analysis was used within treatments to determine whether performance of birds fed different levels of the test products differed from the birds fed the control diet.

**Results and Discussion**

The composition of the four test products is shown in Table 2. The dehulled products (RDS and EDS) are slightly lower in crude fibre. They are also slightly higher in crude protein and ether extract.

The raw products (RWS and RDS) have substantially lower $AME_n$ values than the extruded products. This is in great part due to the anti-nutritional factors, which reduce the digestibility of the raw soya. The $AME_n$ values of the extruded products (EWS and EDS) are higher, not only due to the destruction of anti-nutritional factors but also due to the fact that the shear forces involved during processing have rendered their oil fractions more available as well as denaturing the highly folded protein structure. The $AME_n$ value of the RDS (10.72 MJ/kg) is higher than RWS (10.32 MJ/kg) and that of EDS (15.09 MJ/kg) is higher than that of EWS (13.75 MJ/kg). This is due to the

**Table 2** Composition of different soya products (10% moisture basis)

| | Raw Whole Soya (RWS) | | Extruded Whole Soya (EWS) | | Raw Dehulled Soya (RDS) | | Extruded Dehulled Soya (EDS) | |
|---|---|---|---|---|---|---|---|---|
| | | Avail. % | | Avail. % | | Avail. % | | Avail. % |
| **Dry matter, %** | 90.0 | | 90.0 | | 90.0 | | 90.0 | |
| **$AME_n$ MJ/kg** | 10.32 | | 13.75 | | 10.72 | | 15.09 | |
| **Crude Protein, %** | 34.50 | | 34.52 | | 34.98 | | 34.96 | |
| **Ether extract, %** | 18.32 | | 19.06 | | 20.12 | | 19.57 | |
| **Fibre, %** | 7.77 | | 7.25 | | 6.58 | | 6.11 | |
| **Methionine, %** | 0.33 | 46.1 | 0.29 | 88.0 | 0.34 | 49.6 | 0.32 | 86.3 |
| **Lysine, %** | 2.34 | 53.7 | 2.19 | 96.6 | 2.38 | 58.8 | 2.26 | 92.6 |
| **Tryptophan, %** | 0.57 | 44.3 | 0.52 | 85.9 | 0.64 | 62.5 | 0.66 | 86.5 |
| **Threonine, %** | 1.10 | 38.6 | 1.20 | 91.3 | 1.14 | 31.3 | 1.19 | 92.1 |
| **Aspartic acid, %** | 4.80 | 44.7 | 4.46 | 95.9 | 4.78 | 46.0 | 4.67 | 96.6 |
| **Glycine, %** | 2.37 | 26.9 | 2.32 | 61.4 | 2.41 | 26.8 | 2.36 | 62.7 |
| **Isoleucine, %** | 1.68 | 34.3 | 1.64 | 90.8 | 1.75 | 38.9 | 1.65 | 86.8 |
| **Leucine, %** | 2.76 | 29.7 | 2.66 | 85.9 | 2.82 | 31.9 | 2.72 | 82.8 |
| **Phenylalanine, %** | 1.74 | 41.6 | 1.68 | 90.7 | 1.80 | 41.8 | 1.70 | 88.6 |
| **Arginine, %** | 2.65 | 71.3 | 2.46 | 98.6 | 2.67 | 62.5 | 2.53 | 90.8 |
| **Glutamic acid, %** | 8.49 | 54.1 | 7.51 | 93.5 | 7.90 | 53.5 | 8.36 | 94.2 |
| **Histidine, %** | 0.91 | 58.5 | 0.86 | 91.8 | 0.93 | 54.5 | 0.88 | 91.4 |
| **Tyrosine, %** | 1.04 | 43.9 | 0.96 | 90.7 | 1.11 | 40.6 | 0.98 | 90.9 |
| **Valine, %** | 1.89 | 35.8 | 1.83 | 86.8 | 1.94 | 38.8 | 1.85 | 83.9 |

removal of the fibrous pericarp during dehulling, which leaves a more nutrient dense product. Cell rupture during extrusion renders nutrients highly available (Mustakas *et al.,* 1964). This is clearly evident when comparing the apparent amino acid availabilities of the raw vs extruded products. Both RWS and RDS have lower apparent amino acid availability than either EWS or EDS.

Table 3 shows the protein solubility in 0.2% potassium hydroxide and the urease activity of the four test products. McNaughton *et al.,* (1981) reported that a urease activity of $<0.15\ \Delta$ pH indicated adequate processing to have reduced trypsin inhibitor to acceptable levels. Wright (1981) suggested that a pH change of between 0.05 and 0.20 could be used as an indictor of properly processed soya. Araba & Dale, (1990) and McNaughton *et al.,* (1981) provided evidence however, that urease activity alone is not an adequate measure of over-processing.

**Table 3** KOH solubility and urease activity of RWS, EWS, RDS, and EDS

| | Raw Whole Soya | Raw Dehulled Soya | Extruded Whole Soya | Extruded Dehulled Soya |
|---|---|---|---|---|
| **KOH solubility** | 77.12 | 78.87 | 68.16 | 58.95 |
| **Urease activity (Δ pH)** | 2.17 | 2.24 | 0.19 | 0.03 |

Protein solubility in a 0.2% KOH solution is also used to determine the effectiveness of processing. It has the advantage that protein solubility values do not reach zero even with severe over-processing (Araba & Dale, 1990). This fact allows the protein solubility assay to distinguish between levels of over-processing. Araba & Dale (1990) suggested that solubility of lower than 70% indicated impaired nutrient value and that below 65% certainly indicated over-processing. It seems that a KOH solubility of between 70 and 80% indicates optimum processing. Table 3 shows that RWS and RDS have high urease activity and protein solubility. These products have not been heat-treated and anti-nutritional factors have not been inactivated. According to the standards described it seems that the EWS has been adequately processed to ensure optimum performance. It is possible that the EDS has been slightly over-processed. Lysine (Warnick & Anderson, 1968) and arginine (Renner *et al.,* 1953) are the most likely essential amino acids that can be damaged due to over-processing. Apparent amino acid availabilities reported in Table 2 support this. Both lysine (92.6% vs 96.6%) and arginine (90.8% vs 98.6%) availability is slightly impaired in EDS as compared to EWS.

Figures 1 to 6 show the results of the broiler growth trial. The figures shown represent the results at six weeks. The trends evident at three weeks were very similar to those shown at six weeks. Analysis of the fitted regressions using the "growth curve model" shows that in terms of mass, feed intake and FCR broilers fed the extruded products performed better ($P<0.05$) than those fed the raw products. There was no difference ($P>0.05$), at three weeks, in mass, intake or FCR of broilers fed EWS and EDS. Repeated measures analysis of variance of data at week three show that for the extruded products (EWS and EDS), there is no difference ($P>0.05$) in mass, intake or FCR of broilers fed any level of the test diet and those fed the control diet. This implies that these products can be included in the starter diet at levels up to 263.2 g/kg without any effect on broiler performance.

The performance of broilers fed the raw products (RWS and RDS) was clearly affected. Broilers fed RWS had a lower ($P<0.05$) mass than the control group from the 40 % inclusion of the test diet. Broilers fed RWS had lower ($P<0.05$) intake from 60 % inclusion of the test diet and FCR was negatively affected ($P<0.05$) from the 20 % level of the test diet. For those fed RDS mass was lower than the control ($P<0.05$) from the 40 % inclusion of the test diet, intake was lower ($P<0.05$) from 80 % inclusion of the test diet and FCR was negatively affected ($P<0.05$) from the 40 % level of the test diet. It is clear that the anti-nutritional factors in the raw soya products have a negative impact on broiler performance.

From Figure 1 and Figure 2 it is evident that anti-nutritional factors are still active in both RWS and RDS. Performance of broilers fed RWS and RDS did not differ in any of the parameters measured. Broilers fed EWS were heavier at week six than those fed RWS ($P<0.01$). Extrusion destroys anti-nutritional factors (Herkelman *et al.*, 1993) and renders nutrients more available due to cell rupture (Mustakas *et al.*, 1964). The urease activity and protein solubility values of RWS (Table 3) provide further evidence that anti-nutritional factors are still active.

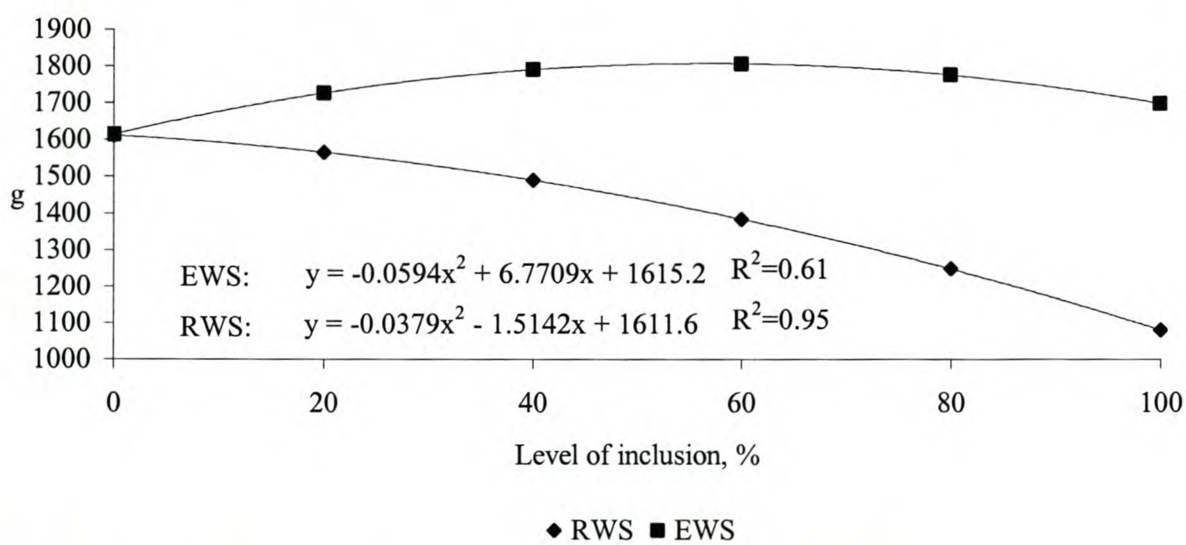


**Figure 1** Mass at week six of broilers fed increasing levels of RWS and EWS

Repeated measures analysis of variance showed that for RWS, broiler mass was negatively affected from the 40 % level of inclusion of the test diet. For broilers fed EWS, six-week mass was higher ($P<0.05$) than those fed the control diet from the 20 % level of inclusion. It was calculated that the mass of broilers fed EWS reached a maximum at 57% inclusion of the test diet over the six-week feeding period.

Figure 2 illustrates the difference in mass at week six of broilers fed RDS and EDS. Those fed EDS were heavier than those fed RDS ($P<0.01$). Again this is due to the presence of anti-nutritional factors in the RDS, as supported by the urease activity and protein solubility values (Table 3). Maximum mass for broilers fed EDS was achieved at an inclusion of 54 % of the test diet. From the 40 % level of inclusion broilers fed RDS were lighter ($P<0.05$) than those fed the control diet. Broilers fed EDS were heavier ($P<0.05$) than those fed the control diet from the 20 % inclusion level.

Broilers fed RDS and RWS did not differ in mass at week six ($P>0.05$). Both performed equally poorly. Broilers fed EDS and EWS did not differ in mass at week six ($P>0.05$).

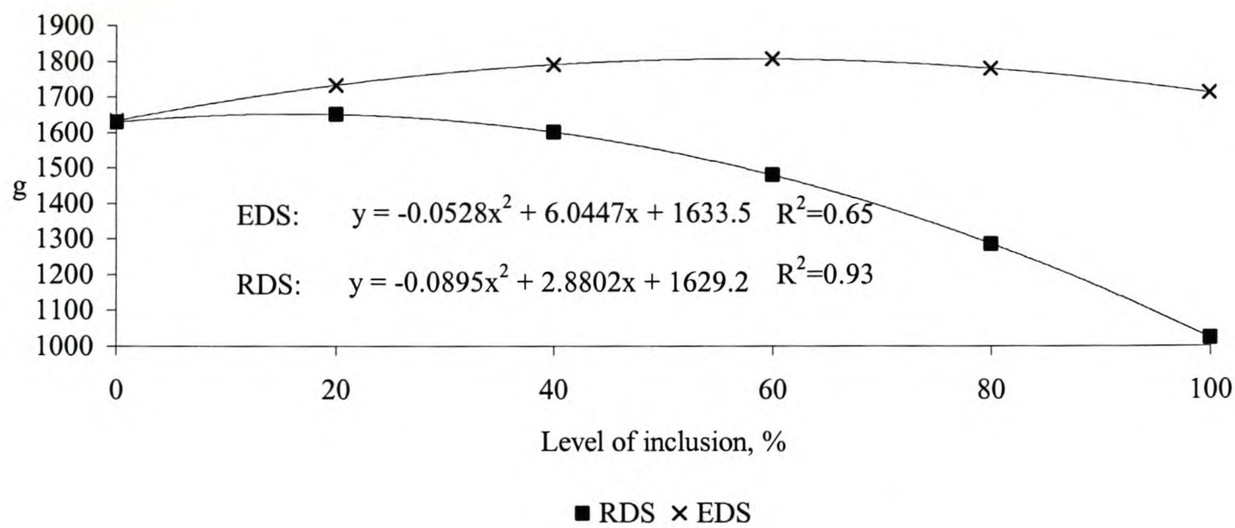


**Figure 2** Mass at week six of broilers fed increasing levels of RDS and EDS

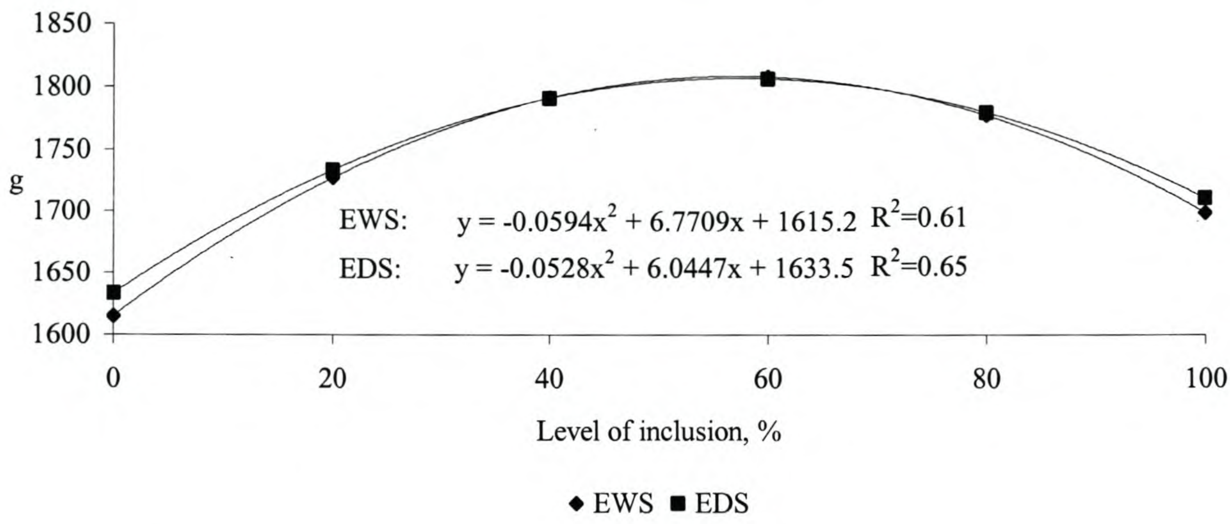


**Figure 3** Mass at week six of broilers fed increasing levels of EWS and EDS

A comparison of mass at week six of broilers fed EWS and EDS (Figure 3) reveals no differences ($P>0.05$). This would indicate that the process of dehulling has no benefits additional to those achieved by extrusion. The protein solubility of EDS suggests that it may be slightly over-processed. The failure of EDS to perform better than EWS may be in part due to this over-processing.

Feed intake of broilers at week six was also influenced by extrusion (Figure 4). The trends shown for feed intake are very similar to those described for mass. Inclusion of raw soya depressed intake. Intake was higher for broilers fed EWS than for RWS ($P<0.01$). The low digestibility of RWS inhibits feed intake. Intake shows a tendency to drop as level of RWS increases in the diet. Analysis showed that this was significant ($P<0.05$) from the 60 % level of inclusion of the test diet. This is due to the decreasing diet digestibility as more RWS is added. Repeated measures analysis of variance showed that intake of broilers was not affected ($P>0.05$) by increasing levels of EWS in the diet. Maximum intake of birds fed EWS was calculated to occur at an inclusion of 51.84% of the test diet.

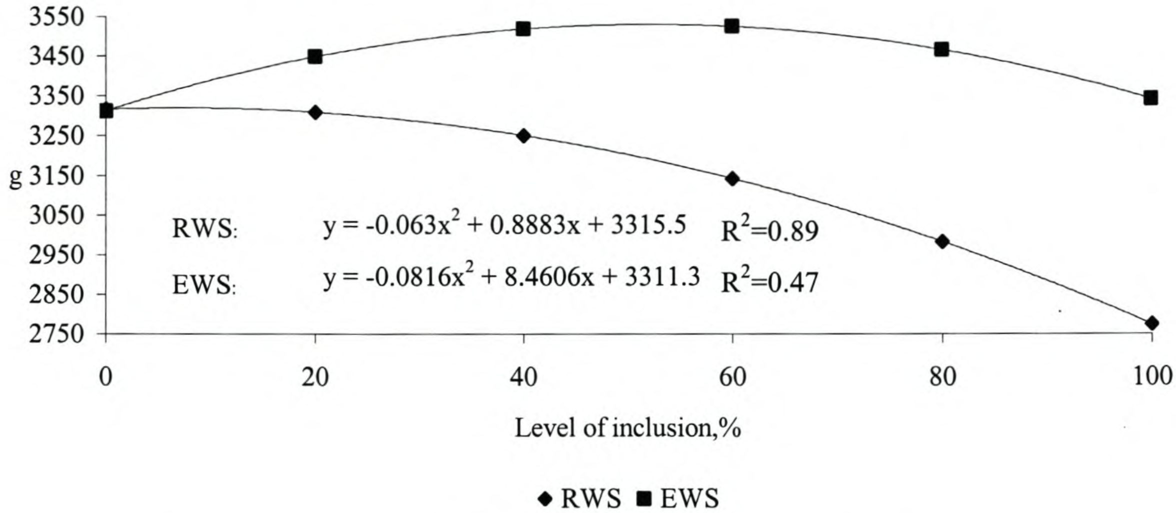


**Figure 4** Feed intake at week six of broilers fed increasing levels of RWS and EWS

Broilers fed EDS consumed more feed than those fed RDS ($P<0.01$) (Figure 5). Broilers fed RDS consumed less ($P<0.05$) than broilers fed the control diet from the 60 % level of inclusion. This is due once again to low digestibility of raw soya.

Dehulling appeared to have no effect on feed intake. There was no difference in intake between broilers fed EWS and EDS ($P>0.05$). Increasing levels of EDS in the diet had no effect ($P>0.05$) on feed intake. Maximum intake of EDS was calculated to occur when the test diet was included at 51.21%. It may have been expected that dehulling of the soya fraction of the diet would result in a reduction in bulk density and an increase in digestibility. These factors would normally lead to an increase in feed intake. This was not found to be the case.

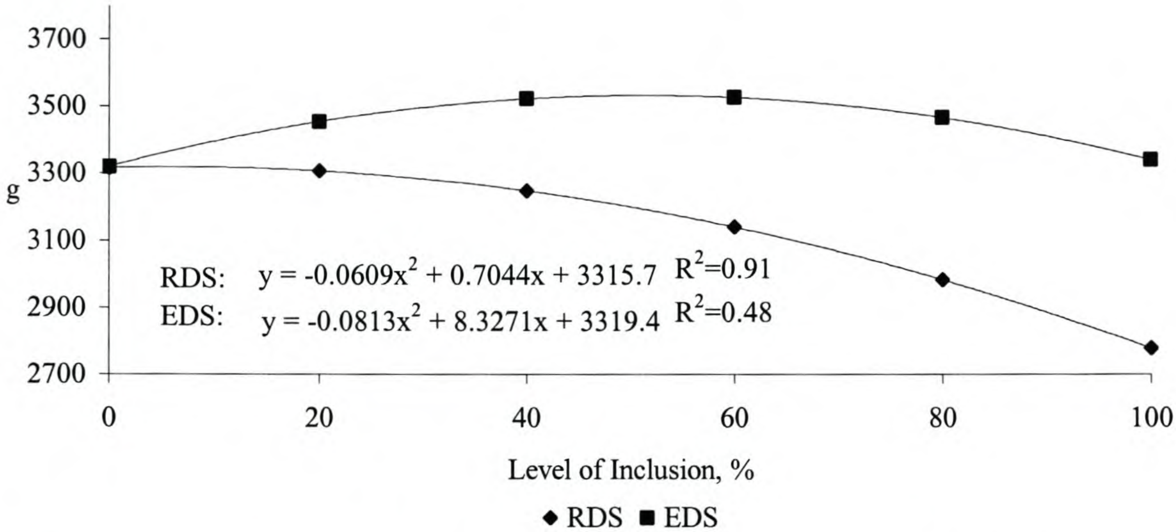


**Figure 5** Feed intake at week six of broilers fed increasing levels of RDS and EDS

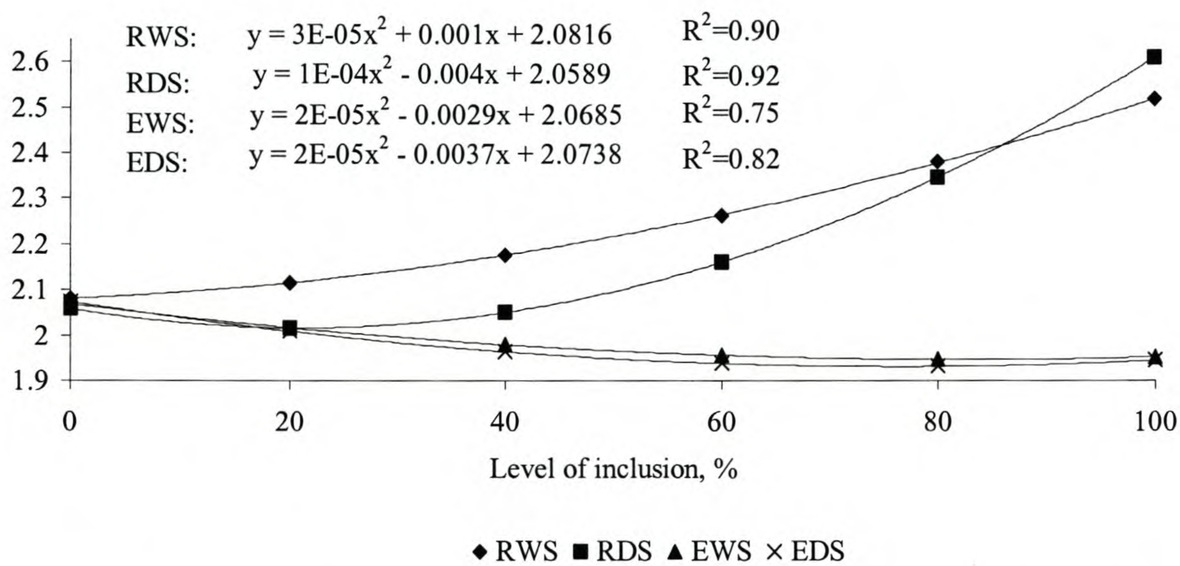


**Figure 6** Feed Conversion Ratio at week six of broilers fed increasing levels of RWS, RDS, EWS and EDS

In terms of feed conversion ratio (FCR) (Figure 6) EWS performed better than RWS ($P<0.01$). EDS also performed better than RDS ($P<0.01$). Extrusion of both whole and dehulled soya led to improved FCR as compared to the raw products. As inclusion of RWS and RDS increased FCR tended to get worse. Analysis showed that the increase in FCR for both RWS and RDS became significant ($P<0.05$) at the 40 % level of inclusion. Dehulling did not improve FCR of the extruded products. FCR of EWS and EDS did not differ ($P>0.05$) although EDS appeared to have a lower

FCR than EWS at all levels of inclusion of the test diets. From the 40 % level of inclusion broilers fed EWS had better FCR's ($P<0.05$) than those fed the control diet. Optimum FCR for birds fed EWS was calculated to occur at an inclusion of 72.50% of the test diet. Broilers fed EDS had better FCR's ($P<0.05$) than those fed the control diet from the 20 % level of inclusion. For EDS optimum FCR was achieved at 92.50% inclusion of the test diet.

**Conclusions**

From the results presented it is clear that effective processing of full-fat soya is essential to ensure optimum broiler performance. This agrees with results reported by other authors (Herkelman *et al.,* 1993; Perilla *et al.,* 1997). Increasing inclusion of RWS and RDS led to lower weight gain, lower feed intake and poorer FCR. Extrusion effectively destroys anti-nutritional factors present in raw soya. It also renders nutrients more available due to cell rupture. This is particularly true of the oil component of the bean. Higher oil availability equates to higher $AME_n$ values. Extruded products had higher $AME_n$ values than raw products. Apparent amino acid availability of raw products was also substantially lower than that of the extruded products. Birds fed RWS and RDS performed poorly in terms of mass, feed intake and FCR. This is due to anti-nutritional factors causing low $AME_n$ values and low apparent amino acid availability. Performance of broilers fed increasing levels of RWS and RDS did not differ in any of the parameters measured. Both EWS and EDS performed better than RWS and RDS in all measured parameters.

Performance of birds fed EWS and EDS did not differ in terms of mass, feed intake or FCR. EDS is a more nutrient dense product due to the removal of the hull, which consists mainly of fibre. The $AME_n$ value of EDS (15.09 MJ/kg) is higher than that of EWS (13.75 MJ/kg). It would be expected that EDS would perform better than EWS. The results presented show that this is not the case. This can be attributed to the possible over-processing of EDS. Protein solubility of EDS was 58.95%, which may be indicative of over-processing. The apparent availability of lysine was lower for EDS (92.6%) than EWS (96.6%) as was apparent availability of arginine (90.8% vs 98.6%). This may be the reason why there is no difference in mass, feed intake or FCR of the two products.

It can be concluded from the results presented that heat treatment is essential to ensure optimum quality of full-fat soya. The process of dehulling, while it does produce a more nutrient dense product, had no further positive effect on broiler performance in the trials conducted due, possibly, to slight over-cooking of EDS. It is clear that the inclusion of raw soya in starter or finisher diets for broilers will have a negative influence on broiler performance. From the results obtained here it seems that extruded whole or extruded dehulled soya can be included up to 263.2 g/kg in the starter and 260.0 g/kg in the finisher while still supporting maximum broiler performance.

**Acknowledgements**

Acknowledgement is given to the Protein Research Trust for their assistance in financing this research.

# 5. The effect of heat-treatment and dehulling of full-fat sunflower (*Helianthus annuus)* on $AME_n$, amino acid availability and broiler performance.

## Introduction

Sunflower (*Helianthus* annuus) is an oilseed found in many parts of the world (Zhang & Parsons, 1994; San Juan & Villamide, 2000). There exists a general lack of information regarding the nutritional value of sunflower seed and its products (Elzubeir & Ibrahim, 1991; Arija *et al.,* 1998; Ortiz *et al.,* 1998; Villamide & San Juan, 1998). The available literature is somewhat contradictory and no consensus has been reached as to optimum and maximum inclusion levels of full-fat sunflower seed for poultry. The use of sunflower seed has been limited in the past due to its relatively high fibre content and a relatively low lysine content as compared to other oilseeds, especially soya beans (San Juan & Villamide, 2000).

The oil in sunflower seed has been recognized as a good fat source for poultry, especially layers, due to its high linolenic acid content (San Juan & Villamide, 2000). Sunflower seed has a high oil content (up to 50%), reasonable crude protein content (up to 23%) and relatively low price, which has lead to an interest in using it as an ingredient in broiler feeds (Ortiz *et al.,* 1998; San Juan & Villamide, 2000). Rodriguez *et al.* (1998) suggested an $AME_n$ value for full-fat sunflower of 18.71 MJ/kg dry matter. This may be of particular significance in the warm climate of South Africa where high-density diets are required. Feeding full-fat sunflower may provide a cheap, convenient method of adding additional energy to broiler diets, while avoiding technical difficulties and quality problems of animal fat addition (Rodriguez *et al.,* 1998). In terms of amino acid content it has been reported that the levels of glutamic acid, arginine and aspartic acid are high, while methionine and cystine levels are low (Ortiz *et al.,* 1998). Daghir *et al.* (1980) stated that lysine is the first limiting amino acid in sunflower seed followed by threonine.

Exposure of full-fat sunflower seeds to high temperature and pressure may cause the rupture of cell walls and thus make the oil more available, improving energy content (Plavnik & Sklan, 1995). If sunflower seed is overprocessed the availability of some amino acids may be reduced, especially lysine (Zhang and Parsons, 1994). This is important because the lysine level is inherently low in sunflower seed. Dehulling removes the fibrous pericarp of the seed and leaves a more nutrient dense, less bulky product.

The aim of these experiments was to determine the $AME_n$ values and amino acid digestibility of whole and dehulled raw full-fat sunflower, as well as whole and dehulled cooked full-fat sunflower. Experiments were then conducted to examine the effect of these products on broiler performance.

**Materials and Methods**

Full-fat sunflower seed was obtained from a local producer. Some of them were dehulled[1]. The removed hulls represented 8% of the initial mass of the sunflower. Seeds were only exposed to the first dehulling operation in a conventional oilseed crushing process. The whole and dehulled sunflower seeds were mixed in a 50:50 ratio with maize. This was done to counteract the extremely high oil content, which may have been a problem during processing. Some of the whole seeds and some of the dehulled seeds were then passed through an expander without steam pre-conditioning. The barrel temperature was 120 $^0$C. Attempts at extruding the sunflower products were unsuccessful due, most likely, to the extremely high oil content of the products. After these processing treatments four test products remained: raw whole sunflower (RWSF), raw dehulled sunflower (RDSF), expanded whole sunflower (EWSF) and expanded dehulled sunflower (EDSF).

Proximate composition of each of the various products was determined (AOAC, 1995). The apparent metabolizable energy values corrected to zero-nitrogen balance (AMEn) were determined according to the European reference method described by Bourdillon *et al.,* (1990) and were calculated as described by Hill & Anderson (1958). Apparent amino acid availability was determined using the same samples as collected for the energy trial. Amino acid analyses were done using High Performance Liquid Chromatography (HPLC) techniques in a Beckman 6300 amino acid analyser.

**Table 1** Composition of starter and finisher diets (g/kg)

| Ingredient | Starter Control | Starter Test | Finisher Control | Finisher Test |
|---|---|---|---|---|
| Oil - sunflower | 42.3 | 1.2 | 44.0 | - |
| Maize gluten 60 | 50.0 | 50.0 | 50.0 | 50.0 |
| Maize | 524.9 | 521.3 | 624.1 | 541.6 |

[1] Unifoods, 511 Commissioner Street, Boksburg, South Africa

| | | | | |
|---|---|---|---|---|
| Soybean 48 | 195.4 | 155.7 | 141.7 | 161.0 |
| Sunflower 37 | 100.0 | 50.0 | 80.0 | - |
| Fish meal 65 | 50.0 | 74.6 | 20.0 | 20.0 |
| L-lysine HCL | 2.1 | 1.9 | 4.3 | 3.8 |
| DL methionine | 0.8 | 0.5 | 1.1 | 0.8 |
| Limestone | 12.5 | 11.3 | 12.4 | 19.4 |
| Monocalcium phosphate | 15.8 | 13.0 | 15.3 | 14.6 |
| Sodium bicarbonate | 1.5 | 1.1 | 2.6 | 2.5 |
| Salt | 2.0 | 1.8 | 2.0 | 2.2 |
| Vit+min premix | 2.5 | 2.5 | 2.5 | 2.5 |
| Coccidiostat | 0.8 | 0.8 | 0.8 | 0.8 |
| *Test ingredient* | - | **115.0** | - | **181.5** |

| Nutrients | **Starter** | | | | | **Finisher** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Control** | **RWSF** | **EWSF** | **RDSF** | **EDSF** | **Control** | **RWSF** | **EWSF** | **RDSF** | **EDSF** |
| $AME_n$ (MJ/kg) | 12.80 | 12.80 | 12.82 | 13.13 | 13.20 | 13.20 | 13.20 | 13.23 | 13.72 | 13.83 |
| Crude protein | 240.01 | 242.95 | 239.97 | 240.31 | 240.39 | 199.03 | 208.65 | 198.96 | 199.50 | 199.63 |
| Crude fibre | 39.02 | 44.87 | 39.15 | 38.36 | 38.21 | 34.72 | 46.32 | 34.93 | 33.69 | 33.45 |
| Ether extract | 87.47 | 87.23 | 87.58 | 88.19 | 88.14 | 93.32 | 93.43 | 93.49 | 94.45 | 94.38 |
| Lysine, (avail.) | 11.60 | 11.60 | 11.58 | 11.60 | 11.59 | 10.47 | 10.47 | 10.44 | 10.48 | 10.45 |
| Methionine, (avail.) | 5.09 | 5.09 | 5.09 | 5.10 | 5.10 | 4.56 | 4.44 | 4.43 | 4.58 | 4.58 |
| Tryptophan, (avail.) | 2.20 | 2.21 | 2.20 | 2.21 | 2.22 | 1.70 | 1.87 | 1.86 | 1.88 | 1.88 |
| Arginine, (avail.) | 13.80 | 13.79 | 13.77 | 13.84 | 13.80 | 10.80 | 10.79 | 10.76 | 10.86 | 10.80 |
| Calcium | 10.00 | 10.00 | 10.00 | 10.02 | 10.02 | 8.50 | 8.50 | 8.50 | 8.54 | 8.54 |
| Available phosphorous | 5.00 | 5.00 | 5.00 | 5.02 | 5.02 | 4.20 | 4.20 | 4.20 | 4.24 | 4.24 |

A control starter diet and a test starter diet containing high levels of raw whole sunflower (RWSF) were formulated. These two diets were formulated to contain equal energy and available lysine levels. The two diets were then blended at the following levels:

100% Control: 0% Test

80% Control: 20% Test

60% Control: 40% Test

40% Control: 60% Test

20% Control: 80% Test

0% Control: 100% Test

The process was then repeated to produce the finisher diets. Each of the test products was used in a starter and finisher diet at the same levels as the RWSF diet. The diets are presented in Table 1.

Each of the blends was fed to three groups of 80 "Ross 308" broilers. The birds were randomly allocated to cages within a completely closed, controlled environment house. They were fed *ad lib.* The starter was fed from week 1 to week 3 and the finisher from week 3 to week 6. The stocking density was 21 birds/$m^2$. The mass and feed intake of the birds were measured at the same time each week. Mortalities were recorded daily.

The performance data was statistically analysed according to the "growth curve model" as described by Kshirsagar & Smith (1995) and first introduced by Potthoff & Roy (1964). Third-degree polynomial regression lines were fitted to the data across levels of inclusion. The regressions were then statistically compared for differences between products using the "growth curve model". A "repeated measures analysis of variance" was also carried out according to the method described by Ferguson (1987). This analysis was used within treatments to determine whether performance of birds fed different levels of the test products differed from the birds fed the control diet.

**Results and Discussion**

The composition of the four test products is shown in Table 2. Comparisons can be drawn between the dehulled and whole products, and also between the expanded and raw products.

It is clear that the removal of the hulls leaves a more nutrient dense product. RDSF is higher than RWSF in $AME_n$, crude protein and ether extract. Amino acid levels are also higher in the dehulled products than the whole products. RDSF has lower fibre levels than RWSF due to the fact that the hulls consist almost entirely of fibre.

**Table 2** Composition of different sunflower products (10% moisture basis)

| | **Raw Whole Sunflower (RWSF)** | | **Expanded Whole Sunflower (EWSF)** | | **Raw Dehulled Sunflower (RDSF)** | | **Expanded Dehulled Sunflower (EDSF)** | |
|---|---|---|---|---|---|---|---|---|
| | | Avail. % | | Avail. % | | Avail. % | | Avail. % |
| **Dry matter, %** | 90.0 | | 90.0 | | 90.0 | | 90.0 | |
| **$AME_n$ MJ/kg** | 16.03 | | 16.22 | | 18.87 | | 19.49 | |
| **Crude Protein, %** | 17.74 | | 17.35 | | 20.31 | | 21.07 | |
| **Ether extract, %** | 42.19 | | 43.13 | | 48.43 | | 48.04 | |
| **Fibre, %** | 20.18 | | 21.35 | | 14.48 | | 13.16 | |
| **Methionine, %** | 0.12 | 86.6 | 0.11 | 85.2 | 0.21 | 96.1 | 0.23 | 92.1 |
| **Lysine, %** | 0.74 | 76.8 | 0.66 | 60.0 | 0.82 | 72.7 | 0.72 | 60.8 |
| **Tryptophan, %** | 0.21 | 87.0 | 0.18 | 60.4 | 0.29 | 79.3 | 0.29 | 90.5 |
| **Threonine, %** | 0.66 | 79.6 | 0.60 | 62.9 | 0.78 | 79.4 | 0.76 | 79.8 |
| **Aspartic acid, %** | 1.49 | 85.2 | 1.36 | 72.2 | 1.77 | 86.8 | 1.63 | 85.4 |
| **Glycine, %** | 0.90 | 64.1 | 0.82 | 46.0 | 1.06 | 57.2 | 0.95 | 51.7 |
| **Isoleucine, %** | 0.65 | 86.6 | 0.60 | 76.8 | 0.79 | 87.8 | 0.82 | 88.3 |
| **Leucine, %** | 0.96 | 81.7 | 0.76 | 68.9 | 1.16 | 80.8 | 1.27 | 82.5 |
| **Phenylalanine, %** | 0.70 | 88.4 | 0.61 | 73.5 | 0.85 | 87.8 | 0.81 | 89.9 |
| **Arginine, %** | 1.17 | 95.6 | 1.00 | 87.0 | 1.50 | 96.0 | 1.21 | 94.0 |
| **Glutamic acid, %** | 3.20 | 91.3 | 2.90 | 84.2 | 4.17 | 92.6 | 3.73 | 91.2 |
| **Histidine, %** | 0.38 | 87.2 | 0.32 | 73.6 | 0.45 | 85.0 | 0.42 | 86.4 |
| **Tyrosine, %** | 0.28 | 85.9 | 0.20 | 70.2 | 0.38 | 85.2 | 0.37 | 90.9 |
| **Valine, %** | 0.73 | 81.6 | 0.67 | 68.2 | 0.87 | 83.2 | 0.80 | 80.6 |

The same situation is seen when comparing EDSF and EWSF. EWSF has a slightly higher energy value than RWSF (16.22 MJ/kg vs. 16.03 MJ/kg). EDSF also has a slightly higher energy value than RDSF (19.49 MJ/kg vs. 18.87 MJ/kg). These relatively small differences may be due to cell rupture during the expansion process. The forces involved during expansion may be severe enough to cause this rupture and render the oil component of the seed more available. This, of course, would yield a higher $AME_n$ value.

It is evident that the lysine level in full-fat sunflower is relatively low. This may limit its inclusion in diets for fast-growing broiler chickens. Methionine levels are also low, while glutamic acid levels are high.

Table 2 also shows the apparent amino acid availabilities of the four products. The apparent amino acid availabilities of EWSF appear to be lower than RWSF, RDSF and EDSF. This could be due to over-processing. The high fibre content of the whole seeds may cause greater friction and slower passage through the expander. This will generate higher temperatures. If processing conditions are too severe, proteins can be damaged and as a result, amino acids are less available to the birds. Although no specific analyses were carried out to determine the efficiency of processing, it does seem that expanding may have compromised the availability of amino acids in EWSF.

Figures 1 to 3 show the results of the broiler growth trial. The figures shown represent the results at six weeks. The tendencies evident at three weeks were very similar to those at six weeks. Analysis of the three-week results using the "growth curve model" revealed no differences ($P>0.05$) between broilers fed any of the test products for mass, feed intake or FCR. The repeated measures analysis of variance at week three showed that for each test product, there was no difference ($P>0.05$) in mass, feed intake or FCR between broilers fed any level of inclusion and those fed the control diet. This implies that feeding 115.0 g/kg of any of these sunflower products in the starter diet will not have any influence on broiler performance.

Figure 1 shows the mass at week six of broilers fed increasing levels of each of the four test products. Statistically there was no difference ($P>0.05$) in the mass of the birds fed any of the four products. It may have been expected that broilers fed the dehulled products (RDSF and EDSF) would have performed better that those fed the whole products (RWSF and EWSF). This was not found to be the case. Broilers may have been able to compensate for slightly less nutrient dense diets by increasing their feed intake.

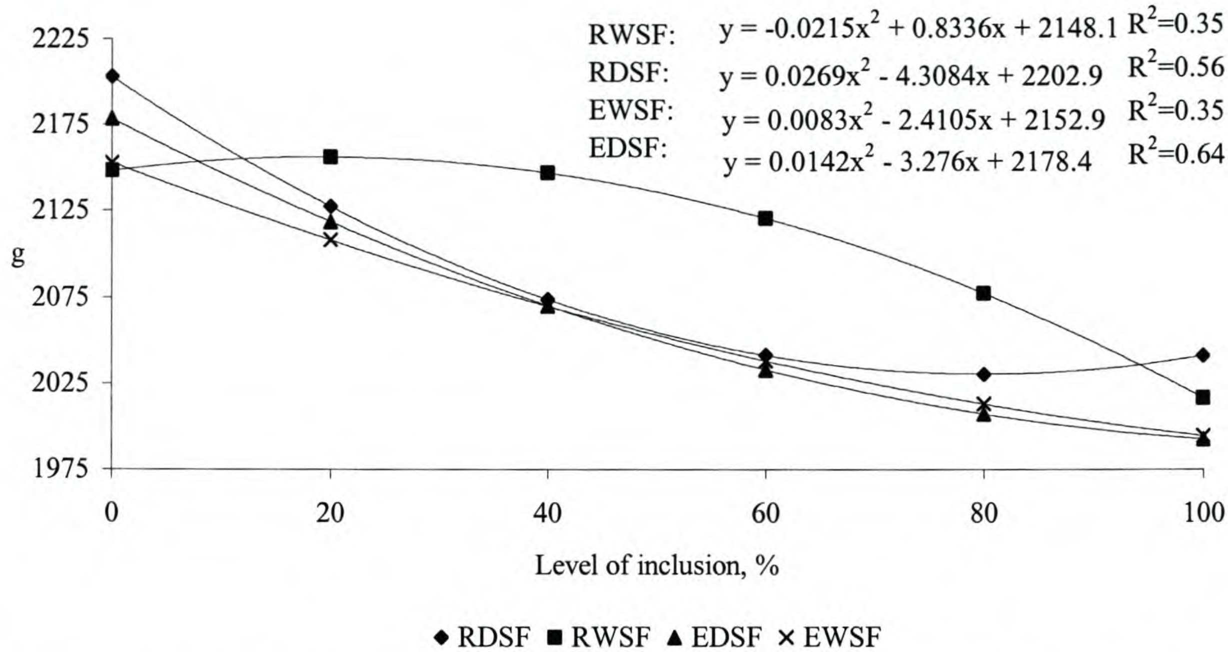


**Figure 1** Mass at week six of broilers fed increasing levels of RDSF, RWSF, EDSF and EWSF

The mass of broilers fed RWSF peaked at an inclusion of 19.38% of the test diet. None of the other regression lines were of such a form that a peak could be identified. The process of expansion also did not have any effect on mass at week six. This is not surprising, as the nutrient composition of the full-fat sunflower products was not greatly affected by expansion (Table 2). The improvement in $AME_n$ of the expanded products may have been too small to have any effect on performance once the products were included as only a small percentage of the complete diet. It is evident from Figure 2 that broilers were able to compensate for lower energy levels by increasing their intake accordingly.

It seems that for each of the products there is a tendency for mass at week six to be reduced as inclusion of the test diets increases. The repeated measures analysis of variance shows however, that within a treatment, increasing levels of inclusion of the test products had no influence ($P>0.05$) on broiler mass at week six. Inclusion of any of the sunflower products tested up to 115.0 g/kg in the starter and 181.5 g/kg in the finisher diet had no influence on broiler mass at week six.

Figure 2 shows the feed intake at week six of the broilers fed increasing levels of each of the four full-fat sunflower products. Again there were no differences ($P>0.05$) in feed intake at week six of broilers fed any of the diets. Although there are no statistical differences it appears that the birds controlled their intake according to the energy level of their various diets. Highest intakes were observed in broilers fed RWSF, which also has the lowest energy level. Next highest intake was of EWSF, which has the next lowest energy level. The same trend was continued as intake of RDSF was next highest and intake of EDSF was lowest. It is clear that the birds were able to compensate for slightly lower energy levels by increasing their intake. Intake of RWSF peaked at 43.73% inclusion of the test diet, while intake of EWSF peaked at 23.87% inclusion of the test diet.

Repeated measures analysis of variance of the feed intake data at week six showed that there were no differences (P>0.05) between intake at any level of inclusion of the test diets and the intake of broilers fed the control diet. This indicates that inclusion of any of the test products up to 115.0 g/kg in the starter and 181.5 g/kg in the finisher diet had no influence on feed intake.

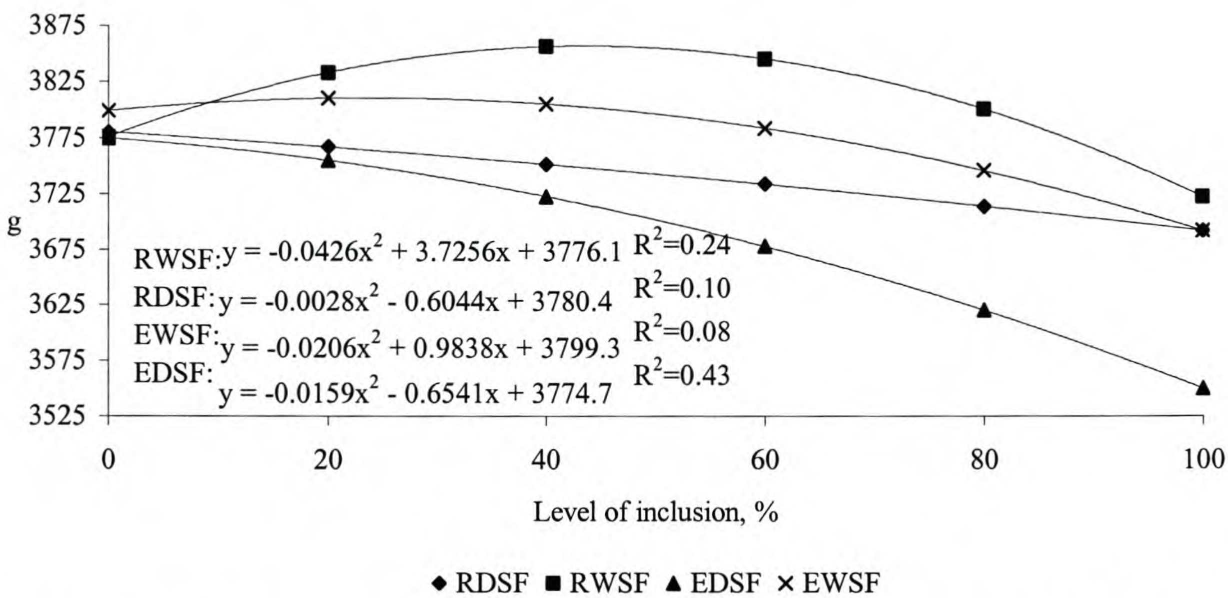


**Figure 2** Feed intake at week six of broilers fed increasing levels of RWSF, RDSF, EWSF and EDSF

Figure 3 shows the feed conversion ratio (FCR) of broilers fed increasing levels of the four full-fat sunflower products. Statistically there were no differences (P>0.05) in FCR between birds fed any of the diets. Broilers fed the dehulled products (RDSF and EDSF) appeared to perform slightly better than those fed the whole products (RWSF and EWSF). Although none of the differences were found to be significant, it is worth noting that this is exactly what would be expected considering the nutrient composition of the various products (Table 2). The fact that EWSF performed worst in terms of FCR is most likely due to the fact that it has lower apparent amino acid availabilities for all amino acids as compared to each of the other products. This may be due to over-processing of EWSF.

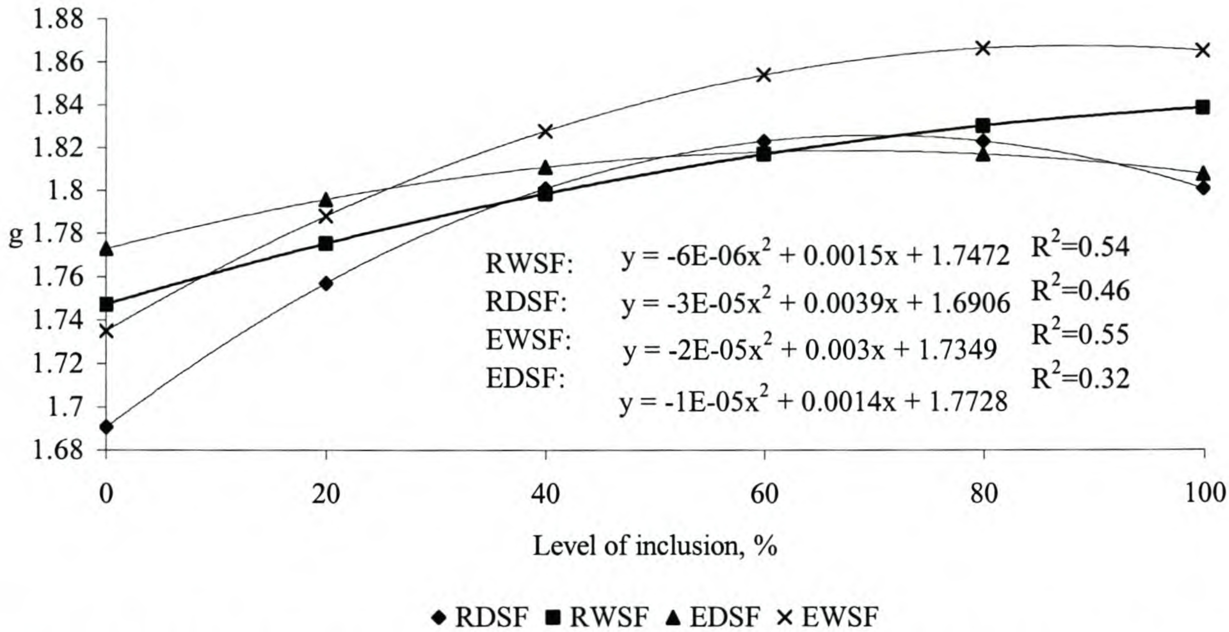


**Figure 3** FCR at week six of broilers fed increasing levels of RWSF, RDSF, EWSF and EDSF

There appears to be a tendency for FCR of broilers fed the four full-fat sunflower products to increase as inclusion increases. Repeated measures analysis of variance showed that for RDSF and EDSF there was no difference (P>0.05) in FCR of broilers fed any level of the test products as compared to those fed the control diet. Inclusion of RDSF and EDSF at levels of 115.0 g/kg in the starter and 181.5 g/kg in the finisher diet had no influence on FCR. For RWSF and EWSF however, FCR's of broilers fed the 100 % level of the test diet were higher (P<0.05) than those of broilers fed the control diet. Broilers fed the 80 % level of the test diet for RWSF and EWSF showed no differences (P>0.05) in FCR when compared to broilers fed the control diet. This implies that optimum FCR can be maintained with inclusion of RWSF and EWSF at 115.0 g/kg in the starter and 145.2 g/kg (80 % of 181.5 g/kg) in the finisher diet.

**Conclusions**

Dehulling of full-fat sunflower yields a more nutrient dense product. Crude protein, ether extract and amino acid levels are all higher in the dehulled products. Amino acid availabilities did not appear to be affected by dehulling. The $AME_n$ values of RDSF (18.87 MJ/kg) and EDSF (19.49 MJ/kg) were higher than for RWSF (16.03 MJ/kg) and EWSF (16.22 MJ/kg). This is to be expected considering that the process of dehulling removes the pericarp within which much of the fibre is trapped. The birds do not utilize the fibre. The results of the growth trial showed no differences in mass, feed intake and FCR of birds fed any of the four products. In terms of nutritional value, however, analyses showed that there are clear differences in the composition of the whole as compared to the dehulled products. Dehulled full-fat sunflower seed is a more nutrient dense product than whole full-fat sunflower seed. Results of the broiler growth trial showed that any of the products could support optimum broiler performance when included at levels up to 115.0 g/kg in the starter diet. Inclusion of 181.5 g/kg of the dehulled products (RDSF and EDSF) in the finisher diet can also support optimum broiler performance. The whole products (RWSF and EWSF) could only support optimum broiler performance at levels up to 145.2 g/kg. At levels higher than this FCR was adversely affected.

Rodriguez *et al.,* (1998) reported that inclusions of full-fat sunflower of up to 250 g/kg have no negative effect on weight gain and feed efficiency for broilers. Elzubeir & Ibrahim (1991) concluded in their study that up to 225 g/kg could be included in broiler rations with no adverse effect on performance or carcass skin colour. On the other hand Arija *et al.,* (1998) found that the inclusion of sunflower kernels adversely affected growth and fat digestibility at levels up to 50 g/kg. The process of expansion did not affect the nutrient composition of full-fat sunflower as much as dehulling did. Only very slight improvements in $AME_n$ were observed. Apparent amino acid availability in EWSF was lower than that in any of the other products. This highlights the possible dangers associated with over-processing. It is extremely important that any processing technique does not compromise protein quality. Protein solubility in a 0.2% potassium hydroxide (KOH) solution has been used to determine protein quality of full-fat soya after processing (Araba & Dale, 1990). The same test could possibly give an indication of protein quality in full-fat sunflower after processing. It is certain however, that over-processing needs to be avoided to ensure optimum nutritional value of the products. The results of the growth trial revealed no differences in mass, feed intake and FCR of birds fed expanded full-fat sunflower as opposed to raw full-fat sunflower.

Dehulling of full-fat sunflower seed made it possible to include slightly higher levels of full-fat sunflower in the finisher diet. At higher levels of inclusion the process of dehulling is beneficial to broiler performance as it allows for optimum FCR while the whole products did not support optimum FCR. The process of expansion did not have any influence on the amount of full-fat sunflower that can be added to broiler diets before performance is negatively affected. The possible benefits of expansion, which include increased cell-rupture and higher fat availability, were not observed in animal performance. It is questionable therefore, whether expansion of full-fat sunflower has any value, particularly in light of the difficulty of processing a product so high in oil, and the possible dangers of over-processing.

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## 6. General Conclusions

It is clear that there is great interest in the use of full-fat oilseeds in broiler and other poultry diets. The fact that oilseeds such as sunflower, soya and canola are being produced on an ever-increasing scale in South Africa means that the potential for use in animal feeding must be explored. Full-fat soya is already used on a relatively large scale but other oilseeds are less well utilized. Information on full-fat soya is also more readily available than other full-fat oilseeds. This study aimed to provide information on the nutritional value of full-fat soya and sunflower products processed in various ways. Heat-treatment and dehulling were the processes under investigation.

From the results obtained it is clear that effective heat-treatment (extrusion in this case) of full-fat soya is essential to destroy anti-nutritional factors and to ensure optimum broiler performance. This is in agreement with results of other authors (Herkelman *et al.,* 1993; Perilla *et al.,* 1997). Inclusion of raw soya in broiler diets led to lower weight gain, lower feed intake and poorer FCR. Extrusion effectively destroys anti-nutritional factors present in raw soya. It also renders nutrients more available due to cell rupture, particularly the oil component. Higher oil availability equates to higher $AME_n$ values. Extruded products proved to have higher $AME_n$ values than raw products. Apparent amino acid availability of raw products was also substantially lower than that of the extruded products. Broilers fed extruded products performed better than those fed raw products in all measured parameters.

Dehulling of raw soya did not improve the performance of broilers to which it was fed. There was no difference in mass, intake or FCR of broilers fed raw whole soya (RWS), or raw dehulled soya (RDS). Similarly, there was no difference in performance of broilers fed extruded whole soya (EWS), or extruded dehulled soya (EDS). EDS is a more nutrient dense product due to the removal of the hull, which consists mainly of fibre. The $AME_n$ value of EDS (15.09 MJ/kg) is higher than that of EWS (13.75 MJ/kg). The fact that EDS did not perform better than EWS can be attributed to the possible over-processing of EDS. Protein solubility of EDS was 58.95%, which may be indicative of over-processing. The apparent availability of lysine was lower for EDS (92.6%) than EWS (96.6%) as was apparent availability of arginine (90.8% vs 98.6%). Over-cooking appears to have reduced amino acid availability.

It is clear that the inclusion of any raw soya in starter or finisher diets for broilers will have a negative influence on broiler performance. From the results obtained here it seems that effectively extruded whole or dehulled soya can be included up to 263.2 g/kg in the starter and 260.0 g/kg in the finisher while still supporting maximum broiler performance. This agrees with reports by other authors. Waldroup and Cotton (1974) suggested that in all-mash diets the maximum inclusion of full-fat soya appears to be limited to 250.0 g/kg. The inclusion levels of correctly treated full-fat soya in pelleted diets appears to be limited only by normal formulation parameters and not other factors.

Heat-treatment (expansion) of full-fat sunflower caused only very slight improvements in $AME_n$ values. It did not have any positive effect on amino acid availability. Apparent amino acid availability in expanded whole sunflower (EWSF) was lower than that in any of the other products. It is extremely important that any processing technique does not compromise protein quality. It appears that protein quality of EWSF has been adversely affected in this case. Protein solubility in a 0.2% potassium hydroxide (KOH) solution has been used to determine protein quality of full-fat soya after processing (Araba & Dale, 1990). The same test could possibly give an indication of protein quality in full-fat sunflower after processing. It is certain however, that over-processing needs to be avoided to ensure optimum nutritional value of the products. The results of the growth trial revealed no differences in mass, feed intake and FCR of birds fed expanded full-fat sunflower as opposed to raw full-fat sunflower. The process of expansion did not have any influence on the amount of full-fat sunflower that can be added to broiler diets before performance is negatively affected. The possible benefits of expansion, which include increased cell-rupture and higher fat availability, were not manifested in animal performance. It is questionable therefore, whether expansion of full-fat sunflower has any value, particularly in light of the difficulty of processing a product so high in oil, and the possible dangers of over-processing.

It was found that dehulling of full-fat sunflower yields a more nutrient dense product. Crude protein, ether extract and amino acid levels are all higher in the dehulled products. The $AME_n$ values of raw dehulled sunflower (RDSF) (18.87 MJ/kg) and extruded dehulled sunflower (EDSF) (19.49 MJ/kg) were higher than for raw whole sunflower (RWSF) (16.03 MJ/kg) and EWSF (16.22 MJ/kg). It is clear that the process of dehulling has produced a more energy dense product. The birds do not utilize the fibre trapped in the pericarp. Amino acid availabilities did not appear to be affected by dehulling. The results of the growth trial showed no differences in mass, feed intake and FCR of birds fed any of the four sunflower products. In terms of nutritional value, however, analyses showed that there are clear differences in the composition of the whole as compared to the dehulled products.

Results of the broiler growth trial showed that any of the products could support optimum broiler performance when included at levels up to 115.0 g/kg in the starter diet. Inclusion of 181.5 g/kg of the dehulled products (RDSF and EDSF) in the finisher diet can also support optimum broiler performance. Dehulling of full-fat sunflower seed made it possible to include slightly higher levels of full-fat sunflower in the finisher diet. The whole products (RWSF and EWSF) could only support optimum broiler performance at levels up to 145.2 g/kg in the finisher diet. At levels higher than this FCR was adversely affected. Rodriguez *et al.* (1998) reported that inclusions of full-fat sunflower of up to 250 g/kg have no negative effect on weight gain and feed efficiency for broilers. Elzubeir & Ibrahim (1991) concluded in their study that up to 225 g/kg could be included in broiler rations with no adverse effect on performance or carcass skin colour. Daghir *et al.*, (1980) found that up to 30% was acceptable in laying hen diets. On the other hand Arija *et al.* (1998) found that the inclusion of sunflower kernels adversely affected growth and fat digestibility at levels up to 50 g/kg.

This study has found that the use of full-fat oilseeds such as soya and sunflower in broiler diets is a realistic option. Prior to use in broiler diets anti-nutritional factors in soya must be destroyed by effective heat-treatment. Dehulling appeared to have no additional benefit for broiler performance. There is no real evidence of anti-nutritional factors in sunflower with any significant effect on performance. From the results obtained it would seem that heat-treatment of full-fat sunflower is unnecessary as it had no positive effect on broiler performance. The results obtained in these trials show that dehulling of full-fat sunflower may allow for higher levels of inclusion before broiler performance is negatively influenced. Unfortunately the composition of sunflower seed, and particularly its oil content, is quite variable. The bulkiness of the full-fat seed also needs to be kept in mind. Another important factor to take note of when utilizing full-fat sunflower is the inherently low lysine content. Once such factors have been taken into account one can consider the possible benefits of using these products that are high in both energy and protein. Considering the desperate need for alternate protein sources in South Africa, products such as full-fat sunflower may find extremely valuable application in the broiler industry. Full-fat soya is already an extremely valuable raw material used in the poultry industry.

This study focused on sunflower and soya but it should be remembered that lupines, canola and other full-fat seeds also have a contribution to make to poultry nutrition. It seems highly likely that this contribution will become ever greater in the times ahead.

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