DETERMINANTS OF SUNFLOWER SEED QUALITY FOR PROCESSING

by

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ABSTRACT

The low and varying protein content and high crude fibre content of sunflower oil cake produced from sunflower seed create problems for the South African oil expelling industry. This prompted research into factors that may affect the seed quality for processing purposes. The seed quality characteristics are the seed oil and protein contents and the hullability. Analysis of the kernel-rich fraction produced after dehulling gives an indication of the potential oil yield, oil cake yield and oil cake protein and crude fibre contents and thus the processed value. Seed hullability and potential losses of oil and protein were affected by seed moisture content and seed size. Drying seed resulted in increased hullability, and sifting it into size classes proved to be a mechanism for differentiating in terms of oil cake quality. The effects of cultivar, environment and selected environmental variables on seed yield and processing quality were investigated by means of field trials. Seed yield and quality were more affected by environment than by cultivar. Seed size and hullability, and as a result also the protein content of the potential oil cake, were affected by plant population, with lower populations associated with better quality. Increased nitrogen application improved seed yield and seed protein content but lowered seed oil content, with no effect on hullability. Boron fertilisation improved seed yield in one trial but suppressed yield in a second trial. Hullability declined in one trial due to boron fertilisation. A mild water stress during the grain-filling stage reduced seed yield by 23% and hullability by 14%. Optimising the seed oil:seed protein ration through breeding may be the most advisable option for improving seed quality for processing. Due to the need for a seed grading system based on seed quality, regression analyses between easily measurable seed characteristics and seed quality parameters were done. The relatively low mean deviation between measured and predicted values indicate that seed oil content, protein content and hullability can be estimated with reasonable accuracy. These relationships must still be validated.

Keywords: Boron, cultivar, hullability, nitrogen, oil, plant population, protein, seed quality, sunflower, water stress.

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CHAPTER 1

MOTIVATION AND LITERATURE REVIEW

MOTIVATION

Sunflower seed (*Helianthus annuus* L.) is the source of 82% of all edible oil produced in South Africa. The annual production of sunflower seed ranged between 170 000 and 1 100 000 tons from 1989/90 to 1998/99, with a mean of 547 000 tons. From this seed, approximately 219 000 tons of oil were extracted. South Africa, however, is a net importer of vegetable oil. The total oil requirement for 1995/96 was estimated to be 390 000 tons by the Oil Seeds Board. At an annual growth rate of 4% the oil requirement for 2000/01 will be approximately 474 000 tons, of which an estimated 176 000 tons will have to be imported. If locally produced sunflower oil can substitute the imported oil, 987 000 tons of sunflower seed will be needed to satisfy the total oil demand, which will require an area of 897 000 to 1 100 000 ha of sunflower to be grown annually.

Oil cake is the byproduct of sunflower oil extraction and is a source of protein for animal feed blends. Sunflower oil cake, however, is considered to be of relatively poor quality due to a high crude fibre content. The value of sunflower oil cake is equivalent to 72% of the value of soybean oil cake. The relatively poor quality of sunflower oil cake restricts the amount that can be included in feed blends for poultry and pigs. The estimated consumption of sunflower oil cake by members of the Animal Feed Manufacturers Association (AFMA) during 1999 was 273 000 tons (Griessel, 1999), produced from 650 000 tons of seed. The demand for sunflower seed is thus limited by the oil cake quality rather than the demand for oil, which is the main product of the seed.

South Africa experiences a shortage of high quality plant protein to supply in the demand of the animal feed industry. As a result 336 000 tons of oil cake (mainly soybean) was imported annually from 1992/93 to 1996/97 to supplement the local production of 254 000 tons, produced mainly from sunflower (Ebedes, 1996; Ebedes, 1997). The import requirement has since risen to 610 257 tons for 1999/2000 (Griessel, 1999). The annual cost of imports has exceeded R1000 million since 1997, which is approximately twice the amount of money local sunflower farmers receive for their sunflower seed (calculated at R1000 per ton).

The feed value of sunflower oil cake will compare well with that of soybean oil cake if it can be improved through more efficient dehulling (Bekker, 1996). According to Bredenhann (1999) the demand for sunflower oil cake would be 544 331 tons if the crude fibre content can be kept below 14% and the protein above 40%. Approximately 1.3 million tons of seed would satisfy this demand.

If the quality of the locally produced sunflower oil cake can be improved, the possibility of over-production would diminish and the supply of oil and oil cake would be more in balance with the demand. This could lead to savings on imports of oil and probably also oil cake since more sunflower oil cake could replace expensive imported protein sources. Although oil content is the only seed quality parameter sometimes taken into account in trade of sunflower seed, higher quality oil cake may affect seed prices positively for the farmer. It is thus clear that improved sunflower oil cake quality would benefit farmers, the oil and oil cake industry as well as the animal feed industry.

Smith, Hayes & Smith (1989) analysed South African produced sunflower oil cake from different suppliers and found the crude fibre content to range from 11.8 to 24.0% and the protein content from 31.5 to 50.9%, with only 18.2% of the samples with a protein content of more than 40%. They observed that sunflower oil cake can be an important source of protein, on condition that the quality improves. Shamanthaka Sastry & Subramanian (1984) managed to produce oil cake with only 8.3% crude fibre and 53.3% protein from sunflower seed. To produce sunflower oil cake in South Africa containing 14% or less crude fibre and 40% or more protein, seems possible.

According to Fourie (1999) the edible oil industry worldwide is currently under pressure due to a decline in demand and record crops. Edible oil prices have dropped during 1999 to a 23-year low, which led to very low profit margins for sunflower seed processing. Improved sunflower seed quality is a prerequisite for the South African oil industry to be globally competitive (Fourie, 1999).

The challenge to identify the main factors which affect seed hullability and other seed quality parameters, and to manipulate them in such a way as to produce better quality seed for processing, motivated this investigation.

LITERATURE REVIEW

GROWTH AND DEVELOPMENT OF THE SEED

The achene (or seed) of sunflower is borne on the capitulum or head. The head consists of an outer whorl of yellow ray flowers and from 700 to 3000 disk flowers (Seiler, 1997). Each disk flower bears one seed. Anthesis of the disk flowers commences at the periphery of the head and progresses inwards at up to four rows per day. This process takes about 10 days to complete. The seed reach physiological maturity approximately 30 days after anthesis of the first ray flowers, resulting in a shorter period of seed growth for seed at inner positions (Connor & Hall, 1997). Seed closer to the centre also have a lower rate of filling than those at the periphery (Villalobos, Sadras, Soriano & Fereres, 1994). As a result of this shorter period of growth and slower growth rate, seed size decreases from the periphery towards the centre of the head.

The seed comprise of a pericarp (or hull), a true seed coat and a kernel which is mostly embryo. The hull comprises usually between 20 and 26% of the total seed mass. Seed development can be separated into well defined phases. Hull development starts before kernel development, with a typical dry mass of 2 mg at anthesis, and stops growing 14 days later (Connor & Hall, 1997). The kernel starts to grow rapidly approximately 8 days after anthesis and has gained 33% of its final weight when hull growth ceases (Villalobos, Hall, Ritchie & Orgaz, 1996). Due to the differences in pattern and timing of hull and kernel growth, stress during grain filling can alter the mass ratio between the hull and kernel (Connor & Hall, 1997).

Deposition of oil in oil bodies in the embryo begins several days after the start of rapid embryo growth (Villalobos *et al.*, 1996). Consequently, little oil is deposited during the first third of the seed-filling period. Synthesis of oil (of which the greater part is triacylglycerols) is complex, involving metabolic transformations in the cytosol, proplastids and endoplasmic reticulum of the embryo cells (Connor & Hall, 1997). Dihydroxyacetone phosphate derived from glycolysis in the cytosol is converted to glycerol-phosphate, the source of the glycerol skeleton of triacylglycerols, in the cytosol, or it may move across the membranes of the proplastid to form acetyl CoA and malonyl CoA, the primary building blocks of the fatty acid chains (Connor & Hall, 1997). In mature seed, lipids (oil) are mostly triglycerides (97%), phospholipids (2%) and glycolipids (1%) (Connor & Sadras, 1992).

The pattern of protein deposition in seed contrasts that of oil, proceeding in concert with seed growth so that the concentration of protein in the seed dry matter remains fairly constant over time (Goffner, Cazalis, Percie du Sert, Calmès & Cavalie, 1988). Protein deposition in the seed, its subcellular localization, its control, and the partitioning of protein among the various functions such as enzymes and storage, are not fully understood and requires further investigation (Connor & Hall, 1997).

SEED HULLABILITY

Russian breeders succeeded in increasing sunflower seed oil content from approximately 30% in the 1920s to 50% in cultivars available in the mid-1960s (Fick & Miller, 1997). Approximately two thirds of this improvement was due to a decrease in hull content and the remainder to an increase in the kernel oil content (Gundaev, 1966). Roath, Snyder & Miller (1985) mentioned that selection for high seed oil content may have resulted in inadvertent selection for seed which is more difficult to dehull. Investigations of the effect of poor hullability on the quality of oil cake started during 1990 in Europe as a result of the increased world demand for oil cake (Evrard, Burghart, Carré, Lemarié, Messéan, Champolivier, Merrien & Vear, 1996).

The main reason for dehulling sunflower seed before processing is to obtain oil cake with an increased protein content and a decreased crude fibre content. Other advantages are that the efficiency of processing increases as the movement of unnecessary mass through the oil extraction system is reduced and the oil contains less wax which needs to be removed. With dehulled seed, wear of the expeller is reduced (Tranchino, Melle & Sodini, 1984; Ward, 1984; Shamanthaka Sastry, 1992; Dorrell & Vick, 1997).
Various types of dehulling equipment are available. The impact type is the most popular in the processing industry. The impact dehuller feeds seed onto the centre of a horizontally rotating impeller fitted with outward directing blades or grooves. The seed is accelerated outwards along the blades and collides with the static wall where the hull is cracked. The loose hulls are then

separated from the dehulled kernels, partially dehulled seed and some unhulled seed by passage through a system of beds containing aspirated screens, to produce the kernel-rich fraction.

Seed from different origins differ in their hullabilities (Dorrell & Vick, 1997) and it is often necessary to adjust dehullers to increase or decrease the impact velocity of the seed. It is, however, difficult to achieve an optimum balance between excessive dehulling, which leads to loss of oil rich material, and insufficient dehulling, which reduces efficiency (Dorrell & Vick, 1997). In this regard, Shamanthaka Sastry (1992) showed that increased dehuller speed also increased both the amount of dehulled seed and fine material. The fine material consists mainly of kernel particles which are removed with the hulls through aspiration. Excessive dehulling therefore leads to a loss of oil and protein. Insufficient dehulling, due to a too slow dehuller speed, leads to inefficiency. Complete separation of hulls and kernels, however, is also not desirable for the extraction of oil with a mechanical screw press as a small amount of hull enhances the extraction process (Morrison III, Akin & Robertson, 1981).

After dehulling, most of the oil is squeezed from the kernel-rich fraction whilst the remainder is extracted with a volatile organic solvent (hexane). The residue is the oil cake. The composition of the oil cake depends on the amount of hull removed, as well as the composition of the kernels.

CALCULATION OF HULLABILITY

Different methods for calculating hullability have been described. Hullability is calculated after the dehulling of a seed sample and the separation into the kernel-rich fraction, a hull-rich fraction and in some cases also fine material. Dedio & Dorrell (1989) calculated hullability as follows:

Hullability = (mass of completely dehulled kernels in the kernel-rich fraction/
mass of seed sample before dehulling) 100%

For this definition, a high percentage indicates a high hullability. In contrast, Wan, Baker, Clark & Matlock (1978) defined hullability as the sum of the mass of unhulled seed and fine material passing through a 2.4 mm screen, expressed as a percentage of the seed sample. For this definition, a smaller percentage indicates a higher hullability.

European researchers also take hull content into account when calculating hullability. Tranchino *et al.* (1984), Merrien, Dominguez, Vannozzi, Baldini, Champolivier & Carré (1992), Baldini, Vannozzi, Cecconi, Macchia, Bonari & Benvenuti (1994), Denis, Dominguez, Baldini & Vear (1994) and Baldini & Vannozzi (1996) all defined hullability as:

Hullability = (FH/HC)   100%

where FH = (mass of hulls removed during dehulling/mass of seed sample before dehulling) 100% and HC = (mass of hulls/mass of seed sample)   100% of a manually completely dehulled sample.

SEED CHARACTERISTICS RELATED TO HULLABILITY

Several seed characteristics like oil, moisture and wax content, hull content, hull thickness, seed size and seed density all affect the hullability of seed. Correlation coefficients and the mathematical relationships between the seed characteristics and hullability, however, vary considerably amongst environments and genotypes.

Seed oil content

The general finding of researchers is that higher seed oil content is associated with lower hullability of the seed (Roath *et al.*, 1985; Dedio & Dorrell, 1989; Beauguillaume & Cadeac, 1992; Merrien *et al.*, 1992; Dedio, 1993; Denis, Dominguez, Baldini & Vear, 1994; Baldini & Vannozzi, 1996; Baldini, Vannozzi, Macchia & Bonari, 1996; Denis & Vear, 1996). One of the aims of sunflower breeding programmes is to increase the seed oil content of cultivars. If the negative relationship between oil content and hullability stays valid in future and the oil content increases above the current level, hullability will decline, resulting in declining oil cake quality. Baldini & Vannozzi (1996), however, found that this negative relationship is not universal since the cultivar Euroflor, in contrast with other cultivars, has a high oil content and a high hullability. According to Baldini *et al.* (1994), no relationship exists between the oil content of the kernel and the hullability of the seed. The absence of any relationship was confirmed by Denis, Dominguez & Vear (1994).

Hull content and hull thickness

Most findings indicate that hullability increases with increased hull content of the seed (Baldini *et* *al.*, 1994; Denis *et al.*, 1994; Baldini & Vannozzi, 1996). Roath *et al.* (1985), however, found no clear relationship, whilst Dedio (1982) found a negative relationship.

According to Beauguillaume & Cadeac (1992) hull thickness has no relationship with hullability, since the cultivar Euroflor has both a thin hull and high hullability. The microscopic investigation of Beauguillaume & Cadeac (1992) has shown that the frequency of parenchyme layers in the sclerenchym of the hull is related to hullability. According to Denis, Dominguez, Baldini & Vear (1994) and Denis & Vear (1996) the negative relationship between the seed oil content and hullability is probably explained by the positive relationship between the hull content and hullability, as well as the negative relationship between the hull content and oil content of seed found in other studies. Morrison III *et al.* (1981) concluded that the adherence of the hull to the kernel, the width of the hull and the thickness of the lignified layer of the hull could all affect the dehulling process.

Seed size

Larger seed usually dehull more easily than smaller seed (Roath *et al.*, 1985; Merrien *et al.*, 1992; Shamanthaka Sastry, 1992). Dedio & Dorrell (1989) found seed size to be the most important determinant of hullability. Due to these differences in hullability, Popova, Serdyuk & Kopejkovskij (1968) suggested that seed should be separated into fractions of uniform size and moisture content. Denis & Vear (1996), however, showed that the relationship between the thousand seed weight (which indicates the seed size) and hullability varies amongst localities. Large seed from one area might have a lower hullability than small seed from another.

Popova *et al.* (1968) found that smaller seed have thinner hulls with more flexibility than larger seed. Increased moisture content increased the flexibility, and an increased force was then needed to break the hull. The hull was easier to crack when the force was applied to the longest axis of symmetry of the seed. The thin hull of cultivars with a high oil content contains more wax than the hull of low oil content cultivars (Morrison III *et al.*, 1981). These thin hulls are also tightly held to the kernels, being connected with more fibres.

Seed density and hectolitre mass

Tranchino *et al.* (1984) found that seed of cultivars with a low density are easier to dehull due to a larger air space between the kernel and the hull, compared to seed of cultivars with a higher density. The hectolitre mass is an indirect measure of seed density and, according to Tranchino *et al.* (1984), seed with a hectolitre mass above 40 kg hl^{-1} are difficult to dehull. Negative relationships between hectolitre mass and hullability were also found by other researchers (Dedio & Dorrel, 1989; Dedio, 1993; Baldini & Vannozzi, 1996; Baldini *et al.*, 1996).

Genotype

According to Merrien *et al.* (1992) and Baldini & Vannozzi (1996) genotype is the main source of the variation in hullability. In their investigation on the hullability of different genotypes, Baldini & Vannozzi (1996) found that some genotypical traits, such as the length of the period from emergence to flowering and from flowering to physiological maturity, correlate negatively with hullability.

Seed moisture content

Several researchers found that hullability increases with decreasing seed moisture content (Beloborodov, Kuznetson & Matsuk, 1970; Wan *et al.*, 1978; Tranchino *et al.*, 1984). This increase in hullability is due to a decrease in the flexibility of the hull with decreasing moisture content (Popova *et al.*, 1968).

During dehulling, some fine material, mainly kernel particles, is also produced. This fine material is undesirable as it is lost with the hulls. Both Wan *et al.* (1978) and Tranchino *et al.* (1984) found that the amount of fine material increased and the amount of unhulled seed decreased with declining seed moisture content. Tranchino *et al.* (1984) found that the mass of unhulled seed plus fine material reached a minimum at a seed moisture content of 3%, which was considered the optimum moisture content for dehulling with a laboratory air-jet impact dehuller. However, seed moisture content at stages other than during dehulling also affects hullability. In this regard, Baldini & Vannozzi (1996) found a negative relationship between hullability and the seed moisture content at harvest.

Seed wax content

Results of studies on how wax content of the seed affects hullability are contradictory. Roath *et al.* (1985) and Dedio (1982) found negative relationships whilst Dedio (1993) found a positive relationship between the wax content and the hullability of seed. Morrison III *et al.* (1981)

suggested that the wax content of the hull determines the force needed to break the hull.

ENVIRONMENTAL FACTORS AFFECTING HULLABILITY

Seed produced in drier locations tend to have higher hullabilities than that produced in wetter localities. Denis, Dominguez, Baldini & Vear (1994) found the mean hullability of seed produced in a relatively dry region of Spain to be 83.1%, which was twice as high as the 41.5% seed hullability produced in the relatively wet conditions of France. Water stress increases hull thickness which leads to increased hullability, according to Leprince-Bernard (1990).

Merrien *et al.* (1992) found the hullability of cultivars to be relatively stable over seasons at a specific locality. They also attributed the change in hullability from one season to another and between localities to the rate of drying of the seed after physiological maturity has been reached. Seed from regularly irrigated sunflower crops had higher hullabilities than seed from less frequently irrigated treatments. To a lesser extent, nitrogen fertilisation also affects hullability. Baldini & Vannozzi (1996) found that the hullability of two cultivars increased due to high nitrogen and water supply, whilst the hullability of a third (long season) cultivar improved due to minor nitrogen and water shortages.

Hullability is also affected by an environment genotype interaction, in which the effect of the genotype was found to predominate (Baldini & Vannozzi, 1996; Denis & Vear, 1996). Evrard *et al.* (1996) also declared that the genetic effects on hullability are always larger than the environmental effects, but Denis, Dominguez & Vear (1994) found the environmental effects to predominate.

FACTORS AFFECTING SEED COMPOSITION

Nitrogen and phosphorus fertilisation

South African research indicates that the effect of fertilisation on seed composition depends on the fertility level of the soil. Blamey & Chapman (1981) found that nitrogen fertilisation of soil with a low fertility status increased seed protein content and that phosphorus fertilisation decreased seed protein, whilst the opposite effect occurred with oil content. Fertilisation with nitrogen and phosphorus, however, increased both oil and protein yield per unit land area. Loubser & Grimbeek (1985) also found that increased nitrogen fertilisation decreased seed oil content and increased protein content while phosphorus fertilisation had no effect, probably due to sufficient available phosphorus in the soil to ensure high oil content. Smith, Smith, Bender & Snyman (1978) found no response of the seed oil and protein contents to liming or nitrogen, phosphorus and potassium fertilisation, but they do not mention the fertility status of the soil.

Research outside South Africa also shows that seed composition is affected by fertilisation. Steer, Coaldrake, Pearson & Canty (1986) found that seed oil content declined and seed nitrogen content increased with increased nitrogen fertilisation. upina, Saka , Plesni ar, Pankovi , Joci & Navaluši (1992) concluded that increased nitrogen fertilisation inhibited oil synthesis whilst the synthesis of protein was stimulated.

The glasshouse trials of Steer, Hocking, Kortt & Roxburgh (1984) showed that high N supply during grain filling resulted in seed with low oil and high nitrogen contents. High nitrogen supply before and low nitrogen supply after anthesis resulted in seed with a low nitrogen content, mainly due to low nitrogen in the kernel. Esendal & Aytaç (1996) found seed oil contents of 41.6 and 39.8% for nitrogen applications of 0 and 50 kg ha^{-1} respectively, with no effect on the seed protein content. Mészáros & Simits (1992), who applied nitrogen to the leaves during different growth stages, also found a decrease in seed oil content with increasing levels of nitrogen application. Oil and grain yield per hectare increased with increased amounts of nitrogen.

Results of studies on the effect of nitrogen source on seed oil and protein contents are contradictory. Seed produced in a glasshouse with nitrate contained 50% oil while seed produced with urea as the nitrogen source contained only 41% oil (Hocking & Steer, 1983). The thousand seed mass of the plants receiving nitrate was higher than for plants which received urea. In contrast, Esendal & Aytaç (1996) found no difference in the oil and protein content of seed produced in a field trial with urea, ammonium or nitrate as sources of nitrogen.

Boron fertilisation

Boron fertilisation of sunflower on soil with a pH (KCl) < 4.9 resulted in increased yield and seed oil content of two cultivars (Blamey & Chapman, 1982). Concomitant with the increased oil content, protein content for one cultivar was significantly decreased by B fertilisation. The decrease in protein content was not as great as the increase in oil brought about by B fertilisation, presumably indicating a change in the kernel to hull ratio. In this trial, liming resulted in a slight increase in the seed protein content while the oil content was unaffected.

Plant density

Results of studies on the effect of plant density on seed composition are contradictory. Allesi, Power & Zimmerman (1977), McWilliam & English (1978), Miller & Fick (1978), Steer *et al.* (1986) and Esechie, Elias, Rodriguez & Al-Asmi (1996) all found no effect of plant density on the seed oil and protein content. Thompson & Fenton (1979) and Mathers & Stewart (1982) found a small response of seed composition to plant density (ranging from 2.5 to 15 plants m^{-2}). Stoyanova (1974), Jones (1978), Gubbels & Dedio (1986), Majid & Schneiter (1987) and Zaffaroni & Schneiter (1991) on the other hand, all found that oil content increased with increased plant density.

Robinson, Ford, Lueschen, Rabas, Smith, Warnes & Wiersma (1980) found that the mean oil content of both low and high oil content cultivars produced at six localities increased from 37.5 to 42.2% when plant density was increased from 1.7 to 6.2 plants m^{-2}. Jones (1984) also found a small increase in seed oil content by increasing the density from 2.5 to 4.5 plants m^{-2}. Seed oil contents of 40.3 and 42.1% were measured by Ortegón & Díaz (1997) for densities of 3.1 and 6.3 plants m^{-2}. This difference in oil content was mainly due to different hull contents. Villalobos *et al.* (1994) also found that oil content increased while the single seed weight decreased with increased plant density. The absolute amount of oil per seed showed a relatively small decrease compared to the decrease of the single seed weight.

A decrease in oil content due to an increase in plant density has also been observed. Esendal & Kandemir (1996) increased the plant population by decreasing the row width to change the plant density from 3.5 to 6.6 plants m^{-2} and found that the seed oil content decreased from 41.8 to 37.6%. The protein content also decreased from 17.4 to 15.3% whilst the kernel content decreased from 73.1 to 72.1%.

After analysing various trials on the response of seed composition to plant density, Connor & Hall (1997) stated that one interpretation of the results is that there is a ceiling to the absolute amount of oil that can be stored in a seed. If availability of carbon during seed filling exceeds the capacity for oil deposition, carbon is allocated to other seed components and the seed oil concentration is diluted. At typical commercial densities, the various effects of density on seed oil content may be hard to establish (Steer *et al.*, 1986).

Shade

By decreasing the radiation intensity of the sun by 45% using shade netting during the grain-filling period, Andrade & Ferreiro (1996) found that the seed oil content decreased from 48.1 to 41.9% and that the protein content increased from 17.2 to 20.6%. Seed yield, however, was affected the most as it decreased from 74 to 48 g per plant.

Water stress

Talha & Osman (1975) found that water stress during the vegetative as well as the reproductive growth periods decreased the seed oil content from 31.9 to 24.7%. It seems, however, that water stress during the vegetative period has a larger affect on the oil content than on the seed protein content. Alessi *et al.* (1977) and Hall, Chimenti, Vilella & Freier (1985) found that water stress during or after anthesis decreased the seed oil content. Muriel & Downes (1974) recorded a decrease in seed oil content from 45 to 39% due to water stress after anthesis. Hall *et al.* (1985) declared that water stress during grain filling allocates captured carbon to components other than oil.

This is supported by the results of Blanchet & Merrien (1990) who found that severe drought during the grain-filling period altered the oil-to-protein ratio from 2.9 for non-stressed seed to 1.6. Goffner *et al.* (1988), who applied abscisic acid to isolated seed lobes, found that incoming ^{14}C-sucrose was translocated from lipid to protein synthesis. This indicates that the larger amount of abscisic acid which is produced in the leaves of stressed plants is translocated to the seed and thus contributes to the decline in the seed=s oil-to-protein ratio (Connor & Sadras, 1992).

The results of Sionit, Ghorashy & Kheradnam (1973) are in contrast to the findings that water stress affects seed oil content. In an experiment conducted in pots, where the soil water potential was kept at different levels for different treatments, yield was dramatically affected but seed oil content and thousand seed weight were unaffected.

Temperature

Results differ with respect to the effect of temperature on seed composition. Canvin (1965) found that the oil-to-protein ratio dropped from 2.6 to 1.8 with an increase in temperature from 10 to 27 C, due to a large increase in protein content associated with the rise in temperature. In a field trial with different planting dates, the highest seed oil content was found for the growing season with the highest mean temperature (Remussi, Saumell & Vidal Aponte, 1972).

Goyne, Simpson, Woodruff & Churchett (1979) found a negative and a positive relationship between the temperature of the growing season and the seed oil content for an open pollinated and a hybrid cultivar respectively. Although these oil content temperature relationships were significant, Goyne *et al.* (1979) concluded that other plant and environmental factors are more important than temperature for the determination of the final seed oil content. In a controlled environment study, Harris, McWilliam & Mason (1978) found that higher temperatures during grain filling resulted in lower seed oil content. They declared that temperature is only one amongst several factors, such as water stress, which affect seed oil content under field conditions. Using planting dates as treatments, Keefer, McAllister, Uridge & Simpson (1976) concluded that seed oil and protein content are not affected by temperature during the grain filling stage.

No South African publications on the hullability of sunflower seed could be found and only a few on the seed composition of out-dated cultivars. The effect of local conditions and current cultivars on the hullability and composition of sunflower seed is currently unknown.

CHAPTER 2

IMPROVEMENT OF SEED QUALITY THROUGH DRYING AND SIFTING

I. THE EFFECT OF MOISTURE CONTENT ON HULLABILITY

INTRODUCTION

The success of dehulling varies considerably amongst different seed samples. Dorrel & Vick (1997) found that between 40 and 90% of seeds dehulled in samples from different sources. The hull-rich fraction, which is separated from the kernel-rich fraction by aspiration, contains some kernel particles adhering to the hulls and some fine material, which is mainly kernel particles. Oil and protein are lost through these particles and some hulls stay in the kernel-rich fraction due to unhulled seeds. Fine material is undesirable as it is difficult to handle and clogs equipment.

Most industrial dehullers are adjustable so as to alter the impact force on the seed as required. If the impact force is too large, an excessive amount of fine material is produced which increases losses. With a low impact force, the amount of unhulled seed increases which leads to inefficiency and low quality oil cake. Due to the undesirability of fine material and unhulled seed, the huller should be adjusted to the point where the percentage unhulled seed and fine material reaches a minimum. Hullability measurements should be made at this setting.

Different methods of calculating hullability exist. Wan *et al.* (1978) expressed hullability in terms of the percentage unhulled seed and fine material (UFM). For this definition, a smaller percentage indicates a higher hullability. Baldini *et al.* (1994) defined mechanical hull extraction (FH) from which hullability (H) is calculated as follows:

$$FH = ((\text{mass of free hulls})/(\text{mass of sample before hulling})) \times 100\%$$

$$H = (FH/HC) \times 100\%$$

where

$HC = (\text{hull mass}/\text{mass of seed sample}) \times 100\%$ of a manually dehulled sample.

For this definition, higher percentages indicate higher hullabilities.

One factor which influences the hullability of seed is the moisture content (Wan *et al.*, 1978; Tranchino *et al.*, 1984). Evrard *et al.* (1996) found that drying of the seed can increase the hullability. These investigations had several shortcomings. The seed was artificially dried or moistened, fixed huller settings were used and the hullers used were not designed for sunflower seed. According to Dorrell & Vick (1997), such hullers are often the source of problems with the dehulling of sunflower seed. The measurement and calculation of hullabaility by Wan *et al.* (1978), Tranchino *et al.* (1984) and Evrard *et al.* (1996) were done in a way that it can not be related to the method described by Baldini *et al.* (1994). Currently the measurement and calculation of hullability as described by Baldini *et al.* (1994) is accepted widely.

Sunflower seed is stored at a moisture content equal to or less than 10%. Seed used by the industry for processing can thus be expected to contain between 5.5% (the lower level of natural drying) and 10% moisture. The aim of this investigation was to determine the effect of the moisture content of two sunflower seed samples, dried naturally, on hullability, with the huller adjusted for maximum efficiency (lowest UFM).

MATERIALS AND METHODS

Seed of two cultivars produced during 1996/97 on a farm near Heilbron was used for the analysis. The first hullability analysis was done at a mean moisture content of 9.4% as measured with a Bullwark P9 seed analyser (Sinar Africa, P.O. Box 1633, Honeydew 2040). The seed was allowed to dry naturally at room temperature for 10 days. During this period the second, third and fourth hullability analyses were done at mean moisture contents of 8.3, 7.2 and 5.7% respectively.

The hectolitre mass was measured during the first hullability analysis with the Bullwark P9 seed analyser. The thousand seed weight was calculated from the mass of 300 randomly chosen seeds. The seed size distribution was determined by passing approximately 100 g of seed through two sieves, with 3.5 and 3.0 mm slot openings. The hull content was measured from three manually dehulled 2 g seed samples and expressed as a percentage. Mean seed length, width and thickness were measured with a calliper on 100 randomly selected seeds.

The seed was dehulled and separated into a hull-rich fraction, kernel-rich fraction (KRF) and fine material (<2 mm) with a Tecmachine laboratory huller and separator (Tecmachine, Rue Benoit, 42166 Andrézieux-Bouthéon, Cedex, France). Eight seed samples of 12-13 g were dehulled at speeds of 2771, 3068, 3365, 3663, 3960, 4257, 4554 and 4851 revolutions per minute, respectively. The mass of the fine material was measured. Unhulled seeds (seed of which the kernels were completely covered by the hull) were manually removed from the KRF and their mass determined. Next, the relationship between the UFM and huller speed was determined by means of a regression analysis using the equation: $y = ax^{0.5} + bx + cx^2 + d$, with y the UFM, x the huller speed and a, b, c and d constants. The huller speed at which the UFM reached a minimum was considered to be the optimum huller speed. Three seed samples of 12-13 g were dehulled at the optimum huller speed and the mass of the hull and kernel-rich fractions, and the fine material determined. Hullability was calculated as described by Baldini *et al.* (1994) and the data analysed using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA).

RESULTS AND DISCUSSION

Seed characteristics

The seed characteristics are shown in Table 1. Both samples had relatively high hectolitre masses and thousand seed masses. The size distribution also showed that a high percentage of the seed was large and that high hullability could be expected. The hull content of approximately 31% was also high as the hull content of high oil cultivars is usually below 26%. A high hull content is also associated with high hullability (Baldini & Vannozzi, 1996). Seed dimensions differed between the two samples. Sample no. 1 was relatively short and thick with the thickness about 35% of the length, compared to sample no. 2 where this relationship was about 30%.

Optimal huller speed

Figure 1 shows the relationship between the UFM and the huller speed for the highest and lowest moisture contents of samples nos.1 and 2. A strong relationship between the UFM and huller speed was found for relatively moist seed, but no relationship was evident for dry seed. The optimal huller speed for dry seed was also lower than for wetter seed. If a constant speed of 3800 rpm had been used as in other studies on hullability (Baldini & Vannozzi, 1996; Denis & Vear, 1996), the UFM value of sample nos. 2 at a high moisture content would have been 19.4% which is about twice the UFM values of 9.7% measured at the optimum huller speed. For sample no. 1 this difference was relatively small. Adjusting the huller speed for moisture content seems necessary for efficient dehulling.

Table 1 Characteristics of the sunflower seed samples

Characteristic	-------------- Sample no. --------------	
	1	2
Cultivar	SNK 75	NX 1224
Hectolitre mass (kg hl^{-1})	43.9	40.2
Thousand seed mass (g)	64.8	62.9
Size distribution (%)		
<3 mm	15	14
3-3.5 mm	29	41
>3.5 mm	56	45
Hull content (%)	31.0	31.8
Dimensions (mm)		
….Length	10.2	11.6
Width	5.8	5.3
….Thickness	3.6	.3.4

Optimal huller speed was affected by moisture content only (Table 2). The relationship between the seed moisture content and the huller speed is shown in Figure 2. Optimal huller speed increases in a nonlinear way with increased seed moisture content. The optimal speed for the laboratory huller for seed containing between 5.6 and 8.4% moisture is about 3800 rpm.

Unhulled seed and fine material

Moisture content affected the percentage of unhulled seed (Table 2). With a seed moisture content decrease from 9.5 to 5.7% the percentage of unhulled seed halved (Figure 3), indicating that a relatively high seed moisture content can lead to lower quality oil cake due to the presence of more hulls.

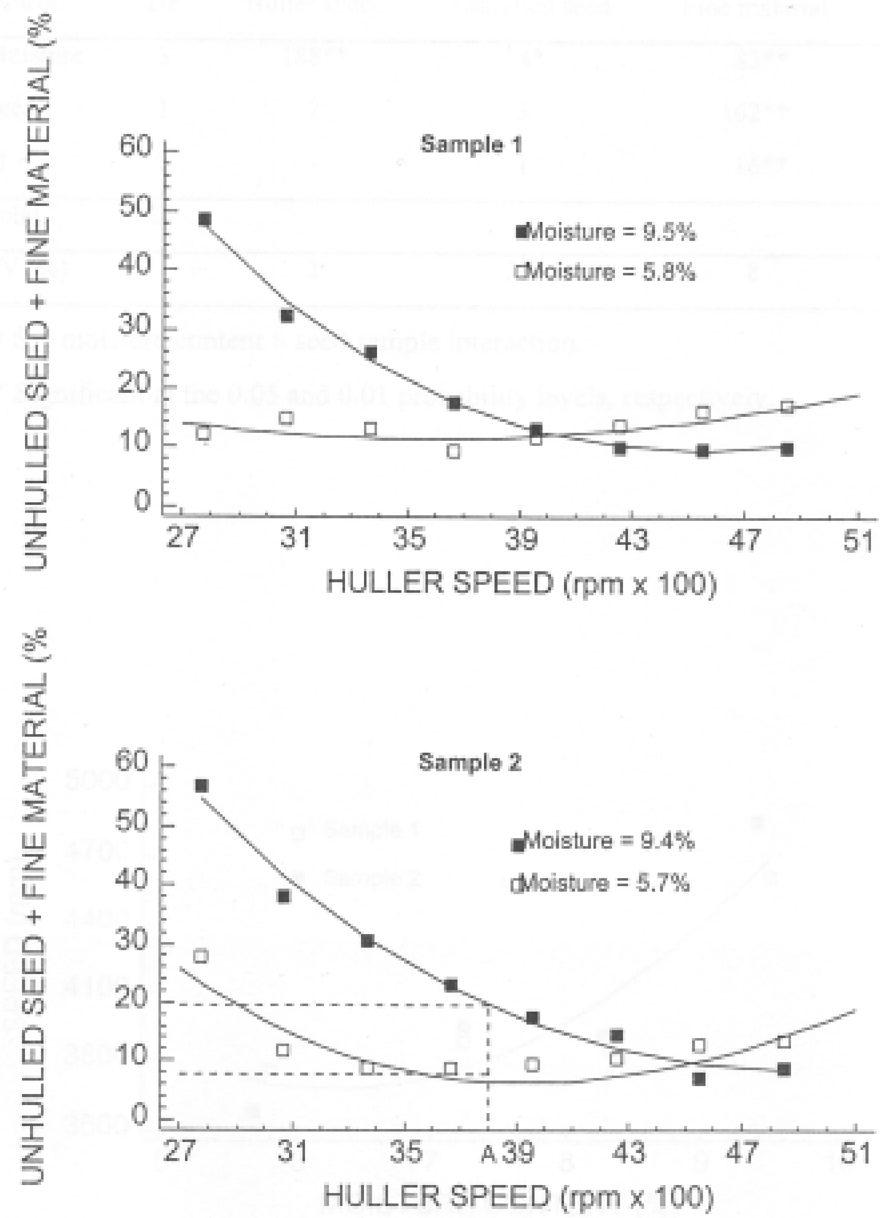


Figure 1 The relationship between the amount of unhulled seed plus fine material and huller speed for relatively wet and dry seed of two sunflower seed samples. Point A on the graph for sample 2 indicates a huller speed of 3800 rpm.

Table 2 Analyses of variance F values for optimal huller speed, percentages of unhulled seed, fine material and hullability as affected by seed sample and moisture content

Source	DF	Huller speed	Unhulled seed	Fine material	Hullability
Moisture	3	188**	4*	83**	11**
Seed	1	2	3	162**	1
M × S	3	-	1	16**	2
Total	23				
CV%		2	37	8	3

M × S = moisture content × seed sample interaction.

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

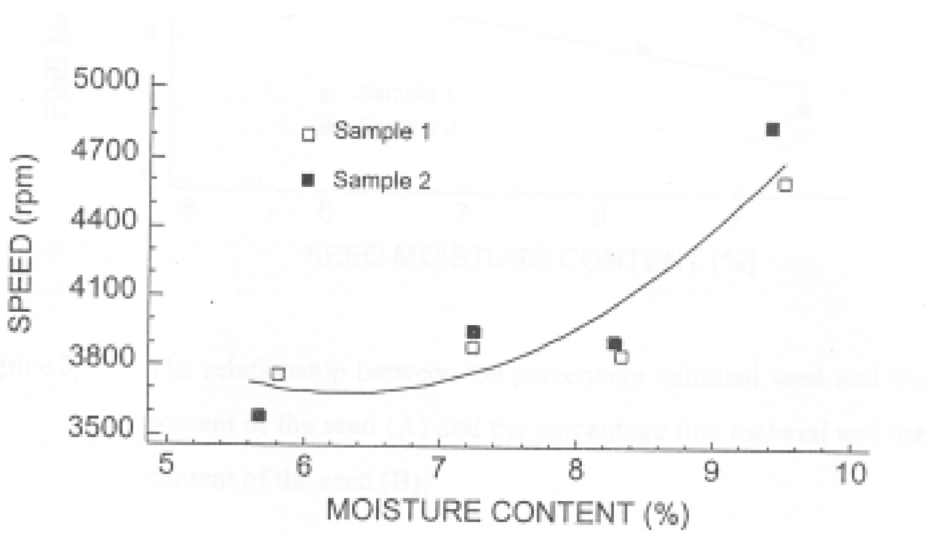


Figure 2 The relationship between the optimal huller speed and the moisture content of the seed.

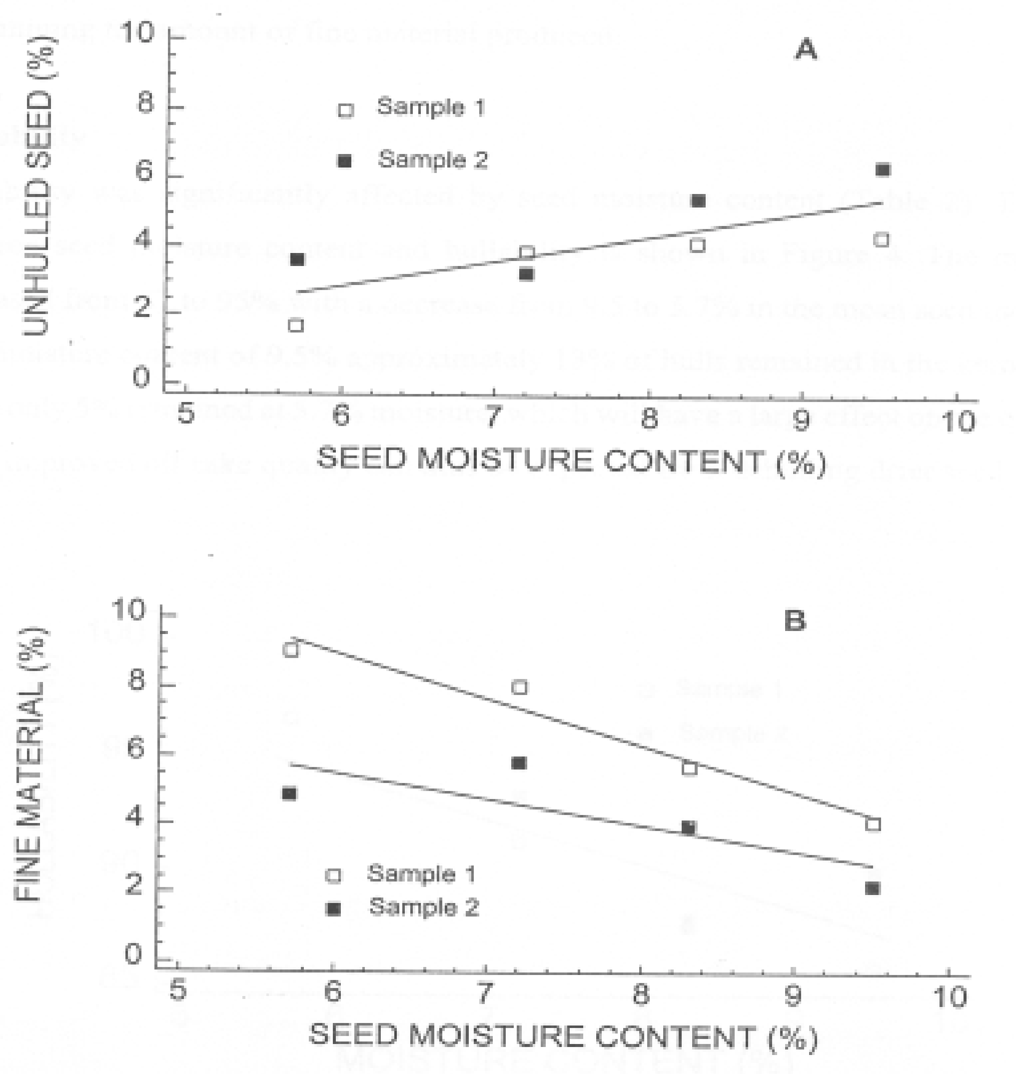


Figure 3 The relationship between the percentage unhulled seed and the moisture content of the seed (A) and the percentage fine material and the moisture content of the seed (B).

The amount of fine material was significantly affected by both sample, moisture content and an interaction between sample and moisture content (Table 2). Sample no. 1 produced 4.1% fine material at 9.5% moisture compared to 9.1% at 5.7% moisture (Figure 3). For sample no. 2 the difference was smaller: at 9.5% moisture only 2.2% fine material was produced abd at 5.7% moisture 4.9% fine material was produced. As the fine material consists mainly of kernel particles, the losses of oil and protein were close to 9 and 4.9% for sample nos. 1 and 2 respectively, at 5.8% moisture. The indication is clear that cultivar plays an important role in determining the amount of fine material produced.

Hullability

Hullability was significantly affected by seed moisture content (Table 2). The relationship between seed moisture content and hullability is shown in Figure 4. The mean hullability increased from 87 to 95% with a decrease from 9.5 to 5.7% in the mean seed moisture content. At a moisture content of 9.5% approximately 13% of hulls remained in the kernel-rich fraction while only 5% remained at 5.7% moisture, which will have a large effect on the quality of the oil cake. Improved oil cake quality can thus be expected from dehulling drier seed.

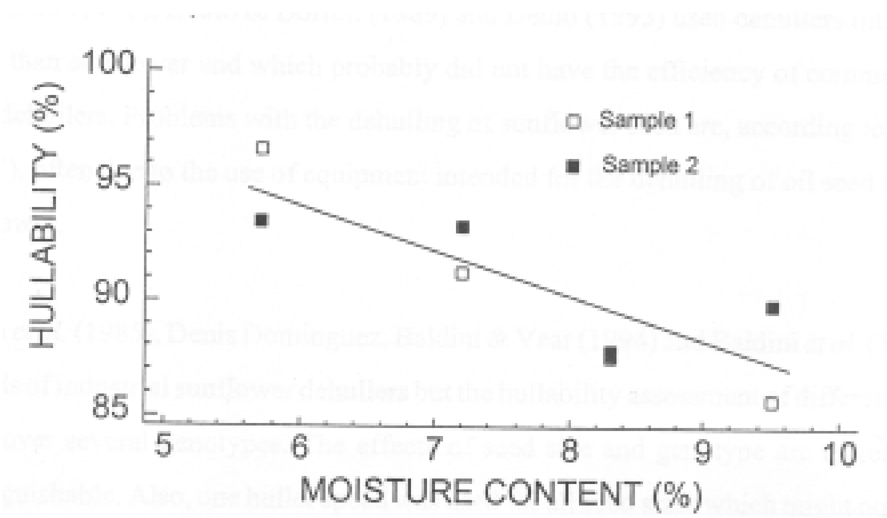


Figure 4 The relationship between hullability and the moisture content of two sunflower seed samples.

Since the production of fine material (and the corresponding losses) also increases as the seed becomes drier it is probably not appropriate to dry the seed too much. Each seed lot should be analysed for hullability and the production of fine material to determine if further drying will increase the efficiency of seed processing. However, if the fine material is separated from the hulls and channeled back to the KRF, drier seeds will benefit oil cake quality due to the inclusion of a smaller percentage of hulls.

II. SEED SIFTING TO INCREASE OIL AND PROTEIN RECOVERY

INTRODUCTION

Several investigations on seed hullability have shown that larger seed are easier to dehull than smaller seed (Wan *et al.*, 1978; Roath *et al.*, 1985; Dedio & Dorrell, 1989; Dedio, 1993; Denis, Dominguez, Baldini & Vear, 1994; Baldini & Vannozzi, 1996; Baldini *et al.*, 1996). Since commercially produced seed comprise a range of sizes which can easily be separated into different size classes, the possibility exists that the efficiency of seed processing could be increased if dehullers are adjusted for optimal dehulling for each size class.

Previous investigations on the hullability of different seed sizes have one or more shortcomings. Wan *et al.* (1978), Dedio & Dorrell (1989) and Dedio (1993) used dehullers intended for grains other than sunflower and which probably did not have the efficiency of commercial sunflower seed dehullers. Problems with the dehulling of sunflower seed are, according to Dorrell & Vick (1997), often due to the use of equipment intended for the dehulling of oil seed crops other than sunflower.

Roath *et al.* (1985), Denis Dominguez, Baldini & Vear (1994) and Baldini *et al.* (1996) used scale models of industrial sunflower dehullers but the hullability assessment of different seed sizes was done over several genotypes. The effects of seed size and genotype are therefore not clearly distinguishable. Also, one huller speed was used for all seed sizes which might not be the optimal for a particular seed size. If differences exist amongst the hullabilities of different seed sizes of a specific cultivar produced at a specific locality, which is the case for commercially produced seed, it cannot be deduced from these results.

The objective of this investigation was to determine whether sifting seed into uniform size classes can improve the hullability by dehulling each class at its optimal huller speed.

MATERIALS AND METHODS

Four samples from seed batches produced from different cultivars at different localities during the 1996/97 season, were used for this experiment (Table 3). Two sieves with slot sizes of 3.0 and 3.5 mm were used to separate part of each seed sample into small, medium and large size classes. Seed moisture content was measured with a Datatec P9 moisture analyser (Sinar Africa, P.O. Box 1633, Honeydew 2040). Mean thousand seed mass was calculated from the mass of 100 randomly selected seeds, sampled in triplicate. Hull content was determined by manually dehulling three samples of 2 g and expressing hull mass as a percentage of the total seed mass (on a fresh mass basis).

Table 3 Sunflower cultivars used in the study and their production localities

SAMPLE	CULTIVAR	LOCALITY
A	CRN 1445	Standerton
B	PAN 7392	Bloemfontein
C	SNK 37	Bloemfontein
D	SNK 48	Standerton

The seed was dehulled and separated using a Tecmachine laboratory dehuller and separator (Tecmachine, Rue Benoit, 42166 Andrézieux-Bouthéon, Cedex, France). To determine the optimal huller speed for each seed sample, between 17 and 18 g were dehulled at huller speeds of 2771, 3068, 3365, 3663, 3960, 4257, 4554 and 4851 revolutions per minute. The mass of the hull-rich, kernel-rich (KRF) and fine material (<2 mm) fractions was determined. Unhulled seed (seed of which the kernel is not visible) were manually removed from the kernel-rich fraction and their mass determined. The dehulling efficiency (unhulled seeds plus fines, UFM) was calculated as: UFM = ((mass of the unhulled seed + mass of fine fraction)/(mass of seed sample prior to dehulling)) x 100%.

The relationship between UFM and huller speed was determined through multiple regression using the equation UFM = $ax^{0.5} + bx + cx^2 + d$; with x the huller speed and a, b, c and d constants. The corresponding huller speed where UFM reached a minimum was considered to be the optimal speed. Accordingly, triplicate samples of between 12 and 13 g were dehulled and separated, and the masses of the different fractions measured. Mean hullability was calculated as described by Baldini *et al.* (1994). Samples of the seed and KRF were chemically analysed for oil and protein content by the PPECB Quality Assurance Laboratory (P.O. Box 433, Silverton 0127), in order to determine the potentially recoverable oil and potential composition of the oil cake.

The potentially recoverable oil (PRO) was calculated as:

$PRO = (O_{KRF}) \times (Y_{KRF})$ where,

O_{KRF} = the oil content of the KRF and

Y_{KRF} = (KRF mass/seed mass used for dehulling)$\times$100, expressed as g oil per 100 g seed.

Analysis of variance was done to determine the effects of seed source and seed size on the measured seed and seed fraction characteristics. Mean values of the different seed samples in the sifted and unsifted form were compared using Student's t-test with contrast, where the contrast values equalled the mass fraction values in the sifted state. The statistical analyses were executed using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA).

RESULTS AND DISCUSSION

Sifted samples

The distribution of mass amongst the seed size classes brought about by sieving differed considerably amongst seed sources and also showed a strong locality effect (Table 4). Samples A and D, both from Standerton, showed a relatively even mass distribution amongst the size classes, whilst samples B and C, produced at Bloemfontein, were mainly medium sized. If the seed size classification is done prior to processing, oil extraction plants should be able to accommodate variable mass distributions amongst the seed classes of different seed lots.

Table 4 The mass distribution, thousand seed mass, hullability, production of fine material, potentially recoverable oil (PRO) and the yield and protein content of the kernel-rich fraction (KRF) of the different seed size classes of the seed samples

Size class	Sample A	Sample B	Sample C	Sample D	Mean
			Mass distribution (%)		
Small	27	24	34	36	30
Medium	40	50	50	36	44
Large	33	26	16	28	26
			Thousand seed mass (g)		
Small	42.4c[‡]	49.5c	46.9c	46.9c	46.4c
Medium	56.9b	64.1b	61.7b	60.6b	60.8b
Large	69.8a	74.3a	74.9a	83.6a	75.7a
			Hullability (%)		
Small	46.7c	68.6b	57.7c	42.5c	53.9c
Medium	69.4b	79.3a	74.7b	54.9b	69.6b
Large	77.6a	82.0a	84.2a	71.4a	78.8a
			Fine material (%)		
Small	7.3a	12.8a	6.9a	8.4a	8.9a
Medium	5.8b	9.1b	5.8b	4.6b	6.3b
Large	4.7c	8.1c	4.6c	4.2b	5.4c
			PRO (g per 100 g seed)		
Small	44.1a	39.4b	37.9a	46.1b	41.9a
Medium	42.8b	39.8b	36.8b	48.7a	42.0a
Large	40.9c	40.6a	35.1c	46.8b	40.8b
			KRF[†] yield (g per 100 g seed)		
Small	38.3a	28.8b	39.9a	35.6a	35.7a
Medium	35.1b	29.5a	36.8b	33.6b	33.8b
Large	34.1c	28.3b	36.8b	32.2c	32.9c
			KRF[†] protein content (%)		
Small	32.2c	45.2b	39.2b	32.6b	37.3c
Medium	36.1b	45.7b	43.7a	34.5b	40.0b
Large	41.6a	48.9a	45.9a	38.8a	43.8a

[‡] Means of a parameter followed by different letters in a column differ significantly at $P \leq 0.05$.

[†]Oil-freebase.

Table 5 Analysis of variance F values for the thousand seed mass, hullability, fine material, potentially recoverable oil (PRO) and the yield and protein content of the kernel-rich fraction (KRF) as affected by the sifting of different sunflower seed samples

Source of variation	DF	Thousand seed mass	Hullability	Fine material	PRO	----------KRF† Yield	----------- Protein
Seed source	3	40**	111**	315**	1087**	1169**	369**
Seed size	2	1096**	293**	306**	29**	211**	80**
S × Z	6	13**	9**	14**	31**	27**	7*
Total	35						
CV (%)		3	4	5	1	1	2

S × Z = Seed source × seed size interaction.

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

†Oil-free base.

Sifting of the seed effectively separated it into classes with different thousand seed mass (Table 4). The thousand seed mass was affected by a seed source × seed size interaction, but the effect of seed size dominated the effects of seed source and the interaction (Table 5). The thousand seed mass of the three classes of sample A (CRN 1445 ex Standerton) were smaller than those of the other samples, while the large class of sample D (SNK 48 ex Standerton) was greater than in the other samples. Seed of sample B, which were relatively thin and elongated, had the highest thousand seed mass for the small and medium classes.

Hullability was significantly affected by seed size (Table 5), supporting the findings of Roath *et al.* (1985), Dedio & Dorrell (1989), Merrien *et al.* (1992), Shamanthaka Sastry (1992) and Denis & Vear (1996) that larger seed dehull better than smaller seed. This relationship not only exists across genotypes as shown by Roath *et al.* (1985), Denis Dominguez, Baldini & Vear (1994) and Baldini *et al.* (1996) but also within genotypes (Table 5). A relatively small interaction between seed source and seed size also affected hullability. This was due to the large and medium classes of sample B which had similar hullabilities, whereas it differed significantly for all the other samples (Table 4).

Fine material is undesirable as it consists mainly of kernel material which is removed with the hulls and contributes to the loss of oil and protein. Seed source and seed size caused very similar variation in the production of fine material, with larger seed producing less than smaller seed. The production of fine material was also affected by a small seed source × seed size interaction due to the large and medium classes of sample D which produced similar amounts of fine material (Table 4). Due to the production of less fine material, larger seed are more acceptable for processing than smaller seed. Sample B produced more fine material than any of the other samples and is, in this respect the least acceptable for processing. The relatively high production of fine material in sample B is probably due to the relatively thin and long dimensions of the seed, which appear to break more easily than thicker seed during dehulling.

The potentially recoverable oil was affected by the seed source and a seed source × seed size interaction (Table 5). The small class in samples A and C and the medium class in sample D had the highest potentially recoverable oil (Table 2). Seed source, however, was by far the largest source of variation for the potentially recoverable oil, with large differences amongst the matching size classes of the different samples. Samples D and C had the highest and lowest amounts of potentially recoverable oil respectively.

The yield and protein content of the KRF was mainly affected by seed source and to a lesser extent by seed size and an interaction between these two factors (Table 5). With the exception of sample B, smaller seed classes had greater kernel-rich fraction yields than larger classes (Table 4). Compared to the other seed samples, sample B had very low KRF yields for all size classes. The protein content of the KRF of larger seed classes was higher than that of the smaller classes due to the higher hullabilities of the larger seed. Sample B was the exception with a relatively high KRF protein content and relatively small differences amongst its seed size classes.

Sifted versus unsifted seed

Results from the analysis of variance on the effect of the seed source and sifting of the seed are shown in Table 6. Mean values of the measured seed traits of the unsifted and weighted means of the sifted seed are shown in Table 7. Seed source was the largest source of variation for hullability, although it was also affected by a seed source × sifting interaction.

Table 6 Analysis of variance F values for the hullability, fine material, potentially recoverable oil (PRO), yield and protein content of the kernel-rich fraction (KRF) as affected by seed source and the sifting of the seed

Source of variation	DF	Hullability	Fine material	PRO	-------------KRF----------	
					Yield	Protein
Seed source	3	63**	85**	638**	1180**	136**
Sifting	1	12**	37**	136**	4	1
S × F	3	33**	44**	157**	55**	5*
Total	23					
CV (%)		3	5	1	1	2

S × F = Seed source x sifting interaction.

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

Table 7 The weighted mean hullability, amount of fine material produced, potentially recoverable oil (PRO) and the yield and protein content of the kernel-rich fraction (KRF) of four sunflower seed samples as affected by seed source and sifting

	Sample				
	A	B	C	D	Mean
	Hullability (%)				
Unsifted	69.5a	73.5b	67.0a	68.5a	69.6a
Sifted	66.0a	77.4a	70.5a	55.0b	67.2b
	Fine material (g per 100 g seed)				
Unsifted	8.1a	8.2b	5.9a	8.5a	7.7a
Sifted	5.8b	9.7a	5.8a	5.9b	6.8b
	PRO (g per 100 g seed)				
Unsifted	40.6b	41.8a	36.7a	41.7b	40.2b
Sifted	42.5a	39.9b	36.9a	47.2a	41.6a
	KRF† yield (g per 100 g seed)				
Unsifted	33.2b	29.8a	39.0a	33.7a	33.9a
Sifted	35.6a	29.0b	37.9b	33.9a	34.1a
	KRF† protein (%)				
Unsifted	39.3a	45.2a	41.9a	32.9b	39.8a
Sifted	36.8b	46.4a	42.5a	34.9a	40.2a

Means of a parameter followed by different letters in a column differ significantly at $P \leq 0.05$.

†Oil-free basis.

The hullability of sample D was 13.5 percentage points lower in the unsifted than in the sifted state, whilst it was 3.9 percentage points higher for sample B. The hullabilities of samples A and C were not affected by sifting. The production of fine material was affected by seed source and a seed source × sifting interaction. For samples A and D, which were produced at the same location, the sifted seed produced respectively 28 and 31% less fine material than in the unsifted state. In contrast, sample B produced 18% more fine material in the sifted than in the unsifted state, while sample C was unaffected.

The potentially recoverable oil was affected by the seed source, sifting and a seed source × sifting interaction, with seed source the dominating source of variation. For samples A and D the potentially recoverable oil was respectively 4.7 and 13.2% higher for the sifted than the unsifted condition. In contrast once again, sample B had 4.5% less potentially recoverable oil in the sifted than in the unsifted state, while sample C was unaffected. The increase or decrease in the potentially recoverable oil is partly due to the differences in the production of fine material. The less fine material produced, the smaller the loss of kernel material and the larger the amount of potentially recoverable oil. The relatively high change in the potentially recoverable oil for sample D can, however, not be fully accounted for by the change in the production of fine material.

The oil free yield of the KRF gives an indication of the oil cake yield that can be expected. This yield was strongly affected by seed source but also by a relatively small seed source × sifting interaction. The KRF yield of sample A sifted was 7.2% higher than for the unsifted state. For samples B and C the KRF yield was approximately 3% lower in the sifted state than in the unsifted state, while the KRF yield of sample D was unaffected by sifting. The changes in KRF yield brought about by sifting are due to changes in hullability and the production of fine material.

The protein content of the KRF is a reflection of the protein content of the oil cake. The KRF protein content was affected by a relatively small seed source × sifting interaction, but the effect of seed source dominated the variation. Sifting did not alter the KRF protein content of samples B and C, whilst it was 6.4% lower in the sifted than in the unsifted form of sample A. In contrast, the KRF of sample D sifted contained 6.1% more protein than in the unsifted state.

CONCLUSION

Seed source is the main source of variation for seed quality. Sifting seed into size classes had only limited success as the potential oil yield of only two of the four samples was increased (by 9%), while for another sample it was decreased. The amount and potential protein content of the oil cake was increased in only one sample. Due to differences in hullability of the seed size classes, sifting resulted in separating the potential oil cake into three classes, with protein content differences of up to 5.5 percentage points.

Results presented in Chapter 2 have been published (Nel, Loubser & Hammes, 1999a; Nel Loubser & Hammes 1999b).

CHAPTER 3

EFFECT OF PLANT POPULATION ON SEED YIELD AND QUALITY

INTRODUCTION

Hullability is related to seed size. Merrien *et al.* (1992), Roath *et al.* (1985) and Shamanthaka Sastry (1992) all found that the hullability of larger seed is better than for smaller seed. Dedio & Dorrell (1989) even declared that seed size is the most important factor determining hullability. The production of fine material is also related to seed size, with larger seed producing less fines (Chapter 2). It can therefore be inferred that the processing of larger seeds can be expected to be more efficient than the processing of smaller seed.

Without exception, seed size has been found to decrease with increasing plant population (Blamey, Zollinger & Schneiter, 1997; Esendal & Kandemir, 1996; Gubbels & Dedio, 1986; Loubser, Grimbeek, Robertson, Bronkhorst, Serfontein & van der Sandt, 1986; Miller & Fick, 1978; Ortegón & Díaz, 1997; Robinson *et al.,* 1980; Thompson & Fenton, 1979; Vannozzi, Giannini & Benvenuti, 1985; Villalobos *et al.*, 1994).

As seed size is also related to hullability and the production of fine material, hullability and oil cake quality may be indirectly affected by the plant population. The possibility also exists that these characteristics can be positively influenced by altering the plant population. However, planting less seed than the conventionally recommended rate to enhance the processing quality, should not impact negatively on yield and chemical composition of the seed.

The objectives of this experiment were to determine the effect of plant population on the hullability, seed composition, amount of fines produced, the potentially recoverable oil, the oil cake yield and the potential oil cake protein and crude fibre content of three South African sunflower cultivars.

MATERIALS AND METHODS

The field trial was planted on the 20th November 1997 at the ARC-Grain Crops Institute, Potchefstroom. A randomised complete-block design with two replicates was used with the factors cultivars (HV 3037, PAN 7392 and SNK 37) and plant population (20 000, 35 000 and 50 000 plants ha^{-1}) in a factorial arrangement. Plots consisted of four rows of 15 m length spaced 0.9 m apart. Plots were planted and thinned shortly after emergence to the desired populations (20 000, 35 000 or 50 000 plants ha^{-1}). Amounts of 69 kg N, 8 kg P, 4 kg K and 5 kg B ha^{-1} were applied at planting. Weeds were controlled with alachlor at 4 l ha^{-1}. An irrigation of 10 mm was applied shortly after planting. At 72 days after planting an irrigation of 30 mm was applied to relieve severe water stress. For the rest of the season dryland conditions prevailed.

For yield determination, 13 m of the two centre rows in each plot were harvested and threshed. The moisture content, hectolitre mass, thousand seed mass, hull content and hullability were determined as described in the materials and methods of Chapter 2 section II. Samples of the seed, kernels and kernel rich fraction were analysed for moisture, oil and protein contents by the PPECB Quality Assurance Laboratory (P.O. Box 433, Silverton 0127). Analysis of variance was done to determine the effects of cultivar and plant population on the seed yield, hectolitre mass, thousand seed mass, hull content, hullability, fine material and the chemical composition of the seed, kernels and the kernel rich fraction. The statistical analyses were executed using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA).

RESULTS

Table 8 summarises the significance of the F-values from the analyses of variance, and Table 9 the grain yield, hectolitre mass, thousand seed mass, hull content, hullability and the amount of fines, respectively. Grain yield was affected by both cultivar and plant population. SNK 37 yielded 19% less than the other cultivars. The yield of the 20 000 population was 15% higher than the yield of the 35 000 and 50 000 plants per hectare populations.

Table 8 Significance of the F values of the analyses of variance of the measured seed traits as influenced by the plant population and cultivar

Factor	DF	Grain yield	Hectolitre mass	Thousand seed mass	Hull content	Hull-ability	Fine material
Population	2	**	**	**	**	**	**
Cultivar	2	**	**	**	**	**	**
P × C†	4	NS	*	NS	NS	**	NS
Total	17						
CV (%)		8	2	10	4	15	24

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

† Plant population × cultivar interaction.

The hectolitre mass was affected by a population × cultivar interaction. The hectolitre mass of PAN 7392 was only slightly influenced by plant population, with a mean value of 42.9 kg hl^{-1} (Table 9). For HV 3037 and SNK 37 however, the hectolitre mass increased 5.6 and 7.4% respectively, with an increase in plant population from 20 000 to 50 000 ha^{-1}. This increase in hectolitre mass with increased population is in agreement with the results of Gubbles & Dedio (1986).

Thousand seed mass was affected by both plant population and cultivar. HV 3037 had the highest thousand seed mass amongst the cultivars, and the thousand seed mass declined as the population increased, which agrees with previous findings (Blamey *et al.*, 1997; Esendal & Kandemir, 1996; Gubbels & Dedio, 1986; Loubser *et al.*,1986; Miller & Fick, 1978; Ortegón & Díaz, 1997; Robinson *et al.*, 1980; Thompson & Fenton, 1979; Vannozzi *et al.*, 1985; Villalobos *et al.*, 1994). Both plant population and cultivars affected the hull content. PAN 7392 had the highest and HV 3037 the lowest hull content. The hull content at the 20 000 population was slightly higher than at the other populations (Table 9). A population × cultivar interaction affected hullability. The hullability of HV 3037 declined almost linearly with 12 and 13 percentage points respectively from the 20 000 to the 35 000 and from the 35 000 to the 50 000 populations.

Table 9 The effect of plant population on the grain yield, hectolitre mass, thousand seed mass, hull content, hullability and production of fine material of three sunflower cultivars

Cultivar	Population (plants ha^{-1})			
	20 000	35 000	50 000	Mean
	Grain yield (kg ha^{-1})			
HV 3037	2555	2469	2752	2649a*
PAN 7392	2861	2465	2271	2533a
SNK 37	2391	1912	2025	2109b
Mean	2660a*	2282b	2349b	
	Hectolitre mass (kg)			
HV 3037	46.4	47.0	49.0	47.5a
PAN 7392	42.6	43.3	42.9	42.9c
SNK 37	45.6	46.1	49.0	46.3b
Mean	44.9b	45.5b	46.4a	
	Thousand seed mass (g)			
HV 3037	90.1	71.7	57.2	73.0a
PAN 7392	73.2	57.9	52.1	61.0b
SNK 37	74.0	51.6	48.6	58.0b
Mean	79.1a	60.4b	52.6c	
	Hull content (%)			
HV 3037	22.1	21.9	21.6	21.9c
PAN 7392	24.1	24.0	23.3	23.8a
SNK 37	23.6	22.2	22.3	22.7b
Mean	23.3a	22.7b	22.4b	
	Hullability (%)			
HV 3037	69.1	56.9	43.6	56.5b
PAN 7392	81.6	87.9	84.4	84.6a
SNK 37	71.3	50.5	52.1	58.0b
Mean	74.0a	65.1b	60.0b	
	Fine material (%)			
HV 3037	5.6	5.3	5.0	5.3c
PAN 7392	7.7	11.2	7.9	8.9a
SNK 37	6.1	7.7	7.5	7.1b
Mean	6.5b	8.1a	6.7b	

* Means of a parameter within a row or column followed by different letters are significantly different at $P \leq 0.05$.

The hullability of SNK 37 declined with almost 21 percentage points from the 20 000 population to the 35 000 population and remained unchanged for the 50 000 population. Plant population had little effect on the hullability of PAN 7392 (Table 9). The percentage fines produced was affected by both population and cultivar. PAN 7392 produced 3.6 percentage points more fines than HV 3037. Fines also increased with increased population (Table 9).

The significance levels obtained in the analyses of variance and the mean values for the moisture free oil, protein and crude fibre content of both the seed and kernels, the moisture and oil free yield, protein and crude fibre content of the kernel rich fraction and the potentially recoverable oil, are shown in Tables 10 and 11 respectively. According to the F-test the oil and protein content of seeds and kernels were not affected by plant population but were significantly affected by cultivars. The seed oil content of SNK 37 was approximately 3.5 percentage points higher than that of the other two cultivars, and the seed protein content of HV 3037 was 2.2 percentage points higher than that of the other two cultivars.

Small differences in kernel oil content were observed among cultivars. The kernel protein content of SNK 37 was 11% lower than the protein content of the other two cultivars. Seed crude fibre content was not affected by plant population but by cultivars. The crude fibre content of PAN 7392 seed was 16% higher than the mean of the other two cultivars which corresponds with its higher hull content.

The yield of the kernel rich fraction, which is a reflection of the oil cake, was affected by cultivar but not by plant population. The yield of the kernel rich fraction of HV 3037 was 16% higher than the mean yield of the other two cultivars. Plant population had no effect on the potential oil yield despite the higher production of fines from the 50 000 population and the accompanying loss of oil. The potentially recoverable oil however, was influenced by cultivars. Seed of HV 3037 and PAN 7392 did not differ in oil content but the potentially recoverable oil of HV 3037 was higher than that of PAN 7392. This might be due to the high production of fine material by PAN 7392. The potentially recoverable oil from the seed was 91, 83 and 88% for HV 3037, PAN 7392 and SNK 37 respectively.

Table 10 Significance of the F values of the analyses of variance of the moisture free oil, protein and crude fibre (CF) content of the seed and kernels, the protein and crude fibre content and yield of the kernel rich fraction and the potentially recoverable oil (PRO) as influenced by plant population and cultivar

Factor	DF	----------- Seed ----------			--------- Kernel --------			-- Kernel rich fraction --			PRO
		Oil	Protein	CF	Oil	Protein	CF	Yield	Protein	CF	
Population	2	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
Cultivar	2	**	*	**	*	**	NS	**	**	NS	**
P × C†	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total	17										
CV (%)		4	6	6	3	5	11	8	3	8	1

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

† Plant population × cultivar interaction.

DISCUSSION AND CONCLUSIONS

The higher grain yield obtained at the 20 000 population as opposed to the other populations, is in contrast with the results of Loubser *et al*. (1986) who found that 20 000 plants ha^{-1} yielded significantly less than 40 000 or 60 000 plant ha^{-1} under high potential conditions. Intense water stress that developed during the first 7 days of the grain filling stage, most likely affected the yield. From the results of Sadras & Hall (1988) it is clear that 20 000 plant ha^{-1} will have a smaller leaf area index than 35 000 or 50 000 plant ha^{-1}. A slower rate of depletion of the soil water could be expected from the 20 000 population due to a smaller transpiring area. Water stress may therefore have been less severe in the 20 000 than in the higher plant populations.

The significantly higher hull content and hullability of grain from the 20 000 population also indicates a lower degree of water stress at this population density. According to Villalobos *et al.* (1996) growth of the hull is completed within two weeks after anthesis. The stage of hull development in our experiment coincided with the stress period. Baldini & Vannozzi (1996) and Merrien *et al*. (1992) found that seed produced on plots which received irrigation frequently,

Table 11 The mean moisture free oil, protein and crude fibre (CF) content of the seed and kernels, the moisture and oil free yield, protein and crude fibre content of the kernel rich fraction and the potentially recoverable oil (PRO) of three cultivars at three plant populations

Factor	----------- Seed -----------			----------- Kernel -----------			-–— Kernel rich fraction -----			PRO
	Oil (%)	Protein (%)	CF (%)	Oil (%)	Protein (%)	CF (%)	Yield (%)	Protein (%)	CF (%)	(g per 100 g seed)
Plant density ha^{-1}										
20 000	48.0a*	21.9a	16.1a	60.3a	27.0a	2.7a	34.9a	53.8a	18.8a	42.0a
35 000	49.2a	21.1a	16.0a	61.6a	25.3b	2.6a	34.5a	51.3b	20.6a	42.6a
50 000	48.6a	21.6a	15.1a	60.8a	26.3ab	2.7a	37.0a	50.6b	20.6a	43.0a
Cultivar										
HV 3037	48.2b	22.9a	15.5b	59.3b	27.8a	2.7a	39.0a	52.8a	19.5a	43.9a
PAN 7392	46.7b	21.1b	17.3a	60.8ab	26.4a	2.7a	32.0b	53.2a	19.7a	38.8b
SNK 37	50.9a	20.4b	14.4b	62.6a	24.4b	2.7a	35.3b	49.6b	20.8a	44.8a

* Means within a column for plant population or cultivar, followed by different letters are significantly different at $P \leq 0.05$.

hulled easier than seed produced on plots less often irrigated.

Plant density did affect seed size and hullability for two of the three cultivars. The results of the two cultivars agrees with to the results of Dedio & Dorrell (1989), Merrien *et al*., (1992), Roath *et al*., (1985) and Shamanthaka Sastry (1992) that thousand seed mass had no significant relationship with hullability (r = 0.14, NS). Denis & Vear (1996), however, found that the thousand seed mass of 36 hybrids produced at one locality correlated well with hullability, while no significant relationship existed for a second locality. It was shown in Chapter 2 that certain size classes of one cultivar did not differ in hullability, while for other cultivars size classes differed significantly in hullability. It seems that the seed size: hullability relationship is not universal.

Due to the differences in hullability among cultivars and plant densities, differences in the crude fibre content of the kernel rich fractions were expected. However, the crude fibre analyses of the kernel rich fractions did not show significant differences, which can not be logically explained. A lack of accuracy of the chemical analyses might be the cause. The implication of these results is that for dryland sunflower production the plant population should rather be closer to 20 000 plants ha^{-1} than to 40 000 plants ha^{-1}. This will maximise hullability and minimise losses due to fine material, without affecting the oil and protein content of the seed.

The work reported in this chapter has been published (Nel, Loubser & Hammes, 2000a).

CHAPTER 4

EFFECT OF ENVIRONMENT AND CULTIVAR ON SEED YIELD AND QUALITY

I. YIELD, HULLABILITY AND PHYSICAL SEED CHARACTERISTICS

INTRODUCTION

European investigations revealed that seed hullability is determined by genotype as well as the pedoclimatic environment, which often also have an interactive effect. Evrard *et al.* (1996) concluded that genetic effects are always predominant over environmental effects. Baldini & Vannozzi (1996) found the variance for hullability due to cultivars much higher than due to seasons, nitrogen fertilisation, water availability or any interactions between these factors. Results reported by Denis, Dominguez, Baldini & Vear (1994) and Denis, Dominguez & Vear (1994), however, indicated that pedoclimatic environment effects dominate over the effect of both the cultivar and cultivar $\times$ environment interaction on hullability.

Unlike Europe, the climate of the South African sunflower production area is generally characterised by moisture deficits, with drought being the rule rather than the exception. This is the predominant reason for the difference in agronomic practices between the two environments. The hullability reaction of cultivars in South Africa may thus be quite different from that in Europe. Indicative of the environmental variation, is the highly variable quality of South African sunflower oil cake. In this respect, Smith *et al.* (1989) found that the protein content of commercially produced oil cake meals varied between 32 and 51%, with only 18% of the samples containing more than 40% protein.

This chapter quantifies the relative importance of environment and cultivar on some physical seed traits and hullability of sunflower seed produced in South Africa.

MATERIALS AND METHODS

Sunflower seed produced at three localities during the 1996/97 and 1997/98 seasons as part of the South African national cultivar evaluation trials was used for the analyses. These trials have randomised complete block designs with three replicates, and include most of the commercially available cultivars. The trials were located on farms in the districts of Heilbron, Potchefstroom and Viljoenskroon.

As crop rotation is a recommended practice for sunflower, production for the second season was on a location close to those of the first season, but not necessarily on the same soil form. A row width of 0.9 m was used at all localities. Tables 12 and 13 summarises the differences of the soil, agronomical practices applied and the prevailing weather at each locality for the two seasons. Due to the different soils used and agronomic practices applied between the two seasons, the seed produced at a specific locality and season were considered to represent an environment.

The cultivars selected for the analyses were CRN 1445, HYSUN 333, HV 3037, PAN 7392 and SNK 37, which were bred by different companies and assumed to be genetically diverse. Seed yield, seed moisture content, hectolitre mass, thousand seed mass, hull content and hullability were determined in triplicate as described in the materials and methods of Chapter 2, section II. Analyses of variance were executed for all measured data using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA).

RESULTS AND DISCUSSION

Grain yield

Mean grain yields for the 1996/97 and 1997/98 seasons were 2300 and 2518 kg ha^{-1} respectively, which is high considering the commercial national average of approximately 1000 kg ha^{-1}. These high yields reflect the favourable rainfall amount and distribution that prevailed during both seasons. One exception though was at Viljoenskroon in 1996/97, where a period of drought reduced the yield to 1661 kg ha^{-1}.

Table 12 Soil form* and agronomic practices at each locality

Locality	Soil form*	Planting date	Population (1000 ha^{-1})	Fertilisation N (kg ha^{-1})	P	K	Weed control
1996/97							
Heilbron	Westleigh	96-12-13	32	31	10	0	Mechanical
Potchefstroom	Hutton	96-12-06	44	45	36	0	Alachlor
Viljoenskroon	Clovelly	96-12-07	36	36	24	12	Alachlor
1997/98							
Heilbron	Arcadia	97-12-04	37	19	8	4	Alachlor
Potchefstroom	Hutton	97-12-04	37	19	8	4	Alachlor
Viljoenskroon	Clovelly	98-01-23	37	19	8	4	Alachlor

* According to the Soil Classification Work Group (1991).

Table 13 Total rainfall, total evaporation, mean minimum and maximum daily temperature for the months December to March

Environment	Environment no.	Rainfall (mm)	Evapo- (mm)	-------Temperature------- (°C)	(°C)
1996/97					
Heilbron	1	274	743	14.7	28.0
Potchefstroo	2	407	870	15.5	27.9
Viljoenskroon	3	228	853	15.2	28.4
1996/97					
Heilbron	4	388	775	14.7	28.9
Potchefstroo	5	322	751	15.4	29.3
Viljoenskroon	6	289	798	14.9	28.1

Grain yield was affected by cultivar, environment and a cultivar × environment interaction (Table 14). The effects of environment, however, dominated over cultivars and the interaction. For five of the six environments HYSUN 333 produced the highest yield, while ranking of the other cultivars changed over environments, causing the significant cultivar × environment interaction (Table 15).

Table 14 F values from the analysis of variance for grain yield and seed characteristics of five sunflower cultivars grown at six environments

Source of variation	DF	Grain yield	Hecto-litre mass	TSM[†]	Hull content	Hull-ability	Fine material
Cultivar	4	6**	25**	43**	12**	65**	23**
Environment	5	20**	51**	32**	63**	48**	65**
C × E[§]	20	2*	4**	3**	2**	9**	18**
Total	89						
CV (%)		18	4	7	4	5	9

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

[†] Thousand seed mass.

[§] Cultivar × environment interaction.

Hectolitre mass, thousand seed mass and hull content

The hectolitre mass, thousand seed mass and hull content were all affected by cultivar, environment and a cultivar × environment interaction (Table 14). For the hectolitre mass and hull content, environment had the dominant effect, while for the thousand seed mass, cultivar had the dominant effect. The significant effect of the cultivar × environment interaction on these seed traits is seen in Table 15 where the relative ranking of the cultivars changed from environment to environment.

Table 15 Grain yield and seed characteristics of sunflower as influenced by cultivar and environment

Cultivar	Environment no.						
	1	2	3	4	5	6	Mean
	Grain yield (kg ha^{-1})						
CRN 1445	2393	2033	1528	2230	2723	2450	2226b*
HYSUN 333	3596	2805	1530	2527	3564	2832	2809a
HV 3037	3133	2727	1806	2018	2774	2250	2451b
PAN 7392	2900	2028	1911	2357	3323	1433	2325b
SNK 37	2007	2565	1532	2359	3104	1828	2233b
Mean	2806a*	2432b	1661c	2298b	3098a	2158b	
	Hectolitre mass (kg)						
CRN 1445	43.2	39.3	37.9	42.9	42.5	37.1	40.5c
HYSUN 333	50.0	43.7	42.5	47.2	45.6	40.7	44.9a
HV 3037	46.0	45.5	41.0	43.6	43.2	37.1	42.7b
PAN 7392	44.1	36.8	38.7	44.0	41.9	41.0	41.1c
SNK 37	47.3	43.0	41.4	45.2	42.5	38.2	42.9b
Mean	46.1a	41.7d	40.3e	44.6b	43.1c	38.8f	
	Thousand seed mass (g)						
CRN 1445	53.3	52.0	58.0	70.9	73.7	67.2	62.5bc
HYSUN 333	50.0	56.3	67.0	73.7	72.6	62.0	63.6b
HV 3037	61.3	80.3	76.3	87.4	78.8	86.9	78.5a
PAN 7392	52.3	52.7	58.0	60.5	64.0	68.9	59.4c
SNK 37	51.7	61.7	67.0	63.7	66.9	64.9	62.7b
Mean	53.7d	60.6c	65.2b	71.2a	71.2a	70.0a	
	Hull content (%)						
CRN 1445	23.0	24.9	23.4	25.5	24.1	30.2	25.2bc
HYSUN 333	24.3	24.7	24.0	27.4	24.6	29.0	25.7b
HV 3037	21.5	22.1	23.1	25.3	25.8	29.3	24.5cd
PAN 7392	25.3	25.9	26.0	27.4	25.8	28.8	26.5a
SNK 37	21.9	22.0	22.0	25.8	24.7	29.1	24.3d
Mean	23.2d	23.9d	23.7d	26.3b	25.0c	29.3a	
	Hullability (%)						
CRN 1445	59.3	78.7	85.3	72.3	67.1	75.5	73.0c
HYSUN 333	45.4	78.1	63.3	75.5	62.2	79.1	67.4d
HV 3037	54.7	82.4	79.0	83.8	75.1	87.4	77.1b
PAN 7392	83.9	92.2	93.0	86.4	83.6	85.9	87.5a
SNK 37	69.4	65.7	73.5	70.7	69.8	81.2	71.7c
Mean	62.6d	79.6ab	78.8b	77.7b	71.6c	81.8a	
	Fine material (%)						
CRN 1445	6.7	6.3	6.7	6.2	5.7	5.4	6.2c
HYSUN 333	9.7	6.3	5.5	7.1	7.2	5.7	6.9b
HV 3037	5.6	7.1	8.7	6.0	5.8	3.6	6.1c
PAN 7392	9.8	6.2	8.4	8.8	7.9	5.4	7.7a
SNK 37	11.5	3.4	6.6	6.4	6.9	5.5	6.7b
Mean	8.7a	5.8d	7.2b	6.9bc	6.7c	5.1e	

*Means of a parameter within a row or column followed by different letters are significantly different at $P \leq 0.05$.

Hectolitre mass (or bulk density) is negatively related to hullability (Tranchino *et al.*, 1984; Dedio & Dorrell, 1989; Dedio, 1993; Baldini & Vannozzi, 1996; Baldini *et al.*, 1996) and low values are therefore indicative of better hullability. The local sunflower industry is currently not considering hectolitre mass to be a parameter of seed quality other than an indication of the utility value regarding storage and transport. High hectolitre mass is thus preferred by the industry. Amongst environments the hectolitre mass varied from 38.8 kg hl^{-1} at Viljoenskroon in 1997/98 to 46.1 kg hl^{-1} at Heilbron in 1996/97. The hectolitre mass for each cultivar at the different environments is shown in Table 15.

Larger seeds are easier to dehull than smaller seeds (Roath *et al.*, 1985; Dedio & Dorrell, 1989; Merrien *et al.*, 1992; Shamanthaka Sastry, 1992) and are thus preferable for processing. The thousand seed mass, reflecting the seed size ranged from 50.0 g for HYSUN 333 at environment no. 1 to 86.9 g for HV 3037 at environment no. 6. The ranking of some cultivars changed over environments, causing the significant cultivar × environment interaction (Table 15).

The hull content, which can sometimes also be associated with hullability (Denis, Dominguez, Baldini & Vear, 1994; Baldini & Vannozzi, 1996) varied between 21.5 for HV 3037 at environment no. 1 to 30.2% for CRN 1445 at environment no. 6. The hull content for each cultivar at the different environments is shown in Table 15.

Hullability

Hullability was affected by cultivar, environment and a cultivar × environment interaction (Table 14), with cultivars the largest source of variation. This is in general agreement with the results of Denis, Dominguez & Vear (1994), Denis, Dominguez, Baldini & Vear (1994) and Baldini & Vannozzi (1996) on sunflower grown in Europe, except that environment was the main source of variation in some instances in Europe. The hullability, calculated over environments, ranged between 67.4% for HYSUN 333 and 87.5% for PAN 7392. PAN 7392 showed a remarkable stability over environments compared to the other cultivars (Table 15). The mean hullability was 75%, which compares favourably with the European results where most of the mean hullabilities for trials reported were less than 75% (Denis, Dominguez, Baldini & Vear, 1994).

Denis, Dominguez & Vear (1994) and Denis, Dominguez, Baldini & Vear (1994) ascribe high hullabilities varying from 60 to 83% found in Spain, to dry cropping conditions. The relatively high mean hullabilities measured in this trial may also be attributed to dry cropping conditions or secondly to plant population, which has been shown to affect hullability (Chapter 3). Plant populations for the European trials are more or less 1.5 times higher than used in trials reported here.

Denis, Dominguez, Baldini & Vear (1994) found the ranking of hybrids quite constant from one location to another. Despite the high and stable hullability of PAN 7392, Spearman's rank correlation analysis resulted in no significant consistency in ranking of cultivars from environment to environment (results not shown).

Fine material

Ideally, no fine material should be produced as it constitutes a loss of oil and protein, and creates a handling hazard during seed processing. The amount of fine material produced ranged from 3.4 to 11.5% for seed samples and was affected by cultivar, environment and an interaction between cultivar and environment (Table 14). Production of fine material therefore changes amongst cultivars from environment to environment, as can be deduced from Table 15. CRN 1445 showed remarkable stability over environments in the production of fine material, when compared to the other cultivars (Table 15).

Correlations among seed traits

Table 16 shows the correlation coefficients between the hullability, amount of fine material produced, grain yield and the physical seed traits. All significant relationships are poor and none of the easily measurable seed characteristics would be a practical indicator for hullability or for the amount of fine material produced.

The negative relationship between the hectolitre mass and hullability is in agreement with the findings of Dedio & Dorrell (1989) and Baldini & Vannozzi (1996). Of significance is the fact that hectolitre mass is also positively related with the amount of fine material produced. Seed with a low hectolitre mass would thus be more desirable for processing than seed with a higher hectolitre mass, due to both higher hullability and reduced losses.

The absence of a relationship between thousand seed mass and hullability is in disagreement with several literature reports where thousand seed mass was found to be positively related to hullability (Wan *et al.*, 1978; Roath *et al*., 1985; Merrien *et al*., 1992; Shamanthaka Sastry, 1992; Dedio & Dorrell, 1989; Dedio, 1993; Denis, Dominguez, Baldini & Vear, 1994; Baldini & Vannozzi, 1996; Denis & Vear, 1996). The lack of a relationship is due to the high and stable hullability of cultivar PAN 7392, despite its variation in thousand seed mass. Excluding PAN 7392 from the correlation analysis, the correlation coefficient improves to a significant 0.47, which is in agreement with other research findings.

Table 16 Correlation coefficients of the relationships between the hullability, fine material yield and physical seed characteristics (n = 30)

	Hullability	Fine material
Yield	-0.46*	0.15
Hectolitre mass	-0.63*	0.47*
Thousand seed mass	0.18	-0.43*
Hull content	0.46*	-0.27
Hullability		-0.05

* Significant at the 0.05 probability level.

The negative relationship between the thousand seed mass and the production of fine material (Table 5) confirms previous results (Chapter 2). Smaller seeds seem to be less rounded than larger seeds and breaking of the kernel appears to be easier. The positive relationship between the hull content and hullability (Table 16) confirms the results of Baldini *et al.* (1994), Denis, Dominguez, Baldini & Vear, (1994) and Baldini & Vannozzi (1996).

CONCLUSIONS

Environmental effects constituted the largest source of variation for grain yield and some physical seed characteristics, namely hectolitre mass, hull content and the production of fine material. Cultivars were the largest source of variation for thousand seed mass and hullability. Grain yield and all the measured seed characteristics were affected by a relatively small cultivar × environment interaction.

Despite the large environmental effect, at least one of the five cultivars showed a stable response for each physical seed trait measured, indicating that breeding for stability of seed traits like hullability should be possible. No easily measurable seed trait gives a reliable measure of hullability. To maximise hullability and minimise losses during processing, large seeds with a low hectolitre mass should be preferred to small seeds with a high hectolitre mass.

II. COMPOSITION AND PROCESSING QUALITY

INTRODUCTION

The oil and protein contents of sunflower are affected by genetic as well as environmental factors like fertilisation (Smith *et al.*, 1978; Blamey & Chapman, 1981; Loubser & Grimbeek, 1985), plant population (Majid & Schneiter, 1987; Zaffaroni & Schneiter, 1991) and water stress (Hall *et al.*, 1985). Commercial sunflower fields vary considerably due to variation in soil properties, prevailing weather and managerial factors like fertilisation and cultivar planted. It is reasonable to expect considerable variation in the composition and related processing quality of seed produced at various environments.

This section reports on the seed and kernel composition and quality for processing as depicted by the potentially recoverable oil and the expected yield and composition of the oil cake of five cultivars grown at six environments in South Africa.

MATERIALS AND METHODS

Seed of five cultivars was produced at three localities, for two successive seasons in trials with randomised complete block designs under dryland conditions. Due to different planting dates, agronomic practices and different weather conditions, the six trials were considered to represent six environments. Details on the seed production, determination of the physical seed characteristics, the dehulling analysis with a laboratory centrifugal dehuller and separation into hull-rich, kernel-rich (KRF) and fine fractions are reported in Section I of this chapter.

The seed, manually dehulled kernels and kernel-rich fraction produced by the centrifugal dehuller were chemically analysed for oil, protein (6.25 × N%), crude fibre and moisture content by the PPECB Quality Assurance Laboratory (P.O. Box 433, Silverton, 0127, South Africa).

Calculation of the potential oil yield is described in the material and methods section of Chapter 2. The statistical analyses (analyses of variance and correlation analyses) were executed using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA). Where applicable, results are reported on a moisture-free basis.

RESULTS AND DISCUSSION

Cultivar and environmental effects

Seed oil, protein and crude fibre contents were affected by cultivar, environment and, for the protein and crude fibre contents, also by a relatively small cultivar × environment interaction (Table 17). Environment, however, was the main source of variation for seed oil and protein contents. The mean oil content varied with 11.4 percentage points amongst environments and 3.2 percentage points amongst cultivars. The mean protein content varied with 6.6 percentage points amongst environments and with 3.5 percentage points amongst cultivars.

The seed crude fibre content varied with 4.3 and 3.8 percentage points amongst environments and cultivars respectively. Seed oil, protein and crude fibre contents for the five cultivars at each environment are shown in Table 18. The cultivar × environment interaction on the seed protein and crude fibre contents indicates that the relative ranking of cultivars for these traits, changed amongst environments.

Kernel oil, protein and crude fibre contents of the five cultivars at each environment are shown in Table 18. Kernel oil and protein content were affected by cultivar and environment with environment being the largest source of variation (Table 17). Amongst environments, mean kernel oil content varied with 10.8 percentage points and amongst cultivars with 3.9 percentage points. The kernel protein content varied with 10.4 and 4.2 percentage points amongst environments and cultivars respectively. Kernel crude fibre content was affected by environment only, ranging from 4.6 to 6.3% at environment no. 1 and no. 2 respectively.

The amount of potentially recoverable oil was affected by cultivar, environment and a cultivar × environment interaction, with environment by far the largest source of variation (Table 17). The amount of potentially recoverable oil varied with 10.2 g per 100 g seed amongst environments. Amongst cultivars, SNK 37 and PAN 7392 had the best and worst amounts of potentially recoverable oil of 45 and 40.4 g per 100 g seed respectively. The potential oil yield of each cultivar at the different environments is shown in Table 19.

The moisture and oil-free KRF yield is an indication of the oil cake yield that can be expected should the oil be extracted from the KRF. The KRF yield was affected by cultivar, environment and a relatively small interaction between cultivar and environment (Table 17). The mean KRF yield ranged with 5.4 g per 100 g seed amongst cultivars and with 4.2 g per 100 g seed amongst environments. The cultivar × environment interaction on the KRF yield indicates that the relative ranking of cultivars changed amongst environments. Table 19 presents the KRF yield for each cultivar at the different environments.

Table 17 F-values from the analysis of variance for oil, protein and crude fibre contents of the seed and kernels, the potentially recoverable oil and the protein, crude fibre and hull contents of the kernel rich fraction (KRF) of five sunflower cultivars grown at six environments

Source of variation	DF	----------------Seed-------------- oil	protein	fibre	---------------Kernel-------------- oil	protein	fibre	Pot. oil yield	---------------KRF---------------- yield	protein	fibre
Cultivar	4	7**	15**	7**	10**	12**	2	37**	87**	7**	5**
Environment	5	67**	38**	8**	59**	43**	4**	118**	65**	16**	7**
C × E	20	1	4**	2*	1	1	1	7**	7**	1	2
Total	59										
CV(%)		3	6	7	3	6	18	3	3	6	9

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

Table 18 The moisture-free mean oil, protein (N × 6.25%) and crude fibre content of sunflower seed and kernels of five cultivars grown at 6 environments

Cultivar	Environment no 1	2	3	4	5	6	Mean
	Seed oil content (%)						
CRN 1445	50.7	46.4	50.5	48.4	47.4	41.1	47.4b*
HYSUN	51.9	41.5	49.8	46.9	47.4	41.2	46.5b
HV 3037	53.7	43.7	48.5	48.0	46.1	38.4	46.4b
PAN 7392	50.7	44.4	49.5	48.4	46.5	42.2	47.2b
SNK 37	53.7	43.7	53.5	50.8	48.4	43.0	49.7a
Mean	52.6a*	44.9e	50.3b	48.3c	47.2d	41.2f	
	Seed protein content (%)						
CRN 1445	13.7	15.8	17.9	19.1	20.4	21.7	18.1cd
HYSUN	15.7	18.2	16.6	20.1	20.9	22.5	19.0b
HV 3037	14.9	20.6	24.3	20.1	21.4	24.8	21.0a
PAN 7392	18.9	20.3	17.9	16.4	19.0	20.9	18.9bc
SNK 37	14.5	16.9	14.9	18.2	19.6	20.8	17.5d
Mean	15.5d	18.4c	18.3c	18.8c	20.3b	22.1a	
	Seed crude fibre content (%)						
CRN 1445	20.7	25.7	25.6	18.5	17.9	21.3	21.6b
HYSUN	21.6	22.9	20.6	20.4	18.9	21.6	21.0b
HV 3037	20.1	20.9	21.4	20.2	20.6	21.7	20.8b
PAN 7392	20.3	28.8	25.3	22.8	21.4	20.6	23.2a
SNK 37	18.5	19.6	18.2	19.7	17.8	22.4	19.4c
Mean	20.2c	23.6a		20.3c	19.3c	21.5b	
	Kernel oil content (%)						
CRN 1445	67.1	58.4	61.8	63.7	60.1	56.2	61.2bc
HYSUN	66.1	55.9	60.7	61.4	60.1	55.8	60.0cd
HV 3037	64.8	58.1	59.2	63.6	59.1	53.9	59.8d
PAN 7392	69.8	56.1	62.0	66.3	61.9	58.6	62.4ab
SNK 37	68.6	61.9	66.0	65.9	61.6	57.9	63.7a
Mean	67.3a	58.1d	61.9c	64.2b	60.6c	56.5d	
	Kernel protein content (%)						
CRN 1445	16.6	21.1	21.4	24.5	24.9	27.8	22.7bc
HYSUN	20.7	25.4	23.1	26.7	26.8	29.1	25.3a
HV 3037	18.8	27.1	25.5	25.4	27.3	32.4	26.1a
PAN 7392	18.8	26.2	21.3	22.0	24.6	27.7	23.4b
SNK 37	17.7	21.3	17.5	23.2	24.5	27.5	21.9c
Mean	18.5e	24.2c	21.8d	24.3c	25.6b	28.9a	
	Kernel crude fibre content (%)						
CRN 1445	5.7	7.4	5.2	4.4	6.0	6.9	5.9ab
HYSUN	4.7	6.7	7.0	5.4	7.2	7.3	6.4a
HV 3037	4.1	5.0	5.8	4.7	6.6	5.8	5.3b
PAN 7392	4.2	6.9	5.8	6.1	5.3	5.1	5.6ab
SNK 37	4.3	5.3	5.3	4.8	4.7	6.2	5.1b
Mean	4.6b	6.3a	5.8ab	5.1b	6.0a	6.3a	

* Means of a parameter within a row or column followed by different letters are significantly different at $P \leq 0.05$.

Table 19 The potentially recoverable oil, yield of the kernel rich fraction (KRF) and the protein (N × 6.25%) and crude fibre contents of the KRF of five cultivars grown at six environments

Cultivar	Environment no.						
	1	2	3	4	5	6	Mean
	Potentially recoverable oil† (g per 100 g seed)						
CRN 1445	48.5	42.5	42.7	43.0	42.2	37.3	42.7b*
HYSUN	45.7	39.4	44.7	41.2	41.6	36.6	41.5c
HV 3037	50.8	40.6	41.3	43.6	42.6	35.9	42.3bc
PAN 7392	44.4	38.2	41.3	40.6	40.1	38.0	40.4d
SNK 37	47.6	47.5	47.7	46.0	42.6	38.4	45.0a
Mean	47.4a*	41.6c	43.6b	42.9b	41.6c	37.2d	
	KRF yield‡ (g per 100 g seed)						
CRN 1445	30.0	30.3	29.6	30.7	34.5	32.9	31.3b
HYSUN	31.9	32.8	28.7	30.2	34.0	32.8	32.5a
HV 3037	30.5	32.5	29.4	27.9	32.6	32.6	30.9b
PAN 7392	23.5	30.4	25.1	24.2	29.1	30.4	27.1d
SNK 37	24.9	32.8	28.7	28.5	32.0	30.4	29.6c
Mean	28.2c	31.8a	29.2b	28.3c	32.4a	31.9a	
	KRF protein content‡ (%)						
CRN 1445	39.4	47.3	48.0	50.9	48.8	52.6	47.8b
HYSUN	42.9	49.8	47.5	53.1	50.1	54.3	49.6b
HV 3037	42.0	51.2	56.9	57.7	53.9	62.0	54.0a
PAN 7392	50.6	54.5	54.4	51.6	52.3	55.2	53.1a
SNK 37	44.9	47.9	47.9	52.6	50.2	55.6	49.3b
Mean	43.9d	50.1c	50.2bc	53.2b		55.9a	
	KRF crude fibre content‡ (%)						
CRN 1445	23.9	24.5	21.2	24.8	29.8	24.6	24.3a
HYSUN	26.6	26.7	23.5	24.6	27.0	21.4	25.0a
HV 3037	25.8	17.8	19.5	21.9	25.8	17.6	21.4b
PAN 7392	21.6	25.6	24.8	28.5	25.6	24.6	25.1a
SNK 37	22.5	23.6	23.0	26.1	24.4	21.0	23.4a
Mean		23.6bc	22.4c	25.2ab	25.9a	21.8c	

† Moisture-free base; ‡ Moisture and oil-free base.

* Means of a parameter within a row or column followed by different letters are significantly different at $P \leq 0.05$.

The protein content of the KRF (moisture and oil-free base) was affected by cultivar and environment, with the environment again the main contributor to the variation (Table 17). The protein content ranged with 6.2 percentage points amongst cultivars and with 12.0 percentage points amongst environments. For individual seed samples, the protein content of the KRF ranged from 39.4 to 62.0% (Table 19). This would correspond with an oil cake protein content of 34.7 to 54.7%, assuming that it also contains 6.68% oil and 6.73% moisture as reported by Smith, Hayes & Smith (1989) for commercial South African oil cake meals. Only 13.3% of the seed samples (all produced at environment no. 1) would be expected to have oil cake with less than 40% protein, which deviates drastically from the 82% reported by Smith *et al.* (1989) for commercially produced oil cakes.

The KRF crude fibre content was affected by cultivar and environment (Table 17). For cultivars, the mean crude fibre content varied with 3.7 percentage points and for environments with 4.1 percentage points. For individual seed samples the KRF crude fibre content varied from 17.6 to 28.5% (Table 19), which would correspond to 15.7 and 24.7% assuming that it also contains 6.68% oil and 6.73% moisture as found for commercial oil cakes (Smith *et al*., 1989). This corresponds well with the range of 11.81 to 23.95% reported by Smith *et al*. (1989). However, only 10% of the potential oil cakes would be below the limit of 16% crude fibre content compared to the 54.6% reported by Smith *et al*. (1989). These deviations for both the protein and crude fibre of the expected oil cake and those reported by Smith *et al*. (1989) are also indicative of the genetic and environmental effects on seed hullability and composition.

Relationships

The correlation coefficients of the relationship between the amount of potentially recoverable oil, KRF yield and composition, and the seed physical characteristics as reported in Table 15, and the seed chemical composition are shown in Table 20. The potentially recoverable oil correlated well with the seed and kernel composition. Obviously, seed with a high oil content will result in a high amount of potential recoverable oil. The moderate negative relationship between the potentially recoverable oil and both hullability and hull content is explained by the negative relationship between seed oil content and hullability and the positive relationship between hullability and hull content (Denis & Vear, 1996).

Table 20 Correlation coefficients between the potentially recoverable oil (PRO), oil and moisture-free yield and protein content of the kernel-rich fraction, and the physical seed traits, seed composition and kernel composition

	PRO	KRF yield	-----KRF content------ protein	fibre
Hectolitre mass	0.56*	-0.12	-0.47*	0.3
TSM†	-0.32	0.37*	0.60*	-0.37*
Hull content	-0.79*	0.1	0.68*	0.01
Hullability	-0.66*	-0.33	0.72*	-0.33
Fines produced	0.24	-0.67*	-0.26	0.11
Seed oil content	0.89*	-0.53*	-0.67*	0.2
Seed protein content	-0.79*	0.39*	0.86*	-0.4
Seed crude fibre content	-0.40*	-0.12	0.21	-0.01
Kernel oil content	0.79*	-0.69*	-0.58*	0.23
Kernel protein content	-0.86*	0.56*	0.81*	-0.24
Kernel crude fibre content	-0.53*	0.45*	0.21	0.15

*Significant at the 0.05 probability level.

† Thousand seed mass

The oil and moisture-free yield of the KRF correlated moderately with the thousand seed mass and the composition of the seed and kernels. No significant relationship was found between hullability and the KRF yield which indicates that seed (and kernel) oil content is the main determinant of the KRF yield.

The protein content of the KRF correlated well with nearly all the physical and chemical seed properties. The relatively good correlation between the hullability and KRF protein content emphasizes the importance of high hullability to oil cake with a high protein content. The negative relationship between the seed oil content and the protein content of the KRF is of importance. It indicates the unlikeliness of having high oil yield combined with high protein oil cake from seed with a high oil content.

Only hectolitre mass and seed protein content correlated moderately with the crude fibre content of the KRF. The lack of a significant relationship between hullability and the KRF crude fibre content is unexpected. By excluding PAN 7392 from the correlation analysis, however, this correlation coefficient increases to a moderate but significant -0.63. Despite the high and constant hullability of PAN 7392 (Table 15), its KRF had an average or above average crude fibre content at five of the six environments (Table 19). A possible explanation is that a large amount of kernel particles of PAN 7392 stay attached to the hulls during dehulling, which are removed with the hulls, thus creating the impression of a high hullability. Consequently, a relatively large amount of hulls and crude fibre remain in the KRF.

The relatively poor relationship between hullability and the KRF crude fibre content compared to hullability and KRF protein content (r = -0.63 compared to r = 0.73, PAN 7392 excluded) is of importance. Most of the crude fibre of seed is located in the hulls, while most of the protein is located in the kernel. Variation in hullability would therefore be expected to affect the KRF crude fibre and protein content to the same extent. High variability of the crude fibre content of hulls might be the cause for this inconsistency. Theerta Prasad & Channakrishnaiah (1995) reported the fibre content of hulls to vary from 59.2 to 86.6%. Smith *et al.* (1989) found the crude fibre content of South African produced seed to vary from 12.8 to 27.9%, which is much more than the oil or protein content.

PAN 7392 clearly demonstrates that high measured hullability of seed is no guarantee for oil cake with a low crude fibre content. For clarity, hullability analysis should be confirmed by analysis for crude fibre. The crude fibre content of seed, factors affecting it and its relationship with hullability also need further investigation as the crude fibre content of sunflower oil cake is the primary restriction to its greater use for monogastric animals such as swine (Park, Marx, Moon, Wiesenborn, Chang & Hofman, 1997).

Environmental factors affected seed and kernel composition more than genetic factors, while the opposite was true for hullability. As the field trials were conducted under more favourable conditions than normally experienced, unfavourable conditions, especially drought, might alter the environmental effect on the seed composition and related quality, an aspect which needs further investigation.

The work reported in this chapter has been published (Nel, Loubser & Hammes, 2000b; Nel Loubser & Hammes, 2000c).

CHAPTER 5

EFFECT OF NITROGEN FERTILISATION ON SEED YIELD AND QUALITY

INTRODUCTION

The availability of nitrogen throughout the growing season is one environmental factor which varies considerably among commercial sunflower fields due to various fertilisation rates, different soils and variation in rainfall. Previous research has indicated that under nitrogen limiting conditions, nitrogen fertilisation tends to increase seed protein content at the expense of oil (Blamey & Chapman, 1981; Loubser & Grimbeek, 1985; Steer *et al.*, 1986). Even in conditions where seed yield was not affected by nitrogen fertilisation, higher levels of nitrogen reduced seed oil content (Geleta, Baltensperger, Binford & Miller, 1997).

In a greenhouse trial, Steer *et al.* (1984) found that timing of nitrogen fertilisation during the growing season influenced seed oil and protein contents. High nitrogen supply after anthesis resulted in lower seed oil and higher protein contents. Hullability is also affected by the availability of nitrogen and water. In this respect Baldini & Vannozzi (1996) have found that an increased supply of nitrogen improves hullability.

It appears that the availability of nitrogen to the sunflower crop may have a determining effect on seed characteristics which influence the processing quality. The objectives of this field trial were to determine the effect of both the amount and timing of nitrogen fertilisation on the seed yield, hullability, seed composition, potential oil yield, potential oil cake yield and potential quality of the oil cake.

MATERIALS AND METHODS

The field experiment was located at the ARC-Grain Crops Institute's experimental farm at Potchefstroom. According to the Soil Classification Working Group (1991) the soil is classified as being of the Kameelbos family and the Avalon form, 60 cm deep with a sandy clay loam texture in both the A and B horizons. In an attempt to deplete the soil of residual nitrogen, oats were sown without fertilisation during June, mowed 100 days later and all the material removed. The experimental area was subsequently fertilised with 28 kg ha^{-1} P and 28 kg ha^{-1} K and ploughed. Seed of the cultivar HYSUN 333 was densely planted in rows spaced 90 cm apart on 14 December 1998 and thinned to approximately 35 000 plants ha^{-1} after emergence. HYSUN 333 was chosen for its hullability response to environmental influences (Chapter 4). For weed control, alachlor was applied at a rate of 4 l ha^{-1} after sowing.

A completely randomised block design was used with two treatment factors and three replicates. Plot dimensions were 10×3.6 m. Treatments consisted of nitrogen application rate and timing of application. The different N rates included inadequate (20 kg ha^{-1} N), adequate (70 kg ha^{-1} N) and luxurious (120 kg ha^{-1} N) supply. Timing of application treatments were: all N applied at planting (1:0) , 25% at planting and 75% at the beginning of flowering (1:3) and equal quantities at planting and at the beginning of flowering (1:1), which is growth stage R5.1 as described by Schneiter & Miller (1981).

Before the first nitrogen application, six topsoil samples were taken on each plot to a depth of 60 cm, mixed to one sample and analysed for NO^{-}_{3} and NH^{+}_{4} nitrogen content. NH^{+}_{4} ranged between 5.2 and 9.0 mg kg^{-1}, and NO^{-}_{3} between 3.2 and 8.3 mg kg^{-1}, with means of 6.8 and 5.9 mg kg^{-1} respectively.

To supplement low rainfall, irrigation was applied several times during the season. Leaf samples were taken at growth stage R4 before the second application of nitrogen and analysed for total nitrogen content. The seed yield was determined on an area of 1.8×8 m for each plot. The hectolitre mass, thousand seed weight and hull content were determined as described in the materials and methods section of Chapter 2, section II.

The seed was dehulled and separated into the three fractions as described in the materials and methods section of Chapter 2 section II. Due to the low moisture content of the seed (5.7%), the huller speed was set at 3800 rpm and three samples of approximately 15 g seed were used. The mass of each of the three fractions was recorded. Hullability was calculated as described previously (Chapter 2). Samples of the seed, clean kernels and kernel-rich fractions were chemically analysed for moisture, oil and protein content (N $\times$ 6.25%) by the PPECB Quality Assurance Laboratory (PO Box 433, Silverton 0127).

RESULTS AND DISCUSSION

Leaf nitrogen content at growth stage R4 responded to the amount of nitrogen applied at planting (Table 21). Cheng & Zubriski (1978) found a nitrogen concentration of 2.79 % in the leaves to be associated with a yield reduction of approximately 10%. Only the 20 kg ha^{-1} and 1:1 timing treatment combination, which received only 10 kg nitrogen per ha at planting, was deficient at 2.71 %. The nitrogen concentration for all other treatment combinations indicated adequate nitrogen supply. The absence of a clear deficit for the 20 kg nitrogen treatment is explained by the high soil nitrogen content. Approximately 46 kg residual nitrogen, bound as NO_3^-, was available per ha, which, according to Robinson (1973), is adequate to produce 1000 kg seed per ha.

Table 21 Leaf nitrogen content (%) at growth stage R4 in response to the N applied at planting

N timing ratio	------------Total N application rate (kg ha^{-1})-------------		
(Planting:R5.1)	20	70	120
1:3	2.88 (5)†	3.01 (17.5)	3.07 (30)
1:1	2.71 (10)	3.11 (35)	3.35 (60)
1:0	2.88 (20)	3.31 (70)	3.86 (120)

† Amount of nitrogen (kg ha^{-1}) applied at planting.

The grain yield increased by 33% with increasing nitrogen application from 20 to 70 kg ha^{-1}, while it increased by only 9.6% in response to an increase from 70 to 120 kg nitrogen per ha (Tables 22 and 23). The mean grain yield achieved, viz. 2642 kg ha^{-1}, represents yields commonly obtained for irrigated rather than dryland sunflower production in South Africa. Despite no indication of a serious deficiency it appears as though 120 kg nitrogen per ha was not sufficient to produce maximum seed yields for the conditions that prevailed.

The hectolitre mass was affected by the amount of nitrogen applied. However, the response was small with an increase of only 2% for each increment of 50 kg of nitrogen applied (Table 3). Neither the amount of nitrogen applied nor the timing of application had any affect on the thousand seed weight (mean 61.2 g), hull content (mean 24.1%), hullability (mean 54.7%) or the amount of fine material produced (mean 6.3%).

The lack of a response of hullability to increased nitrogen fertilisation apparently does not support the findings of Baldidni & Vannozzi (1996) who have found hullability to be improved by nitrogen fertilisation. The apparent discrepancy might be explained by the different nitrogen application rates and conditions used in the two experiments. In the Potchefstroom trial, nitrogen application varied from 20 to 120 kg ha^{-1}, compared to the extreme rates of 0 and 180 kg nitrogen ha^{-1} combined with high and low water availability in the trial of Baldini & Vannozzi (1996). Recommended nitrogen fertilisation rates for dryland conditions with a yield potential of 2000 kg ha^{-1} in South Africa vary from 40 to 70 kg N ha^{-1}, depending on the clay content of the soil (du Toit, Loubser & Nel, 1995). Assuming that these recommendations also reflect the actual nitrogen applications by farmers, it seems unlikely that the hullability of commercially produced seed is affected by nitrogen fertilisation.

Seed oil content decreased while seed protein content increased with increased amounts of applied nitrogen (Tables 24 and 25) thereby supporting previous findings (Blamey & Chapman, 1981; Loubser & Grimbeek, 1985; Steer *et al.*, 1986). Timing of nitrogen application had no effect on the seed oil and protein content (Table 4). Steer *et al*. (1984), however, have found in a controlled environment with sunflowers grown in washed sand that high nitrogen supply compared with a low supply during seed filling gave a high seed nitrogen concentration.

Table 22 F-values from the analysis of variance for grain yield and physical seed characteristics of sunflower as affected by rate and timing of nitrogen application

Source of variation	DF	Grain yield	Hectolitre mass	Thousand seed weight	Hull content	Hull-ability	Fine material
N-amount	2	25.6**	5.9*	1.2	2.5	0.9	0.1
N-timing	2	0.9	0.6	1.6	1.8	0.2	0.2
Interaction	4	2.8	0.1	1.5	1.4	0.8	0.5
Total	26						
CV (%)		10	3	7	3	15	13

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

Table 23 Grain yield and physical seed characteristics of sunflower as affected by rate and timing of nitrogen application

Treatment	Grain yield (kg ha^{-1})	Hectolitre mass (kg hl^{-1})	Thousand seed weight (g)	Hull content (%)	Hull-ability (%)	Fine material (%)
N-amount (kg ha^{-1})						
20	2096	45.7	59.3	24.4	54.2	6.32
70	2800	46.6	61.7	23.8	55.8	6.16
120	3027	47.4	62.4	24.0	54.2	6.42
N-timing (Planting:R5.1)						
1:3	2548	46.3	61.8	23.6	52.7	6.34
1:1	2768	46.8	62.2	24.2	55.0	6.27
1:0	2608	46.5	59.5	24.2	56.5	6.3

Similar to seed oil and protein content, kernel oil content declined and protein content increased with increased rate of nitrogen fertilisation (Tables 24 and 25).

In commercially grown sunflower, kernel crude fibre content in excess of 10% is sometimes found, which is of concern since oil cake with unacceptably high crude fibre content can thus be expected. The kernel crude fibre content was significantly affected by the timing of nitrogen fertilisation at the 5.2% probability level. Increasing the portion of nitrogen applied at growth stage R5.1 resulted in a moderately increased kernel fibre content (Table 25). However, considering the levels and timing of nitrogen fertilisation on commercial fields it is unlikely that crude fibre levels in excess of 10% are the result of nitrogen supply.

The amount of potentially recoverable oil decreased moderately with less than two percentage points for each increment of 50 kg nitrogen applied per ha (Tables 24 and 25). The change in the potentially recoverable oil corresponds with the changes in both the seed oil and kernel oil contents due to the amount of nitrogen applied.

The oil and moisture-free yield of the KRF gives an indication of the oil cake yield that can be expected from the seed. The KRF yield was affected by the amount of nitrogen fertiliser applied (Table 24). Each increment of 50 kg of nitrogen per ha resulted in a small KRF yield increase of approximately 1.5 percentage points (Table 25). This increase in the KRF yield is explained by the higher protein and lower oil content of the seed associated with the higher rates of nitrogen fertilisation.

The oil and moisture-free protein and crude fibre contents of the KRF, which reflect the quality of the oil cake, were affected by the amount of nitrogen applied (Table 24). The protein content increased with 4.1 percentage points per 50 kg of nitrogen applied (Table 25). The crude fibre content decreased with 1 and 3.1 percentage points from the 20 to the 70 kg and from the 70 to the 120 kg nitrogen per ha respectively (Table 25). The change of the KRF composition was also due to the change in seed composition associated with different nitrogen application rates.

Table 24 F-values from the analysis of variance for seed and kernel composition, potentially recoverable oil (PRO) and the yield and composition of the kernel-rich fraction (KRF) of sunflower as affected by rate and timing of nitrogen application

Source of	DF	----------------Seed----------------			-------------Kernel-----------------			PRO	-----------------KRF----------------		
variation		Oil	Protein	Fibre	Oil	Protein	Fibre		Yield	Protein	Fibre
N-amount	2	11.1**	21.6**	0.5	24.1**	25.9**	0.7	11.5**	5.6*	14.8**	4.5*
N-timing	2	0.1	0.5	0.5	0.7	1	3.7	0.1	1.5	0.3	0.2
Interaction	4	0.7	0.1	2.2	0.4	0.2	0.7	0.6	0.3	0.3	0.3
Total	26										
CV (%)		4	9	6	3	8	9	3	5	7	10

**,* Significant at the 0.05 and 0.01 probability levels, respectively.

Table 25 Seed and kernel composition, potentially recoverable oil (PRO) and the yield and composition of the kernel-rich fraction (KRF) of sunflower as affected by rate and timing of nitrogen application

Treatment	Seed[†]			Kernel[†]			PRO[†]	KRF[‡]		
	Oil	Protein	Fibre	Oil	Protein	Fibre		Yield	Protein	Fibre
	(%)	(%)	(%)	(%)	(%)	(%)	g per 100 g	g per 100 g	(%)	(%)
N-amount (kg ha^{-1})										
20	50.2	15.4	19.7	65.4	19.7	4.9	45.6	34.8	40.5	31.7
70	49.3	17.9	19.3	62.5	22.8	4.8	44.5	36.4	44.6	30.7
120	46.6	20.3	19.8	59.8	25.8	5.1	42.8	37.8	48.7	27.6
N-timing (Planting:R5.1)										
1:3	48.6	18.3	19.7	62.1	23.4	5.3	44.5	37.2	45.1	30.3
1:1	48.7	17.6	19.3	62.5	22.6	4.9	44.3	36.2	44.0	29.5
1:0	48.8	17.8	19.8	63.1	22.3	4.7	44.2	35.7	44.6	30.3

[†] Moisture-free basis

[‡] Oil and moisture-free basis

Smith *et al.* (1989) have found the mean oil and moisture contents of commercially produced oil cakes to be 6.68 and 6.73% respectively. Applying this to the KRF composition, the protein contents would be 35.1, 38.6 and 42.2% and the crude fibre content would be 27.4, 26.6 and 23.9% for the 20, 50 and 120 kg ha^{-1} nitrogen application rates respectively. Accordingly, only the 120 kg ha^{-1} nitrogen application rate would be expected to yield oil cake with an acceptable (above 40%) protein content. The crude fibre content, however, is more than double the value that can be considered as acceptable for sunflower oil cake of high quality (Smith *et al*., 1989).

CONCLUSION

Timing of nitrogen application had no response on the seed yield or the seed quality characteristics of sunflower. Seed yield increased on average by 22% per 50 kg of nitrogen applied per ha, while changes in the recoverable oil yield, KRF yield and composition of the KRF were equal to or less than 10%. These changes were due to changes in seed composition as the hullability was unaffected by nitrogen application rate. For commercial seed production it seems logical that seed yield would remain the main determinant for nitrogen application rates rather than the composition of the seed.

The work reported in this chapter, has been published (Nel, Loubser & Hammes, 2000d).

CHAPTER 6

EFFECT OF BORON FERTILISATION ON SEED YIELD AND QUALITY

INTRODUCTION

The importance of B deficiency for sunflower (*Helianthus annuus* L.) in South Africa has been reported by Blamey (1976) and Blamey & Chapman (1982). Yield increases of up to 30.7% (Armstrong & McGee, 1982) and 48% (Blamey, Mould & Chapman, 1979) have been reported as a result of fertilisation with B on deficient soils. Fertilisation with B at planting has become a standard procedure for many farmers. Despite these fertilisation practices, B deficiency symptoms are reported every year in South Africa. This is not surprising since B deficiency is unusual in that drought stress affects its incidence and severity, especially under low topsoil moisture conditions (Moraghan & Mascagni, 1991). According to Batey (1971) turnip (*Brassica rapa*) in Wales normally becomes B deficient on soils with less than 0.3 mg kg^{-1} of extractable B. However, deficiency in a dry summer was observed in fields with extractable B levels of 0.5 to 0.6 mg kg^{-1}. On the other hand, fertilisation with B sometimes suppresses seed yields. In field trials done by the Fertilizer Society of South Africa (FSSA, 1977), the lowering of sunflower seed yields or a declining trend in yield due to B-fertilisation, were observed. Hilton & Zubriski (1985) found in North Dakota that the yield of a B-fertilised treatment was the lowest at three out of four sites, and significantly lower than a treatment which was fertilised with Fe and S.

Apart from the effect of B on yield, seed oil content can also be affected by B supply (Blamey *et al.*, 1979; Chatterjee & Nautiyal, 2000). The effect of B supply on the other seed quality characteristics is not known. As some of the sunflower produced in South Africa may be affected by B availability, the objectives of this trial were to determine the effect of B fertilisation on the seed yield, the physical and chemical seed characteristics and the potentially recoverable oil, potential oil cake yield, and the protein and crude fibre contents of the potential oil cake.

MATERIALS AND METHODS

Two field trials were planted during the 1999/2000 season at two localities in the sunflower production area of South Africa, on fields where B deficiency was observed during previous seasons. The localities were the ARC-Small Grain Institute at Bethlehem and the farm “Hoekom” close to Petrus Steyn. Details of the soils at these two experimental sites and the agronomic practices applied are shown in Table 26.

Treatments applied were: soil surface applications of B at a rate of 1.6 kg ha^{-1} as sodium borate (Solubor); B at a rate of 1.6 kg ha^{-1} as sodium calcium borate (Boronat 32, supplied by Agrofert, P.O. Box 518, Ferndale 2120, South Africa); and a control treatment which received no B. Sodium calcium borate (SCB) is less soluble than sodium borate (SB) and thus expected to be less susceptible to leaching.

Completely randomised block designs were used, with three replicates at Bethlehem and five replicates at Petrus Steyn. Plots consisted of four rows, 0.9 m apart and 10 m long. The inner two rows were harvested for yield and seed quality determinations. At growth stage R5.1, as described by Schneiter & Miller (1981), the youngest fully expanded leaf blades were sampled. These samples were dried at 65°C and analysed for B content by the ARC-Institute for Soil Climate and Water (Private Bag X79, Pretoria 0001, South Africa).

The hectolitre mass of the seed, thousand seed mass and hull content were determined as described in the materials and methods of Chapter 2 section II. Seed dehulling, separation into the different fractions, calculation of hullability, fines produced and chemical analyses were done as described in the materials and methods of Chapter 5.

The potential oil yield, the oil and moisture-free yield of the KRF, and the protein and crude fibre content of the KRF were calculated as described in the materials and methods of Chapter 2 section II. Analyses of variance were done on the data collected using Statgraphics Plus (Manugistics, Inc., 2115 East Jefferson Street, Rockville, Maryland 20852, USA).

RESULTS

Results of the B content of the leaves, the seed yield and physical seed characteristics are shown in Table 27. At both localities, the B content of the leaves was above the 34 mg kg^{-1} threshold for deficiency, as determined by Blamey *et al.* (1979) and Fernandez, Baudin, Esquinas & Vara (1985), and well below the toxicity limit of 1130 mg kg^{-1}, as determined by Blamey, Asher & Edwards (1997). Leaf B content did not differ amongst treatments at Bethlehem. At Petrus Steyn, however, the leaf B content in the Boronat treatment was 35% higher than in the control treatment.

Seed yield decreased by 12% at Bethlehem due to B fertilisation. At Petrus Steyn, the seed yield of the SB treatment was almost 25% higher than the yield of the control treatment. SB lowered the hectolitre mass of the seed by 3.8% compared to the control treatment at Bethlehem, while the hectolitre mass was unaffected at Petrus Steyn. The thousand seed mass, hull content and fine material were unaffected by the B fertilisation or the type of B fertiliser used at either locality. At Bethlehem the hullability of the SCB treatment was 16.6% lower than that of the control treatment. Hullability was unaffected by the B fertilisation at Petrus Steyn.

The oil, protein and crude fibre contents of both the seed and kernels were unaffected by the treatments at either locality (Table 28). The differences in the seed oil and protein contents between the two localities are remarkable, taking into account that the yields differ by only 3%. The seed produced at Bethlehem had an exceptionally high oil content (47.5% at 7% moisture content) associated with an exceptionally low protein content (12.6% at 7% moisture content). At Petrus Steyn, the seed oil content was very low at 37.3% (at 7% moisture) while the seed protein content can be described as normal at 21.1%.

Results of the potentially recoverable oil, KRF yield and the protein and crude fibre contents of the KRF, as affected by B fertilisation, are shown in Table 29. B fertilisation had no effect on the potentially recoverable oil of the seed.

Table 26 Soil description and agronomic inputs of the field trials at two localities

Soil parameters and inputs	--------------- Locality ---------------	
	Bethlehem	Petrus Steyn
Soil classification	Avalon	Avalon
Effective depth (m)	0.7	1
pH (KCl) 0 - 0.3 m depth	5.5	3.9
Ca (Ambic 1, mg kg^{-1})	639	148
K (Ambic 1, mg kg^{-1})	167	93
Mg (Ambic 1, mg kg^{-1})	139	30
P (Ambic 1, mg kg^{-1})	11	19
Planting date	1999-10-28	2000-01-6
Cultivar	HV 3037	HYSUN 333
Plant density (plants m^{-2})	4	1.2
N fertilisation (kg ha^{-1})	61	64
P fertilisation (kg ha^{-1})	13	17
K fertilisation (kg ha^{-1})	6	8

The moisture and oil-free yield of the KRF, which is an indication of the yield of the expected oil cake, was affected by the application of SCB at Bethlehem where its seed yield was 7.3% higher than that of the control treatment. This higher KRF yield is explained by the lower hullability of the SCB treatment, which resulted in more hulls remaining in the KRF. The lower hullability of the SCB treatment, compared to the control, is also the cause of the difference in the KRF protein content between these two treatments (Table 29). B fertilisation, however, had no effect on the KRF yield or protein content at Petrus Steyn.

The crude fibre content of the KRF was unaffected by the application of B at either locality. This is unexpected for the Bethlehem trial and cannot be logically explained. Approximate equal differences between the crude fibre content of the KRFs, and between the hullabilities of the SCB and control treatments, were expected.

Table 27 Leaf B content at growth stage R5.1, grain yield, hectolitre mass, thousand seed mass, hull content, hullability and the amount of fine material produced as affected by fertilisation with sodium borate (SB) and sodium calcium borate (SCB) at two localities

Treatment	Locality	
	Bethlehem	Petrus Steyn
	B content (mg kg^{-1})	
Control	54.5a*	74.2b
SB	57.8a	84.4ab
SCB	77.1a	100.0a
	Grain yield (kg ha^{-1})	
Control	2801a	2236b
SB	2437b	2792a
SCB	2493b	2462ab
	Hectolitre mass (kg hl^{-1})	
Control	39.3a	38.8a
SB	37.8b	39.9a
SCB	38.5ab	39.5a
	Thousand seed mass (g)	
Control	58.7a	75.4a
SB	54.7a	74.1a
SCB	47.9a	73.4a
	Hull content (%)	
Control	23.2a	29.7a
SB	24.0a	28.4a
SCB	22.5a	28.2a
	Hullability (%)	
Control	89.3a	88.2a
SB	85.2a	92.7a
SCB	74.5b	88.3a
	Fine material (%)	
Control	5.2a	4.8a
SB	5.5a	5.4a
SCB	5.5a	5.0a

* Means of a parameter within a column followed by different letters are significantly different at $P \leq 0.05$.

Table 28 The oil, protein and crude fibre contents of the seed and kernels of sunflower as affected by fertilisation with sodium borate (SB) and sodium calcium borate (SCB) at two localities

Treatment	Locality					
	Bethlehem	Petrus Steyn	Bethlehem	Petrus Steyn	Bethlehem	Petrus Steyn
	Oil content[†] (%)		Protein content[†] (%)		Crude fibre content[†] (%)	
			Seed			
Control	50.9a*	38.7a	13.9a	21.3a	17.2a	20.2a
SB	50.6a	40.1a	13.0a	21.2a	17.4a	19.5a
SCB	51.0a	40.8a	13.5a	20.8a	17.3a	19.8a
			Kernel			
Control	65.7a	54.6a	17.2a	29.1a	2.6a	2.3a
SB	66.1a	56.1a	16.0a	27.9a	2.3a	2.3a
SCB	65.4a	56.7a	16.6a	27.2a	2.4a	2.2a

[†]Moisture-free basis.

*Means of a parameter within a column followed by different letters are significantly different at $P \leq 0.05$.

Table 29 The potentially recoverable oil, yield of the kernel-rich fraction (KRF) and the protein and crude fibre contents of the KRF of sunflower as affected by fertilisation with sodium borate (SB) and sodium calcium borate (SCB) at two localities.

Treatment	Locality	
	Bethlehem	Petrus Steyn
	Potentially recoverable oil (g per 100 g seed[‡])	
Control	43.8a*	35.8a
SB	44.1a	37.1a
SCB	45.5a	37.8a

Continued overleaf

Table 29 continued

Treatment	------ Locality ------	
	Bethlehem	Petrus Steyn
	------ KRF yield † (g per 100 g seed) ------	
Control	30.1b	34.3a
SB	29.7b	32.5a
SCB	32.3a	33.6a
	----- KRF protein content † (%) -----	
Control	39.5a	55.8a
SB	37.2ab	57.2a
SCB	36.4b	55.2a
	---- KRF crude fibre content † (%) ----	
Control	21.7a	11.1a
SB	22.7a	12.5a
SCB	21.9a	12.7a

‡ Moisture-free basis.

†Oil and moisture-free basis.

*Means of a parameter within a column followed by different letters are significantly different at $P \leq 0.05$.

DISCUSSION AND CONCLUSIONS

The mean seed oil contents of 50.8 and 39.9 for Bethlehem and Petrus Steyn respectively, compares well with the mean maximum and minimum values of 52.6 and 41.2% found for environments in Chapter 4 (Table 18). The potentially recoverable oil of the seed produced at Petrus Steyn (36.9 g per 100 g seed) was poor and approximately 17% lower than that of the seed produced at Bethlehem (445 g kg^{-1}). The KRF protein content at Petrus Steyn was extremely high and almost 1.5 times that for the KRF produced from the Bethlehem seed. Despite the relatively high hullability of the seed produced at Bethlehem, the KRF protein content of 37.7% is below, and the crude fibre content of 22.1% is above the statutory moisture-free limits of 44.4 and 17.8% respectively.

The reactions of sunflower yield and seed characteristics to B fertilisation are inconsistent. Yield increases were anticipated at both localities as B deficiency symptoms are often observed in these areas. Leaf analyses indicated neither deficiency nor toxicity. The results however, are not unique as yield reductions due to B fertilisation have been reported (FSSA, 1977; Hilton & Zubriski, 1985).

The lack of consistency in the reaction of the seed yield and hullability to B fertilisation may be due to the large difference in soil fertility between the two localities (Table 26) and the fact that soil moisture status, temperature and even light intensity affect the uptake of B (Moraghan & Mascagni, 1991). What is more, published B deficiency (and most likely also toxicity) limits are not in agreement. Using solution culture experiments, the critical concentration for deficiency was determined as 190 mg kg^{-1} by Blamey *et al.* (1997) which is more than five times the limit of 34 mg kg^{-1} determined through field trials (Blamey *et al.*, 1979; Fernandez *et al.*, 1985).

The inconsistent results are probably due to the fact that the effect of B deficiency on plants is not well understood, as stated by Moraghan & Mascagni (1991), and the fact that so many environmental variables affect the uptake of B. Although differences between treatments were small and no boron deficiency was observed, the indications are that apart from yield, B supply can also affect hullability and consequently oil cake quality.

CHAPTER 7

EFFECT OF WATER STRESS DURING GRAIN FILLING ON SEED YIELD AND QUALITY

INTRODUCTION

The yield of sunflower is profoundly affected by water stress (Muriel & Downes, 1974; Talha & Osman, 1975). Seed composition is also affected by water stress. Water stress during the vegetative and reproductive growth stages reduces the seed oil content (Muriel & Downes, 1974; Hall *et al.*, 1985). Seed protein content, however, seems to be less affected by water stress after anthesis than the oil content (Connor & Sadras, 1992).

Water stress during seed filling affect physical seed characteristics like the seed size (Baldini & Vannozzi, 1999), hectolitre mass (Unger, 1982) and hull content (Connor & Hall, 1997). The effect of water stress on seed hullability, a seed trait determining the efficiency of seed processing and the quality of the oil cake, is still unknown. Denis, Dominguez & Vear (1994) grew several genotypes at two localities and found the hullability of seed from the drier locality to be higher than seed from the wetter locality. Merrien *et al.* (1992) and Baldini & Vannozzi (1996) on the other hand, found the hullability of seed from a frequently irrigated treatment to be higher than that of a less frequently irrigated treatment.

As water stress affects yield and seed composition, the objective of this field trial was to create two levels of crop water stress during the reproductive period, to quantify it and measure its effect on the seed yield, some physical and chemical seed characteristics, hullability and the potentially recoverable oil and the oil cake yields of three cultivars.

MATERIALS AND METHODS

A field trial, designed with three complete blocks was planted on 20th November 1997 at ARC-Grain Crops Institute, Potchefstroom. Plots consisted of four rows spaced at 0.9 m and 10 m long. After emergence seedlings were thinned to 35 000 plants ha^{-1}. Treatments consisted of three genetically unrelated cultivars (HV 3037, PAN 7392 and SNK 37) and crop water stress (high and low water stress). The low water stress treatment received 55 mm of irrigation at the opening of the inflorescence on 26th January 1998, which is growth stage R4 according to Schneiter & Miller (1981), and another 55 mm two weeks later. The high water stress treatment received no irrigation. From planting to growth stage R4, 166 mm of rain was recorded. On days 15, 20 23 and 24, after R4, 0.5, 1.8, 9.7 and 6.7 mm of rain was recorded. On day 25 after R4, 93 mm of rain was recorded which terminated the stress treatment.

To quantify the crop water stress, the relative water content of the leaves was measured twice a week from growth stage R4 to R8. This was done by clipping approximately 4 cm^2 from the tip of one of the five upper leaves from four randomly chosen plants from the two inner rows of each plot between 12:00 and 13:00. The leaf cuttings were immediately sealed in a plastic bag to prevent water loss, transported to a laboratory and the fresh mass determined. After floating the cuttings on de-ionised water in closed petri-dishes for 18 h at room temperature in darkness, the turgid mass was determined. The dry mass was measured after drying for 3 h at 75°C. The relative water content (RWC) was calculated as follows:

$$RWC = ((\text{Fresh mass - dry mass})/(\text{Turgid mass - dry mass})) \times 100\%$$

Grain yield was measured by harvesting 8 m each from the two central rows per plot. The hectolitre mass, moisture content, thousand seed mass, hull content and hullability were measured as previously described in the materials and methods of Chapter 2 section II. After dehulling, samples of the seed, kernels and kernel rich fractions were chemically analysed for oil, protein, crude fibre and moisture content (PPECB Quality Assurance Laboratory, P.O. Box 433, Silverton, 0127).

The potentially recoverable oil, the oil and moisture-free yield of the KRF, and the protein and crude fibre content of the KRF were calculated as described in the materials and methods of Chapter 2 section II. Analyses of variance were done on the data collected using Statgraphics (Version 5, Statistical Graphics Corporation, Rockville, Maryland USA).

RESULTS AND DISCUSSION

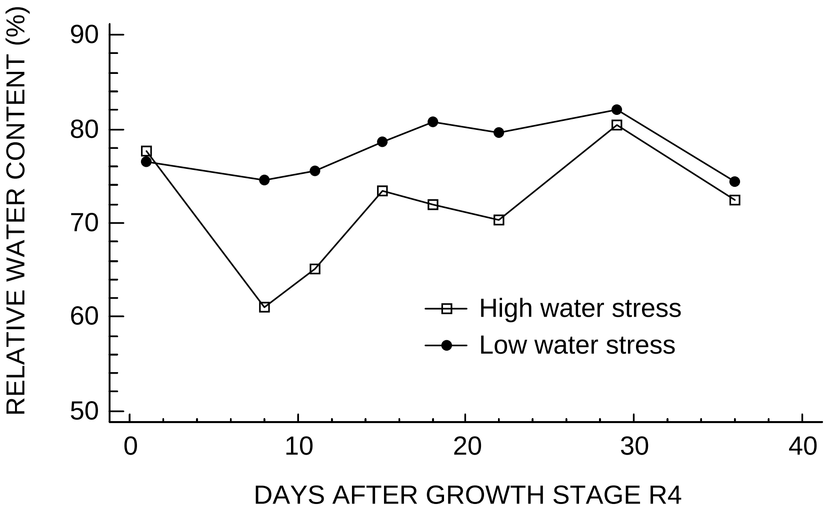
Crop water stress

Due to the irrigation applied to the low water stress plots, the RWC of the low and high water stress treatment levels differed from the R4 stage until 25 days later when 93 mm of rain alleviated it (Figure 5). The occurrence of less rain than 10 mm day^{-1} had no measurable effect on the RWC nor were differences among cultivars measured at any stage. According to norms laid down by Hsiao (1973), the difference in water stress between the two treatment levels varied from moderate at 8 and 11 days after R4, to mild at 15, 18 and 22 days after R4. Calculated for the period of measurement which covered the whole grain filling period, the RWC of the low and high stress levels was 77.8 and 71.4% respectively. The high stress level therefore experienced a mild stress compared to the low stress treatment (Hsiao, 1973) for the duration of the reproductive growth period.

Yield and physical seed characteristics

Grain yield was affected by crop water stress with the high stress level yielding 23% less than the low stress level (Table 30). The thousand seed mass was affected by both cultivar and crop water stress. Calculated over cultivars the thousand seed mass for the high stress level was 18% lower than that for the low stress level. The reduction in grain yield was thus mainly due to the reduction in thousand seed mass.

The hectolitre mass was affected by crop water stress, cultivars and an interaction between the two factors (Table 30). Both HV 3037 and PAN 7392 had higher hectolitre mass values for the high crop water stress level than for the low stress level while SNK 37 was unaffected (Table 31). Differences in hectolitre mass amongst cultivars were larger than between the high and low crop water stress levels with PAN 7392 having only 90% of the hectolitre mass of HV 3037.



Hull content was affected by cultivar and crop water stress × cultivar interaction (Table 30). The hull content of PAN 7392 and SNK 37 for the low crop water stress level was approximately 3% higher than for the high stress level (Table 31). The opposite was found for HV 3037 where the hull content of the low crop water stress level was approximately 8% lower than of the high stress level, The change in hull content was small in comparison to the changes in yield and the thousand seed mass, brought about by the water stress levels.

Hullability was affected by both crop water stress and cultivar (Table 30). Hullability for the high crop water stress level was 14% lower than for the low stress level. This supports the observations of Baldini & Vannozzi (1996) and Merrien *et al* (1992) that seed from frequently irrigated plots hulled easier than seed from less frequently irrigated plots. Differences in hullability amongst cultivars were larger than between the high and low crop water stress levels with HV 3037 having only 60% of the hullability of PAN 7392.

Table 30 Grain yield, hectolitre mass, thousand seed mass (TSM), hull content, hullability and fines produced during dehulling from the seed of three sunflower cultivars as affected by crop water stress during the grain filling period.

Treatment	Grain yield (kg ha $^{-1}$)	Hectolitre mass (kg hl $^{-1}$)	TSM (g)	Hull content (%)	Hullability (%)	Fines (%)
Crop water stress						
Low	2814a‡	46.4b	61.4a	22.1a	66.9a	8.9a
High	2170b	47.6a	50.6b	22.2a	57.5b	8.3a
Cultivar						
HV 3037	2570a	49.4a	56.6b	20.8c	46.3c	7.0b
PAN 7392	2483a	44.7c	49.4c	23.8a	80.2a	11.1a
SNK 37	2422a	47.0b	62.0a	21.9b	60.0b	7.7b
Significance of the F values from the analysis of variance						
Water stress	**	**	**	NS	**	NS
Cultivar	NS	**	**	**	**	**
W × C†	NS	*	NS	**	NS	**
CV(%)	11	3	9	3	10	14

‡ Means followed by different letters in a column differ significantly at P ≤ 0/05.

**,* Significant at the 0.05 and the 0.01 probability levels, respectively.

† W × C = water stress × cultivar interaction.

Table 31 Interactions of hectolitre mass, hull content and fines produced of three cultivars at the low and high water stress levels

Cultivar	Hectolitre mass (kg hl $^{-1}$)		Hull content (%)		Fines (%)	
	Low stress	High stress	Low stress	High stress	Low stress	High stress
HV 3037	48.7	50.0	19.9	21.6	6.5	7.4
PAN 7392	43.5	45.9	24.1	23.5	11.5	10.6
SNK 37	47.0	47.0	22.2	21.5	8.7	6.8

Table 32 The moisture free protein, oil and crude fible (CF) content of the seed and kernels, the potentially recoverable oil (PRO) and the oil and moisture free protein and crude fibre content and yield of the kernel rich fraction (KRF) of three cultivars as affected by crop water status during the grain filling period

Factor	--------------------Seed--------------------			------------------Kernel------------------			PRO	--------------------KRF--------------------		
	Protein	Oil	CF	Potein	Oil	CF		Yield	Protein	CF
	(%)	(%)	(%)	(%)	(%)	(%)	-----g 100 g seed-----		(%)	(%)
Water stress										
Low	18.2a[‡]	50.3a	18.2a	22.0a	64.4a	2.9a	43.5a	32.7a	47.1a	24.2a
High	19.6a	49.6a	17.9a	23.1a	62.9b	2.9a	44.1a	34.5a	49.1a	23.8a
Cultivar										
HV 3037	19.8a	50.7b	16.5b	23.7a	62.4b	3.0a	45.8a	36.9a	48.6a	24.1a
PAN 7392	19.0ab	46.9c	20.5a	23.1a	63.2b	2.7a	38.9b	30.3c	50.1a	23.2a
SNK 37	17.8b	52.2a	17.1b	20.8b	65.2a	3.0a	46.8a	33.6b	45.6b	24.7a
Significance of the F values from the analysis of variance										
Water stress	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Cultivar	NS	**	**	*	**	NS	**	**	*	NS
W × C[†]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	7	2	6	6	2	9	3	5	4	9

[‡] Means followed by different letters in a column differ significantly at at P ≤ 0/05.

**,* Significant at the 0.05 and the 0.01 probability levels, respectively.

[†] W × C = water stress × cultivar interaction.

The production of fine material which is an indication of losses during processing was affected by cultivar and crop water stress × cultivar interaction (Table 30). The fine material produced by PAN 7392 and SNK 37 showed a decline of 8 and 22% respectively, from the low to the high crop water stress level. HV 3037 on the other hand showed an increase of approximately 14% in the production of fine material from the low to the high crop water stress level (Table 31).

Chemical composition and potentially recoverable oil and yield of the kernel rich fraction

The protein, oil and crude fibre content of the seed, the kernel and the kernel rich fraction, the potentially recoverable oil and the oil and moisture free yield of the kernel rich fraction, are shown in Table 32. Seed oil content was not affected by the crop water stress treatment but by cultivar only. This seems to contradict the results of Alessi *et al* (1977), Hall *et al* (1985), Muriel & Downes (1974) and Talha & Osman (1975). However, the moisture free oil content of the kernels was affected by the crop water stress treatment with the high stress level containing 2.3% less oil than the low water stress level. The wild water stress thus reduced the oil content of the kernels which was most likely obscured from the seed analyses due to the presence of the hulls. The protein and crude fibre content of the seed were not affected by the water stress treatments. Seed oil and crude fibre content differed amongst cultivars.

The moisture and oil free yield and protein content of the kernel rich fraction, which is an indication of the yield and quality of the oil cake that can be expected, was not affected by the water stress treatments. It was, however, affected by the cultivar (Table 32). The crude fibre content of the kernel rich fraction was not affected by the water status treatment nor by cultivar, which is unexpected considered the differences in hullability observed. This might be due to variation in the crude fibre content of the hulls which was not determined in this investigation. Theerta Prasad & Channakrishnaiah (1995) reported the fibre content of hulls to vary from 59 to 87%. Smith *et al* (1989) also found the crude fibre content of South African produced seed to vary from 13 to 28%, much more than the oil or protein content.

CONCLUSIONS

A mild water stress developed and persisted for the first 25 days of the reproductive growth period for the high water stress level, compared to the low water stress level. Grain yield, which was reduced by 23%, was more sensitive to this water stress than any of the physical or chemical seed traits. Hullability was reduced by 14% and the kernel oil content by only 2.3% while the seed composition was not affected. The potentially recoverable oil was not affected by the water stress nor were the yield of the kernel rich fraction or its protein and crude fibre contents. How the seed quality parameters will be affected by moderate or severe water stress and stress during the latter part of the reproductive stages is still unknown. Due to the difference in seed composition, hullability and production of fine material of cultivars, the potentially recoverable oil, yield of the kernel rich fraction and protein content differed amongst cultivars.

The work reported in this chapter, has been published (Nel, Loubser & Hammes, 2000e).

CHAPTER 8

RELATIONSHIP BETWEEN SEED QUALITY AND EASILY MEASURABLE SEED CHARACTERISTICS

INTRODUCTION

South African sunflower seed quality parameters vary considerably. Judged from the results of the annual national cultivar trials, oil content ranges between 36 and 50% and protein content between 10 and 24%. Hullability, which is the percentage hull that can easily be removed, varies between 45 and 94% (Chapter 4). This variation in the quality parameters consequently gives rise to variation in the value of the seed for the oil expressing industry.

Most of the high oil content sunflower is currently traded without grading the seed in terms of its processing value. This lack of a grading system often leads to a purchase price that is not in line with the processed value of the seed, which puts the oil expressing industry under unnecessary financial risk. On the other hand, producers may not be adequately remunerated for high quality seed produced. In some cases, the seed oil content is measured and the price adjusted accordingly, while the protein content and hullability, the other two quality characteristics, are not taken into account. The value of the oil cake is approximately 20% of the total value of the seed for the oil expressing industry, depending on the current price of oil and oil cake and the yield of these entities from the seed (Fourie, 1999).

The lack of a grading system for sunflower seed and related pricing structure does not motivate farmers to produce seed with a high processing quality. Thus seed yield per ha remains the only measure of success for the sunflower producer. This will not enhance the competitiveness of the sunflower industry.

No grading system other than the statutory limits set on the amount of poisonous seed and foreign matter in the seed is currently in use worldwide, although price is determined by oil content in certain countries. A distinction between high and low oil content sunflower is also made locally without quantifying the oil contents of these two types. Seed protein content and hullability are not taken into account. According to Fourie (1999) the existing South African infrastructure does not cater for the classification and storage of different grades. The cost of equipment and the slow and tedious procedure to determine oil and protein contents are reasons for the lack of grading. Currently, equipment to measure the hullability quickly and accurately on a routine basis is unavailable.

The possibility exists that seed quality can be estimated from easily measurable seed characteristics. Research has indicated that seed characteristics such as seed size and seed density, which are easily measurable, correlate poorly to reasonably well with some of the quality parameters like hullability (Chapter 4, Dedio, 1993; Baldini & Vannozzi, 1996). The estimation of the quality parameters may even improve if multiple regression techniques are used. If these relationships between the easily measurable characteristics and quality parameters are universal, and capable of estimating seed quality with acceptable accuracy, it will provide a practical procedure for classifying seed according to its processing value.

In Chapter 4, simple correlation coefficients between seed quality parameters and easily measrable seed characteristics are reported for only five cultivars grown at six environments. At least 15 cultivars are commercially available annually which are grown at various and diverse locations. The objectives of the investigation reported in this chapter were to analyse seed from all the available cultivars produced at various environments:

1. To quantify the easily measurable seed characteristics (hectolitre mass, thousand seed mass and seed size distribution), the not so easily measurable seed characteristics (hull content and seed dimensions) and the seed quality characteristics (oil content, protein content, hullability and amount of fine material produced).

2. To determine if any reliable relationships exist between the seed quality parameters (oil content, protein content and hullability) and the easily measurable seed characteristics for application in a seed grading system through multiple regression analyses.

MATERIALS AND METHODS

Seed samples of the 19 cultivars included in the national cultivar trials, produced during the 1999/2000 season in 11 trials at various localities were used for the analyses. Easily measurable seed characteristics were considered to be the moisture content, thousand seed mass, hectolitre mass and seed size distribution. The seed moisture content was measured by means of the near infrared method by the PPECB Quality Assurance Laboratory (P.O. Box 433, Silverton 0127, South Africa). The thousand seed mass was measured by recording the mass of 100 randomly selected seeds and the hectolitre mass by determining the mass of 0.5 l seed. To determine the seed size distribution, two sieves with slot sizes of 3.0 and 3.5 mm were used to classify approximately 300 ml of seed into small, medium and large size classes. All measurements were done in triplicate.

The seed dimensions and hull content are considered less easily measurable seed characteristics due to the time it takes to determine them and the precision required. Seed dimensions (length, width and thickness) were measured using a caliper on 10 randomly chosen seeds. A seed sample of between 1.5 and 2 g was manually dehulled for hull content determination as described in Chapter 2.

Seed dehulling, separation into the different fractions, calculation of hullability, fines produced and chemical analyses were done as described in the materials and methods of Chapter 5. The other two seed quality parameters, namely the oil and protein contents, were determined with the near infrared method by the PPECB Quality Assurance Laboratory. Multiple linear regression equations were developed relating the seed quality parameters firstly with the easily measurable seed characteristics and secondly with both the easily and not so easily measurable seed characteristics, by means of the step up variable selection procedure of the Statgraphics *Plus* for Windows statistical software package (Manugistics Inc., 2115 East Jefferson Street, Rockville, Maryland 20852, USA).

RESULTS AND DISCUSSION

Seed characteristics

Table 33 shows the F-values from the analyses of variance, means, standard deviations, minimum and maximum values for the easily measurable seed characteristics for the 1999/2000 season. Due to the analysis of only one sample replicate, the effect of the cultivar × environment interaction could not be calculated. Mean values for these characteristics for each cultivar and locality are shown in Table 34. The F values for the easily measurable characteristics indicate that locality was a larger source of variation than cultivar, with the exception of seed length and hull content which were more affected by cultivar. Seed moisture content ranged from 5.9 to 8.1%. This range in moisture content might be less than what can be expected for commercially produced fields as the upper limit of 10% moisture content is set for storage. All the other easily measurable characteristics showed large variations, as indicated by the minimum and maximum values recorded (Table 33).

Table 35 shows the F-values from the analysis of variance, and the mean, standard deviation, maximum and minimum values measured for the seed quality parameters for the 1999/2000 season. Mean values for these characteristics for each cultivar and locality are shown in Table 36. All the seed quality parameters were affected more by the environment than by cultivar, as indicated by the F-values. The ranges of these characteristics were also wide, as indicated by the minimum and maximum values recorded.

Relationships

Table 37 shows the multiple regression equations obtained with the highest R^2-values. Hullability is poorly related to the easily measurable and not so easily measurable seed characteristics, as indicated by the relatively low R^2-values and high mean absolute errors of the estimate. However, comparing the mean absolute error with the range in hullabilities found (Table 35), the equations might be useful for the estimation of the hullability in order to divide seed into two broad hullability classes.

Table 33 Results of the analyses of variance and summary statistics for the moisture content (MO), hectolitre mass (HM), thousand seed mass (TM), percentages of small (SS), medium (MS) and large seed (LS), seed length (DL), seed width (DW), seed thickness (DT) and hull content (HC) of sunflower seed produced from 19 cultivars at 11 localities during the 1999/2000 season

	DF	MO (%)	HM (kg hl^{-1})	TM (g)	SS (%)	MS (%)	LS (%)	DL (mm)	DW (mm)	DT (mm)	HC (%)
F-values from the analyses of variance											
Cultivar	18	6**	7**	11**	10**	4**	9**	13**	10**	5**	12**
Locality	10	8**	26**	29**	13**	16**	22**	9**	18**	39**	8**
Total	208										
CV(%)		3	5	9	41	24	32	4	6	8	8
Summary statistics											
Mean		6.9	41.7	65.4	24.0	33.9	42.1	11.1	5.4	3.2	27.3
Standard dev.		0.3	2.7	10.7	15.0	11.3	22.1	0.6	0.5	0.4	3.3
Minimum		5.9	31.1	35.7	1.0	3.3	1.8	9.6	4.3	2.3	19.8
Maximum		8.1	50.2	100.6	85.6	61.2	95.6	12.7	7.3	4.9	37.6

** Significant at the 0.01 probability level.

Table 34 Mean values for the moisture content (MO), hectolitre mass (HM), thousand seed weight (TW), percentages of small (SS), medium (MS) and large seed (LS), seed length (DL), seed width (DW), seed thickness (DT) and hull content (HC) of sunflower seed produced from 19 cultivars at 11 localities during the 1999/2000 season

	MO (%)	HM (kg hl^{-1})	TW (g)	SS (%)	MS (%)	LS (%)	DL (mm)	DW (mm)	DT (mm)	HC (%)
Cultivars										
AG SUN 5551	6.71	39.5	66.6	20.2	36.5	43.3	11.3	5.22	3.04	25.5
AG SUN 8751	6.86	40.3	64.5	26.0	35.5	38.5	11.0	5.15	3.19	27.2
CRN 1414	6.62	37.2	66.6	18.6	30.0	51.3	11.0	5.74	3.34	25.4
CRN 1424	6.65	37.5	70.9	16.2	31.0	52.8	11.8	5.73	3.37	30.7
CRN 1435	6.95	37.5	63.4	19.3	30.9	49.9	10.3	5.87	3.46	26.1
HV 3037	6.77	39.2	73.5	12.5	26.2	61.3	11.8	5.38	3.30	24.7
HYSUN 333	7.15	40.2	67.4	23.3	37.2	39.5	11.1	5.35	3.04	26.8
HYSUN 345	7.03	36.9	54.6	32.2	32.3	35.5	10.4	5.41	3.22	27.6
HYSUN 350	6.89	36.7	52.0	52.3	34.4	13.4	10.8	4.81	2.83	28.6
LG 5630	6.73	39.8	65.2	19.0	29.6	51.4	10.5	5.48	3.24	23.0
PAN 7351	7.13	39.4	66.2	23.4	41.9	34.7	11.3	5.10	3.08	30.2
PAN 7355	7.18	40.7	64.0	35.5	41.9	22.7	11.4	5.09	3.00	31.9
PAN 7371	7.09	39.4	61.3	34.9	39.5	25.5	11.5	5.12	3.01	29.7
PAN 7392	6.99	37.2	66.5	19.7	39.3	40.9	11.5	5.30	3.14	27.2
PHB 6488	6.66	37.7	61.7	26.3	34.7	39.1	11.6	5.20	3.12	26.8
PHB 6500	6.90	40.8	60.4	24.0	36.1	39.9	10.6	5.39	3.30	26.8
SNK 50	6.74	39.5	73.4	16.0	28.0	56.0	10.8	5.77	3.52	28.0
SNK 73	6.98	38.0	69.6	19.1	31.1	49.8	11.1	5.44	3.24	28.0
SNK 77	6.8	38.7	74.9	17.4	27.4	55.1	11.1	5.67	3.36	24.4
$LSD_{(P = 0.05)}$	0.17	1.4	5.1	8.2	6.8	11.2	0.3	0.25	0.22	1.9
Localities										
Bloemfontein	7.17	41.5	74.3	18.4	36.3	45.3	11.5	5.43	3.49	27.9
Koppies	6.83	37.7	68.1	24.6	31.4	44.0	10.9	5.24	3.32	27.6
Marikana	6.71	38.3	56.9	29.0	39.8	31.2	11.1	5.19	2.80	27.6
Potchefstroom 1	6.68	41.6	65.8	36.9	42.8	20.3	10.8	5.08	3.25	27.3
Potchefstroom 2	6.96	38.9	63.8	34.2	39.0	26.8	10.8	4.98	3.16	25.1
Potchefstroom 3	6.94	37.1	51.5	32.8	36.9	30.3	10.8	5.19	2.72	26.7
Settlers	6.65	38.8	67.3	18.5	34.3	47.2	11.3	5.42	2.91	27.4
Theunissen	7.23	36.5	71.3	12.9	16.5	70.6	11.5	6.02	4.00	28.5
Ventersdorp	6.70	35.7	59.1	17.8	31.3	50.9	10.8	5.54	3.03	30.1
Viljoenskroon	7.03	40.0	75.9	18.2	26.3	55.4	11.2	5.63	3.57	26.9
Warmbaths	6.85	40.1	65.4	20.5	38.1	41.4	11.3	5.44	2.96	25.1
$LSD_{(P = 0.05)}$	0.13	1.1	3.8	6.3	5.2	8.5	0.3	0.19	0.17	1.4
Mean	6.89	38.7	65.4	24.0	33.9	42.1	11.1	5.38	3.21	27.3

Table 35 Results of the analyses of variance, mean, standard deviation, minimum and

maximum for the hullability (H), amount of fine material produced (F), oil content (O) and the protein content (P) of sunflower seed produced from 19 cultivars at 11 localities during the 1999/2000 season

Source	DF	Hull-ability (%)	Fine material (%)	Seed oil (%)	Seed protein (%)
F-values from the analyses of variance					
Cultivar	18	7**	7**	6**	6**
Locality	10	11**	13**	21**	37**
Total	208				
CV (%)		14	11	3	6
Summary statistics					
Mean		73.1	6.3	43.8	18.3
Standard dev.		14.3	1.0	1.8	2.0
Minimum		37.5	3.7	39.1	12.7
Maximum		100.0	9.8	49.0	22.4

** Significant at the 0.01 probability level.

Seed oil content is also poorly related to both the easily measurable and not so easily measurable seed characteristics with its R^2-values below 59%. The mean absolute error (MAE) of 1.2% or less for both equations is small, however, considering the range of oil contents involved (Table 35). Either of these two equations can thus be used to classify seed into two or three oil content classes, especially if the threshold values dividing these classes are several percentage points apart. Although seed might be wrongly classified, the mean oil content of this seed will only be one percentage point above or below the threshold value as the mean absolute error equals 1% (Table 37).

Seed protein content is poorly related to the measured seed characteristics, even less so than the hullability and oil content. The mean absolute error is again small in relation to the range of measured protein contents, making the equation useful if the seed is to be separated into two or three classes (Table 37).

Table 36 Mean values for hullability, amount of fine material produced, seed oil content and the seed protein content of sunflower seed produced from 19 cultivars at 11 localities during the 1999/2000 season

	Hullability (%)	Fine material (%)	Seed oil (%)	Seed protein (%)
Cultivars				
AG SUN 5551	72.3	6.97	45.1	18.1
AG SUN 8751	70.6	6.87	44.4	18.1
CRN 1414	82.3	6.79	44.9	17.1
CRN 1424	81.2	6.10	43.9	17.8
CRN 1435	75.4	5.87	43.2	19.1
HV 3037	70.3	6.38	44.6	19.3
HYSUN 333	71.6	5.30	43.0	19.4
HYSUN 345	60.2	5.95	42.8	18.9
HYSUN 350	59.1	6.33	42.3	18.5
LG 5630	58.0	6.84	43.8	20.1
PAN 7351	81.6	5.59	42.9	17.7
PAN 7355	76.5	5.97	42.9	17.7
PAN 7371	74.7	5.67	43.4	18.0
PAN 7392	82.7	5.79	43.8	17.5
PHB 6488	66.2	7.37	45.2	17.6
PHB 6500	66.7	6.41	43.6	18.4
SNK 50	81.8	6.48	44.2	18.0
SNK 73	82.9	6.17	43.5	18.1
SNK 77	72.8	6.87	45.2	17.7
$LSD_{(P = 0.05)}$	8.4	0.58	1.0	0.9
Localities				
Bloemfontein	80.1	6.52	44.0	18.5
Koppies	77.8	6.12	45.5	15.0
Marikana	73.9	6.46	43.5	18.8
Potchefstroom 1	65.9	7.44	45.3	17.3
Potchefstroom 2	71.2	6.43	44.3	17.7
Potchefstroom 3	65.5	6.21	42.8	18.4
Settlers	66.1	6.41	43.7	19.6
Theunissen	87.8	5.04	41.1	20.5
Ventersdorp	78.4	6.41	44.7	15.5
Viljoenskroon	73.7	6.01	43.7	19.1
Warmbaths	62.5	6.26	43.5	19.5
$LSD_{(P = 0.05)}$	6.4	0.44	0.7	0.7
Mean	73.0	6.30	43.8	18.3

Table 37 Results of the regression analyses relating the seed quality characteristics to both the easily and the not so easily measurable seed characteristics

Equations	R^2 (%)	MAE[c] (%)
Hullability		
H^a = 10.12MO - 2.219HM + 0.5381TM - 0.4223SS - 0.1913LS + 72.25	41.2	8.7
H^b = 8.368MO - 1.621HM + 0.4326TM - 0.2402SS + 0.7386HC + 35.51	42.3	8.6
Oil content		
O^a = -3.897MO + 0.068TM - 0.029LS + 67.44	51.4	1.0
O^b = -3.73MO + 0.06TM + 0.035MS - 0.328DL - 1.162DW + 0.661DT - 0.067HC + 74.01	58.3	1.2
Protein content		
P^a = 1.482MO + 0.153HM - 0.06MS + 4.175	18.3	1.4
P^b = 2.186MO + 0.178HM - 0.053MS + 1.601DW - 1.501DT - 0.095HC - 1.987	27.8	1.3
Fine material		
F^a = -2.006MO + 0.104HM + 0.01SS + 15.83	49.6	0.5
F^b = -1.919MO + 0.094HM + 0.01SS - 0.034HC + 16.54	50.7	0.5

DL = seed length (mm); DW = seed width (mm); DT = seed thickness (mm); HC = hull content (%); H = hullability (%); HM = hectolitre mass (kg hl^{-1}); LS = large seed (%); MO = moisture content (%); MS = medium seed (%); O = oil content (%); P = protein content (%); SS = small seed (%); TM = thousand seed mass (g).

[a] Only easily measurable seed characteristics included. [b] Both easily and not so easily measurable seed characteristics included.

[c] Mean absolute error.

Poor relationships also exist between the amount of fine material produced and the easily and not so easily measurable seed characteristics. The mean absolute error associated with these relationships, however, indicates that they too can be used as a measure for the classification of seed into a few classes.

Seed moisture content plays an important role in all the relationships found between the seed quality parameters and measurable seed characteristics (Table 37). Moisture loss can occur during storage. This can be expected if harvest and delivery for storage take place at a relatively high (10%) moisture content, followed by a relatively long period of storage and aeration with relatively dry air.

A decline in the moisture content will affect the quality parameters of the seed and will probably alter the classification of the seed, especially those close to the threshold value dividing different classes. Seed left to dry naturally usually reach a constant moisture content of approximately 6%. Assuming that this is also the case during storage, this drying (from 10% to 6%) will lead to an increase in the seed oil content of less than 1.8 percentage points and less than 0.8 percentage points for the protein content. The hullability and production of fine material can increase by up to 8 and 4 percentage points respectively (Chapter 2).

CONCLUSION

Although relationships between the seed quality parameters and the easily measurable seed characteristics are generally poor, as indicated by their low R^2-values, reasonably accurate classification of seed seems possible using the easily measurable seed characteristics due to the relatively small absolute errors found.

CHAPTER 9

GENERAL DISCUSSION AND CONCLUSIONS

In the past, sunflower breeding was focussed on increasing seed oil content and grain yield, while the seed protein content and hullability received little attention. This lack of focus on the hullability and protein content probably contributed to the problem of poor and variable quality of the oil cake. To be economically sustainable the South African sunflower seed processing industry need seed which not only have an acceptable oil yield but also oil cake with acceptable quality. Seed of acceptable quality will have an oil yield of at least 40 g of oil per 100 g seed and oil cake with at least 40% protein and less than 16% crude fibre at a maximum moisturecontent of 10%. A large proportion of the oil cake produced in South Africa does not meet these standards (Smith *et al.*, 1989).

Results reported in Chapter 2 showed that by natural drying of seed from 9.5 to 5.7% moisture content, hullability improved, leaving only 5% of the hulls in the kernel-rich fraction instead of 13%. The undesirable production of fine material which is lost with the hulls, however, increased simultaneously. It is also clear that the hullability and the production of fine material of seed from different origins (from different cultivars or locations) will respond differently to drying. If the fine material is separated from the hulls and channeled back to the kernel rich fraction, drier seed will benefit oil cake quality due to the inclusion of a smaller percentage of hulls.

It has been observed several times that larger seed tend to dehull more easily than smaller seed (Merrien *et al.*, 1992; Dedio & Dorrell, 1989). Accordingly, the sifting of seed into size classes may also be a means to separate seed into quality classes. Sifting of a seed lot (one cultivar produced at a specific locality) into different size classes and dehulling them separately, showed little benefit for the potentially recoverable oil and protein yield (Chapter 2). Seed sifting, however, proved to be an effective method to produce different potential oil cakes with differentiated qualities from one seedlot. Differences in the protein content of up to 5.5 percentage points between potential oil cakes produced from different size classes have been found, which represent the difference between poor quality oil cake (e.g. 35% protein) and oil cake with acceptable quality (e.g. 40% protein content).

Environmental variables played the major role in determining the physical (hectolitre mass, thousand seed mass, seed size distribution, hullability) and chemical (oil, protein and crude fibre contents) seed composition while cultivars played a less important role, as shown in Chapter 8. Genetic variation was restricted to the 19 available cultivars included in the national cultivar performance trials, which can be assumed to be good performers in terms of grain yield, oil content and disease resistance. Thousand seed mass and hullability were also strongly affected by cultivar and sometimes the cultivar effect dominated over the environmental effects, as shown by the results in Chapter 4. The seed physical characteristics were also affected by a relatively small environment □ cultivar interaction. This was due to the change in ranking of cultivars from one environment to another, which does not support the results on hullability of Denis, Dominguez & Vear (1994). The environment □ cultivar interaction affected the potential oil and oil cake yield only slightly, due to changes in ranking of cultivars and small effects on the seed protein and crude fibre contents. The stability of certain seed traits from specific cultivars was also evident. The apparent stable hullability of PAN 7392 and stable production of fine material of CRN 1445 over environments give clear indications that the stability of these characteristics is genetically determined. Consequently, it seems possible to genetically improve and stabilize the characteristics in cultivars through breeding, a view also held by Baldini & Vannozzi (1996).

Water stress is one of the major uncontrollable environmental variables that affects the seed yield of sunflower. From literature it is also evident that seed hullability, seed oil and protein content (in order of sensitivity) are all negatively affected by moisture stress during the grain-filling period. While the effects on grain yield and seed oil content have received much attention, the effect of water stress on hullability has not been extensively studied, with mere indications of the effect of wetter and drier conditions having been reported (Merrien *et al.,* 1992; Denis, Dominguez & Vear, 1994; Baldini & Vannozzi, 1996). The results of the mild water stress during the first 25 days of the grain-filling period (Chapter 7) support the results of Baldini & Vannozzi (1996) that water stress reduces hullability. Hullability was, however, less affected than seed yield by water stress. Indications exist that water stress during the last approximate 10 days of the grain-filling period may improve hullability. During this period hull growth has ceased but the kernel is still growing. Water stress will reduce kernel growth and final kernel mass, thereby reducing the kernel content or increasing the hull content of the seed. The general observation is that higher hull content is generally associated with higher hullability. This might explain the results of Denis, Dominguez

& Vear (1994) that seed from a drier environment had a higher hullability than seed from a wetter environment. Taking into account that water stress is probably the major environmental variable affecting sunflower seed yield in South Africa, that its timing and severity can vary considerably in commercial fields and that the effect of a mild stress during the first part of the grain-filling period was investigated, the effect of water stress on seed quality warrants further investigation.

The hypothesis, based on the relationship between hullability and seed size, that hullability can be improved by reducing the plant density, has been confirmed for some cultivars like HV 3037 and SNK 37 (results reported in Chapter 3). To maximise the hullability, the plant density should be as low as possible without affecting yield. This appears to be in the order of 20 000 plants per ha, for the conditions reported in Chapter 3. Emergence of sunflower is often poor due to supra-optimal temperatures in sandy soils (Nel, 1998). To assure that low plant population does not restrict yield, a relatively large amount of seed (up to 50 000 per ha) is planted by farmers. The result is often an uneven spacing of plants and variation in the population density due to uneven emergence. In Chapter 3 only evenly spaced populations were considered. The effect of uneven spacing of plants on seed quality warrants further investigation. Different cultivars should be included in such an investigation as they can differ in their ability to compensate for low plant density under high potential conditions, as shown by Loubser *et al.* (1986).

The results of Chapter 5 show that the hullability was unaffected by N fertilisation within the normal recommended rates of application. The seed protein content increased, however, and the seed oil content decreased with increased nitrogen application, confirming previous research. Through these changes, the protein content of the potential oil cake also increased, while the potential oil yield decreased. Accordingly, nitrogen fertilisation appears to be a mechanism that can be used to manipulate the processing quality of seed by changing the protein content of the seed. Within the range of nitrogen applied, seed yield was more affected than the protein and oil contents of the seed. Only if the sunflower seed price is determined by its oil and protein contents can the economically optimum nitrogen fertilisation rate for seed quality and yield be compared with that of the grain yield per hectare, which is currently the criterion.

Boron fertilisation did not affect seed composition, most likely due to the lack of a serious boron deficiency at the experimental sites (Chapter 6). The fact that the hullability was affected by boron fertilisation at one experimental site can be explained from previous studies on boron. From some experimental evidence and theoretical considerations, Brown & Hu (1997) suggested that the primary and possibly sole function of B is as a structural component of growing tissue. In an overview, Römheld & Marschner (1991) reported that boron is, amongst other structural functions, also related to lignification. From a microscopic analysis of the hull structure, Beauguillaume & Cadeac (1992) concluded that the hullability of seed depends on the structure of the hull, including the degree of lignification of the sclerenchyma cell layer. The yield reduction due to boron fertilisation reported in Chapter 6, indicates that caution should be taken with preventive soil application of boron. Application of boron only after diagnosis of a crop deficiency may be a safer approach. However, the dissimilar seed yield results, the inconsistency of the deficiency and toxicity levels of tissue boron content reported in literature, and the fact that the seed chemical composition and hullability can be affected by boron nutrition, indicate that the boron nutrition of sunflower is still not adequately understood. As the preventive boron fertilisation of sunflower is a standard procedure for many farmers in South Africa, and boron deficiency symptoms are also reported annually, further research into boron nutrition of sunflowers is clearly needed.

The need for an improved seed grading system for sunflower and the possibility of estimating the seed oil and protein contents and the hullability from easily measurable seed characteristics have been discussed in Chapter 8. The relationships between seed characteristics and the seed quality parameters, such as between hectolitre mass and both hullability and amount of fines produced or the seed hull content and hullability, were shown in Chapter 4 and in general confirm the findings of other researchers. Some of these relationships are obvious such as the relatively high positive correlation between the seed oil content and the potentially recoverable oil, or the negative correlation between the seed oil content and the yield of the potential oil cake, or the correlation between both the seed oil and protein contents and the protein content of the expected oil cake. Validation of the equations for estimating the seed oil and protein contents and hullability from easily measurable characteristics, however, has yet to be done. In Chapter 4 it was shown that the relationship between thousand seed mass and hullability of the cultivar PAN 7392 deviated from that of the other cultivars. Validation of the equations for estimating the seed quality parameters should therefore consider cultivars on an individual basis.

A model for estimating the protein and crude fibre contents of the expected oil cake from the seed quality parameters (hullability, oil and protein contents) will be useful. In Chapter 4 it has been shown that simple correlations exist between the oil cake protein and crude fibre contents on the one hand and the hullability and the oil and protein contents of the seed on the other hand (Table 20). Estimating both the protein and crude fibre contents of the potential oil cake from the hullability, seed protein and crude fibre contents appear to be possible. To investigate this possibility, the data reported in Chapters 3 to 7 were combined for regression analyses. The oil and protein contents of the seed were expressed as oil:protein ratios. Multiple linear relationships were derived with the protein and crude fibre contents of the expected oil cake as dependent variables, and the seed oil:seed protein ratio and the seed hullability as independent variables:

$$P = 64.2 - 8.37R + 0.095H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$F = 24.1 + 4.56R - 0.235H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

where P = expected protein contents of the oil cake expressed as a percentage, on a moisture free and oil free basis

F = expected crude fibre contents of the oil cake expressed as a percentage, on a moisture free and oil free basis

R = seed oil:seed protein ratio

H = hullability

The R^2 = 0.83 for equation 1and 0.46 for equation 2, while the mean absolute errors were 1.9% for equation 1and 4.3% for equation 2.

Equations 1 and 2 were used to calculate the threshold relationships between oil:protein ratio and the hullability of seed for an oil cake protein content of 44.4% and a crude fibre content 17.8% which are the moisture free statutory limits. These thresholds are graphically displayed in Figure 6 as solid lines, differing markedly in their slopes and intercepts. Seed with different hullabilities and oil:protein ratios can fall into one of four possible oil cake quality categories. These categories range from where both the protein and crude fibre are within the statutory limits, to where both are outside these limits. It is also clear that for seed with a oil:protein ratio larger than 3.3, it is most unlikely that an oil cake containing 44.4% or more protein (with 0% moisture plus oil), can be produced from it, as hullability can not exceed 100%. It is clear that hullability, seed oil or protein contents should not be judged in isolation to characterise seed quality for oil cake quality purposes, but that it should be seen as interdependent variables.

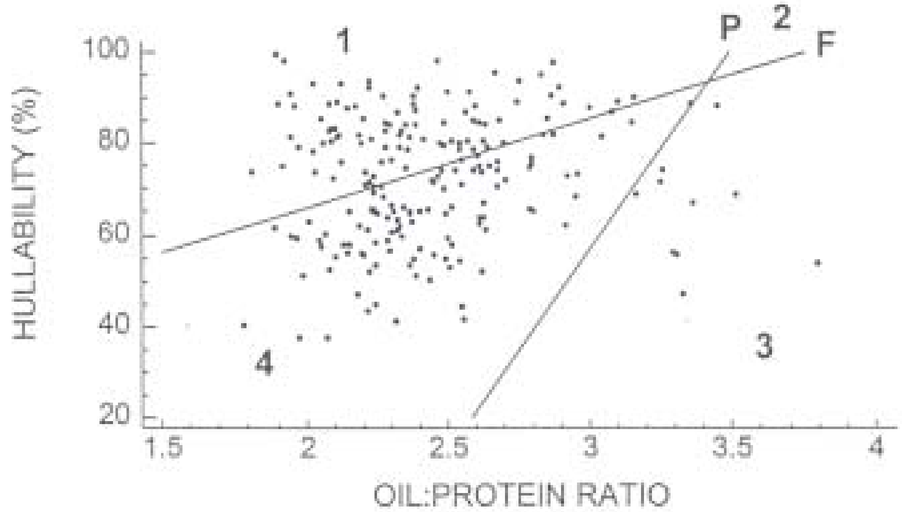


Figure 6 The relationship between hullability and the seed oil:protein ratio of sunflower seed (data points) and the threshold lines for an oil cake protein content of 44.4% (P) and a crude fibre content of 17.8% (F) assuming the oil cake contains no moisture and oil. Quadrant 1: oil cake protein > 44.4%, fibre [illegible] Quadrant 2[illegible] oil cake protein < 44.4%, fibre [illegible] 17.8%; Quadrant 3: oil cake protein < 44.4%, fibre > 17.8%; Quadrant 4: oil cake protein > 44.4%, fibre > 17.8%.

The data points in figure 6 represent the 209 seed samples analysed in Chapter 8 (Table 36). As these samples include all the cultivars available in 1999, produced at 11 localities it gives an indication of the quality range of oil cake produced from the national sunflower crop. Approximately 45% of the samples are in quadrant 1, 5% in quadrant 3 and 50% in quadrant 4 assuming that the oil cake contains 0% oil plus moisture. An estimated 95% of these samples will result in oil cake containing 44.4% or more protein (N × 6.25%). An estimated 45% of the samples will result in oil cake containing 17.8% or less crude fibre. This corresponds reasonably well with the 55% commercially produced oil cake samples analysed by Smith *et al* (1989), which contained less than 17.8% crude fibre.

Smith *et al* (1989) stated that sunflower oil cake with less than 10% crude fibre, will be considered as a product of high quality. Less than 1% of the samples analysed in Chapter 8, will be in this category. To produce oil cake with less than 10% crude fibre at 13% moisture and oil, the hullability should be complete and the oil:protein ratio should be extremely low. For example, assuming seed has an oil:protein ratio of 1.8 which is the approximate lower limit for high oil content sunflower, and applying it to equation 2, the hullability should be approximately 99% to produce oil cake with less than 10% crude fibre at 13% oil plus moisture. It appears that high oil content sunflower is unsuitable for producing oil cake with less than 10% crude fibre. Sunflower seed with a relatively low oil:protein ratio may be suitable for producing such oil cake. Open polinated cultivars available during the 1960's had an oil:protein ratio of approximately 1.5:1 indicating that high quality oil cake can be produced from it. This however, has to be confirmed.

Progress was made in identifying several of the factors affecting the processing quality of sunflower seed in South Africa, especially those affecting the oil cake quality. The relative importance of seed conditioning, setting of dehulling equipment, cultivar and environment variables has been shown. The most important environmental variables, which are dufficult to control or manipulate, appear to be water stress, nitrogen supply and possibly boron supply. As these variables were studied independently, it may be worth while investigating what effect treatment combinations and other nutrients would have on seed quality. The importance of plant density, a more easily manageable environmental variable, on seed hullability has been shown. Optimising the seed oil:seed protein ratio through breeding may be the most advisable option for improving seed quality for processing. Efforts to improve seed quality will only be made if they prove to be economically justifiable. One condition for the economic drive for any adjustment to seed quality is that the sunflower seed price should be related to seed quality, something that is currently absent in the South African industry. Some regression models which might be useful for seed quality estimation were presented.

SUMMARY

DETERMINANTS OF SUNFLOWER SEED QUALITY FOR PROCESSING

1. The low and varying protein as well as high crude fibre contents of oil cake produced from sunflower seed create problems for the South African sunflower oil expelling industry. This prompted research on factors that may affect the seed quality for processing purposes. The seed quality characteristics are the seed oil and protein contents and the hullability. Analysis of the kernel-rich fraction produced after dehulling and separation of the hulls gives an indication of the potential oil yield, oil cake yield and oil cake protein and crude fibre contents of the seed, and thus the processed value.

2. The effect of seed moisture content, while drying naturally, on the hullability of seed samples was investigated. Drier seed needed a lower huller speed for optimum dehulling. Hullability increased as seed moisture content declined. Simultaneously the amount of fine material, and associated loss of oil and protein, increased. Sifting seed into size classes had limited success, as the potential oil yield of only two of the four samples was increased by 9%, while for one sample it was reduced. Due to differences in hullability of the seed size classes, different oil cakes with different protein contents resulted.

3. In a number of field trials, the effects on the yield and seed quality characteristics of cultivar, environment and selected environmental variables, namely plant population, nitrogen and boron fertilisation and water stress during grain-filling, were studied. Seed yield and quality were more affected by environment than by cultivar. Cultivars differed in their stability for characteristics such as hullability over environments. Seed size and hullability, and as a result also the protein content of the potential oil cake, were affected by plant population, with lower populations favouring quality. Increased nitrogen application improved seed yield and seed protein content but lowered seed oil content, with no effect on hullability. Consequently the amount of recoverable oil declined, the potential oil cake yield increased, and the protein and crude fibre contents of the expected oil cake increased and decreased respectively. Seed yield increased in one trial but declined in a second due to boron fertilisation, whilst the seed

composition was unaffected. Hullability was also reduced at one locality due to boron fertilisation, leading to changes in oil cake yield and quality. A mild water stress during the grain-filling stage reduced seed yield by 23% and hullability by 14%.

4. Due to the need for a seed grading system based on seed quality, multiple linear regression analyses between easily measurable seed characteristics and seed quality parameters were done on seed samples representing 19 cultivars grown at 11 localities. The relatively low mean absolute errors between the measured and estimated values indicate that seed oil content, protein content and hullability might be estimated with reasonable accuracy. These relationships must still be validated, however.

5. An analyses of the combined data of all the field trials, revealed that optimising the seed oil:seed protein ratio through breeding may be the most advisable option for improving seed quality for processing.

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