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 × 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	P	K	Weed control
				(kg ha^{-1})			
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	Environ-ment 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	DF	----------------Seed-------------			---------------Kernel-------------			Pot. oil	---------------KRF----------------		
variation		oil	protein	fibre	oil	protein	fibre	yield	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).