Sunflower Processing Quality : A South African Perspective

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Introduction

Sunflower is the main oil seed crop produced in South Africa. The annual production of seed varied from 170 000 to 1 109 000 tonne from 1990/91 to 2000/2001 with a mean annual production of 560 000 tonne. Approximately 224 000 tonne of edible oil is produced annually from this seed, providing 41% of the estimated local oil demand of 600 000 tonne. An estimated 241 000 tonne of oil cake is produced which is consumed by the animal feed industry.

Sunflower oil cake is considered to be of relatively poor quality mainly due to a high crude fibre content. The protein content is also relatively low and the value of sunflower oil cake is equivalent to 72% the value of soybean oil cake. Inclusion of sunflower oil cake in feed blends for poultry and pigs is restricted by its relatively high crude fibre content. Concern has been raised in the past that the low and variable quality of sunflower oil cake may restrict its demand which in turn may impact negatively on the demand for sunflower seed by the processing industry. This limit, being below the limit to satisfy the demand for oil production.

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

The South African production of sunflower has room for expantion and even more so if the quality of the oil cake can improve. Increased sunflower production will save the country money on importation of high quality protein sources and oil. The aim of a project which was recently completed, was to determine those factors that affect the processing quality of seed.

Seed quality parameters and variation

Sunflower seed quality for processing is determined by four factors:

1. The oil content which determines the oil yield during processing which should preferably be above 400 g kg^{-1}.

2. The protein content which should be as high as possible to ensure high protein content in the oil cake.

3. The hullability, which is the amount of hull that can be easily removed, preferably not lower than 60% to reduce the crude fibre content of the oil cake.

4. The amount of fine material produced during the dehulling process which should be as low as possible. The major part of the fine material consists of kernel particles. These particles are lost when the hulls are removed through aspiration. Part of the oil and protein is lost in this way. Fine material also tends to clog equipment and hampers processing.

South African produced seed varies considerably in their quality parameters. Judging from the results of the annual national cultivar trials, oil content ranges from 360 to 500 g kg^{-1} and protein content from 100 to 240 g kg^{-1}. Hull ability varies from 45 to 94% and the amount of fines produced from 3 to 12%. This variation in quality parameters consequently gives rise to variation in the value of seed for the crushing industry. Seed quality variation also impacts on the quality of oil cake. In this regard Smith, Hayes & Smith (1989) found that the protein content of commercially produced South African oil cakes varied from 320 to 510 g kg^{-1}, with only 18% of the samples containing more than 400 g kg^{-1} protein, the minimum value of preference.

Two factors give rise to variation in seed quality, firstly the genetic diversity among cultivars and secondly prevailing environmental difference during seed production. Between 12 and 18 sunflower cultivars from 6 seed companies are available annually for commercial production. As these cultivars are bred from different genetic backgrounds, variability between cultivars can be expected. Environmental conditions where sunflower is grown vary considerably in South Africa, in particular the soil. Soil texture varies from clay contents of less than 10% to more than 50%. Planting dates, which vary from September in some areas to late January in others, adds to the variation in temperature and rainfall.

Effect of environment and cultivar on seed yield and quality

Some environmental factors that affect seed oil and protein content of sunflower are fertilization (Smith, Smith, Bender & Snyman, 1978; Blamey & Chapman, 1981; Loubser & Grimbeek, 1985), plant population (Majid & Schneiter, 1987; Zaffaroni & Schneiter, 1991) and water stress (Hall, Chimenti, Vilella & Freier, 1985).

European investigations revealed that seed hull ability is determined by genotype as well as the pedo-climatic environment, which often also have an interactive effect. Evrard Burghart, Carré, Lemarié, Messéan, Champolivier, Merrien, & Vear (1996) concluded that genetic effects are always predominant over environmental effects. Baldini & Vannozzi (1996) found the variance for hullability due to cultivars to be 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 pedo-climatic environment effects on hull ability dominate over the effect of both the cultivar and cultivar × environment interaction.

A study was conducted on seed of five cultivars produced at six environments. The cultivars were bred by different companies and are assumed to be genetically diverse. The trials were located on farms close to the towns of Heilbron, Potchefstroom and Viljoenskroon over two seasons. 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. All agronomical inputs like seeding rate, fertilization etc. were done according to recommended practices.

After yield determination, the seed were analysed for their physical characteristics (hectolitre mass, thousand seed mass, hull content and hull ability) and chemical characteristics (moisture, oil and protein contents).

Grain yield and all physical seed characteristics were affected by cultivar, environment and a cultivar × environment interaction (Table 1). Environmental effects dominated over cultivars and the interaction for grain yield, hectolitre mass, hull content and amount of fine material produced. Thousand seed mass and hull ability were more affected by cultivar than by environment. The ranking of some cultivars changed over environments, causing a significant cultivar × environment interaction (Table 1).

Seed oil, protein and crude fibre content were affected by cultivar, environment and, in the case of protein and crude fibre contents, also by a relatively small cultivar × environment interaction (Table 2). Environment, however, was the main source of variation in oil content.

The general conclusion from this study was that environmental factors affect seed composition more than genetic factors, while the opposite was true for hull ability. The potential oil yield, oil cake yield and quality were also more affected by the environment than genetic factors. The complete results have been published (Nel, Loubser & Hammes, 2000b; Nel, Loubser & Hammes, 2000c)

Table 1 F values from analysis of variance and summary statistics for grain yield and physical seed characteristics of five sunflower cultivars grown at six environments

Source of variation	Df	Grain yield ($kg\ ha^{-1}$)	Hectolitre mass (kg)	TSM[†] (g)	Hull content ($g\ kg^{-1}$)	Hull-ability (%)	Fine material (%)
F-values from the analyses of variance							
Cultivar	4	6**	25**	43**	12**	65**	23**
Environment	5	20**	51**	32**	63**	48**	65**
C × E[§]	8	2*	4**	3**	2**	9**	18**
Summary statistics							
Minimum		1 433	37.1	50.0	215	45.4	3.6
Maximum		3 596	50.0	87.4	293	87.4	11.5
Mean		2 409	42.4	65.3	252	75.4	6.7

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
[†] Thousand seed mass.
[§] Cultivar × environment interaction.

Table 2 F values from the analysis of variance and the summary statistics for oil, protein and crude fibre contents of the seed, the potential oil yield 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[†]-----------			Pot. oil[†]	---------------KRF[‡]----------------		
Variation		oil	protein	fibre	yield	yield	protein	fibre
		($g\ kg^{-1}$)	($g\ kg^{-1}$)	($g\ kg^{-1}$)	---($g\ kg^{-1}$seed)---		($g\ kg^{-1}$)	($g\ kg^{-1}$)
F-values from the analyses of variance								
Cultivar	4	7**	15**	7**	37**	96**	7**	5**
Environment	5	67**	38**	8**	118**	76**	16**	7**
C × E	20	1	4**	2*	7**	8*	1	2

Summary statistics							
Minimum	384	137	178	380	235	394	176
Maximum	537	248	288	476	345	620	298
Mean	474	189	212	424	322	507	238

† Moisture free base; ‡ Moisture and oil free base.
*,** Significant at the 0.05 and 0.01 probability levels, respectively.

Plant Population

A number of studies have shown that hull ability is related to seed size. Dehulling larger seed is easier than dehulling smaller seed. Dedio & Dorrell (1989) suggested that seed size is the most important factor determining hull ability. The production of fine material is also related to seed size (Nel, Loubser & Hammes, 1999b), with larger seed producing less fines. It can therefore be inferred that the processing of larger seeds can be expected to be more efficient than smaller seeds.

Without exception, seed size has been found to be negatively correlated with plant population in at least ten investigations. As seed size is also related to hull ability and the production of fine material, the possibility exists that the variation in seed quality of commercially produced seed, is partially due to variation in plant population. If plant population has a significant effect on hull ability and thus also the seed quality, it may be a way of manipulating the quality. 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.

A field trial was conducted to determine the effect of plant population on the hull ability, seed composition, amount of fines produced, potential oil yield, oil cake yield and potential oil cake protein and crude fibre content of three South African sunflower cultivars.

The field trial was planted at Potchefstroom with three cultivars in rows 0.9 m apart at densities of 20 000, 35 000 and 50 000 plants per ha, the normal range of recommended densities for local conditions. Thousand seed mass was affected by both plant population and cultivar. Thousand seed mass declined as the population increased (Figure 1), which agrees with previous findings. A population × cultivar interaction affected hull ability. The hull ability of two of the three cultivars declined with increased population. In the third cultivar however, plant population had no significant effect on the hull ability which was 81, 88 and 84% for the 20 000, 35 000 and 50 000 populations respectively. Fine material increased only slightly with increased population. The seed oil, protein and crude fibre contents were not affected by the plant population density.

The implication of these results is that for dryland sunflower production the plant population should rather be closer to 20 000 plant ha^{-1} than to 40 000 plant ha^{-1}. This will maximise hull ability and minimise losses due to fine material, without affecting the oil and protein content of the seed.

Figure 1 Thousand seed mass (TSM) as affected by plant population

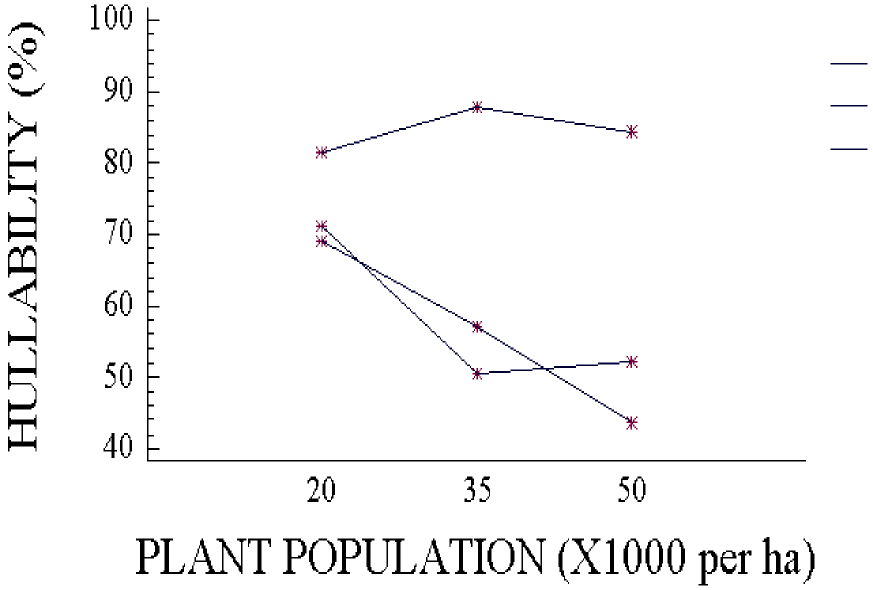

Figure 2 The hullability of three sunflower cultivars as affected by plant population

Nitrogen fertilisation

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, Coaldrake, Pearson & Canty, 1986). Even under conditions where seed yield was not affected by nitrogen fertilisation, higher levels of nitrogen reduced seed oil content (Geleta, Baltensperger, Binford & Miller, 1997). 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 and water improves hullability.

From the above it appears that the availability of nitrogen to the sunflower crop might have a determining effect on seed characteristics which influence the processing quality. The aims of this field trial were to determine the effect of both the rate and timing of nitrogen fertilisation on the composition and hullability of sunflower seed, potential oil yield, potential oil cake yield and potential quality of the oil cake in a field trial. Nitrogen application rates were 20, 70 and 120 kg ha^{-1} with limestone ammonium nitrate as nitrogen source.

Timing of application treatments were:

1. All nitrogen applied at planting

2. Split applications with 50% applied at planting and 50% at the commencement of flowering (ratios of 1:1)

3. A split application with 25% applied at planting and 75% at the commencement of flowering (ratios of 1:3)

The seed 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 (Table 3). Timing of nitrogen application had no effect on the seed oil content nor on seed protein content. Application rate nor timing of nitrogen had any affect on seed hullability. Seed oil content decreased while seed protein content increased with increased amounts of applied nitrogen (Table 3) thereby supporting previous findings (Blamey & Chapman, 1981; Loubser & Grimbeek, 1985; Steer *et al.*, 1986).

Table 3 Seed composition, potential oil yield and the yield and composition of the kernel-rich fraction (KRF) reflecting the oil cake of sunflower as affected by rate of nitrogen application

N rate	------------Seed†	-------------			Potential†	----------KRF‡	-----------	
	Yield	Oil	Protein	Fibre	oil yield	Yield	Protein	Fibre
(kg ha^{-1})	(kg ha^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})

20	2096c*	502a	154c	197a	456a	348b	405c	317a
70	2800b	493a	179b	193a	445a	364ab	446b	307a
120	3027a	466b	203a	198a	428b	378a	487a	276b

† Moisture-free basis.

‡ Oil and moisture-free basis.

* Means followed by different letters in a column differ significantly at P # 0.05.

The potential oil yield decreased moderately by approximately 3% for each 50 kg nitrogen increment applied per ha (Table 3). 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 3). Each increment of 50 kg of nitrogen per hectare resulted in a small KRF yield increase of approximately 4.2%. 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 were affected by the amount of nitrogen applied (Table 3). The crude fibre content decreased with 3.1 and 10.1% with the 20 to 70 and the 70 to 120 kg nitrogen per hectare rates respectively (Table 3). The change in KRF composition was also due to the change in seed composition associated with different nitrogen application rates.

Conclusions on the nitrogen fertilisation studies were that timing of nitrogen application had no response on the seed yield or the seed quality characteristics of sunflower. Seed yield increased by an average of 22% per 50 kg of nitrogen applied per ha, while changes in 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.

Water Stress

The area in South Africa, where sunflower is grown, is well known for its relatively low and variable rainfall. Accordingly, water stress is considered to be the main limiting factor for crop production. The effect of water stress on sunflower seed characteristics such as oil and protein content and physical seed characteristics is well documented. The effect of water stress on hullability is however unclear. Denis, Dominguez & Vear (1994) grew several genotypes at two localities and found the hullability of seed from the drier locality to be higher than that of seed from the wetter locality. Merrien, Dominguez, Vannozzi, Baldini, Champolivier & Carré (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.

A field trial was conducted to quantify the effect of crop water stress during the reproductive period on the seed yield and seed quality characteristics of sunflower. Two levels of water stress were applied through an irrigated and a non-irrigated or dryland treatment during the grain filling stage. The midday relative water content of the leaves was measured twice a week to quantify the crop water stress. The relative water content of the leaves showed that the dryland treatment induced a mild to moderate stress compared to the irrigated treatment, which persisted for 25 days from the opening of the inflorescences (Figure 3).

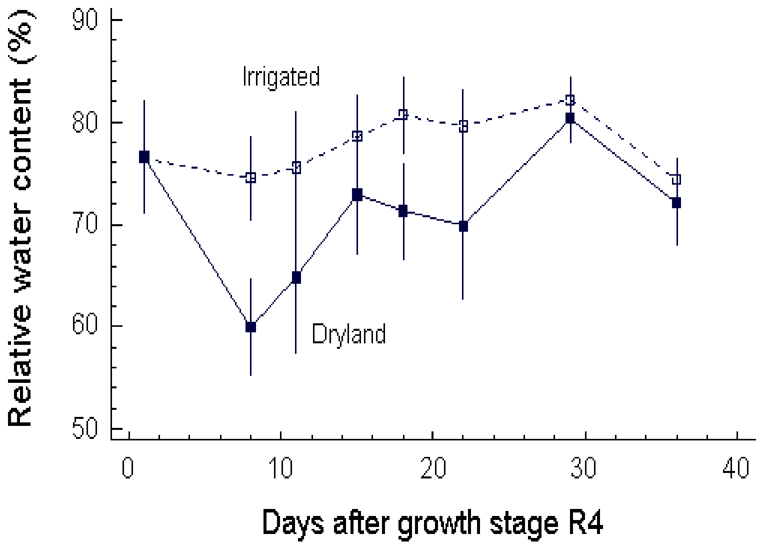

Figure 3 The relative water content of the irrigated and dryland treatments from growth stage R4 to physiological maturity.

Seed yield was affected by crop water stress with the dryland treatment yielding 23% less than the irrigated treatment (Table 4). The thousand seed mass was affected by both cultivar and crop water stress. Calculated over cultivars the thousand seed mass for the dryland subtreatment was 18% lower than that for the irrigated subtreatment. The reduction in seed yield, was thus mainly due to the reduction in thousand seed mass.

Table 4 Seed yield, hectolitre mass, thousand seed mass, hull content, hullability and fines produced during dehulling from the seed of three sunflower cultivars as affected by water stress during the grain filling period

Treatment	Grain yield	Hectolitre mass	TSM	Hull content	Hullability	Fines
	($kg\ ha^{-1}$)	($kg\ hl^{-1}$)	(g)	(%)	(%)	(%)
Irrigated	2814a‡	46.4b	61.4a	22.1a	66.9a	8.9a
Dryland	2170b	47.6a	50.6b	22.2a	57.5b	8.3a

‡ Means followed by different letters in a column differ significantly at P # 0.05.

Hullability was affected by the water stress with the hullability of the dryland treatment approximately 14% less than that of the irrigated treatment. 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 irrigated and dryland treatments (Nel, Loubser & Hammes, 2001).

Seed oil content with a mean moisture free value of 499 g kg^{-1}, was not affected by the crop water stress treatments which seems to contradict the results of Alessi, Power & Zimmerman (1977), Hall *et al*. (1985), Muriel & Downes (1974) and Talha & Osman (1975). The moisture free oil content of the kernels, however, was affected by the crop water stress treatment with the dryland treatment containing 2.3% less oil than the irrigated treatment. The mild water stress thus reduced the oil content of kernels which was most likely obscured for the seed analyses due to the presence of the hulls. The protein and crude fibre content of the seed and kernels were not affected by water stress. Consequently, the moisture and oil free yield and protein content of the kernel rich fraction, as well as the potential oil yield from the seed were also not affected by the water stress treatments. The complete results have been published (Nel *et al.*, 2001).

Discussion

A model for estimating the protein and crude fibre contents of expected oil cake from seed quality parameters (hullability, oil and protein contents) would be useful. 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 (Nel, Loubser & Hammes, 2000b; Nel, Loubser & Hammes, 2000c). Estimating both the protein and crude fibre contents of the potential oil cake from hullability, seed protein and crude fibre contents appear to be possible. To investigate this possibility, the data reported in a number of investigations (Nel *et al.*, 2000a; Nel *et al.*, 2000b; Nel *et al.*, 2000c; Nel *et al.*, 2000d; Nel *et al.*, 2001; Nel, 2001) 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:

$$P = 64.2 - 8.37R + 0.095H \quad (1)$$

$$F = 24.1 + 4.56R - 0.235H \quad (2)$$

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 1 and 0.46 for equation 2, while the mean absolute errors were 1.9% for equation 1 and 4.3% for equation 2.

Equations 1 and 2 were used to calculate the threshold relationships between the oil:protein ratio and the hullability of seed for an oil cake protein content of 444 g kg^{-1} and a crude fibre content 178 g kg^{-1} which are the moisture free statutory limits. These thresholds are graphically displayed in Figure 4 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 beyond these limits. It is also clear that for seed with an oil:protein ratio larger than 3.3, it is most unlikely that an oil cake containing 44.4 g kg^{-1} or more protein (moisture and oil free), can be produced from it, as hullability cannot 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 should be seen as interdependent variables.

The data points in Figure 4 represent 209 seed samples produced from 19 cultivars at 11 localities during the 1999/2000 season in the South African national cultivar trials (Loubser & Lodewyckx, 2000). As these samples include all the cultivars available during 1999 and a wide range of localities in the sunflower producing area, they give an indication of the quality range of oil cake produced from the national 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 no oil and moisture. An estimated 95% of these samples will result in oil cake containing 444 g kg^{-1} or more protein (N × 62.5 g kg^{-1}). An estimated 45% of the samples will result in oil cake containing 178 g kg^{-1} 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 178 g kg^{-1} crude fibre.

Smith *et al.* (1989) stated that sunflower oil cake with less than 100 g kg^{-1} crude fibre, will be considered a product of high quality. Less than 1% of the 209 cultivar trial samples analysed, are in this category. To produce oil cake with less than 100 g kg^{-1} crude fibre at 130 g kg^{-1} 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 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 100 g kg^{-1} crude fibre at 130 g kg^{-1} oil plus moisture. It appears that high oil content sunflower is unsuitable for producing oil cake with less than 100 g kg^{-1} crude fibre. Sunflower seed with a relatively low oil:protein ratio may be suitable for producing such oil cake. This however, has to be confirmed.

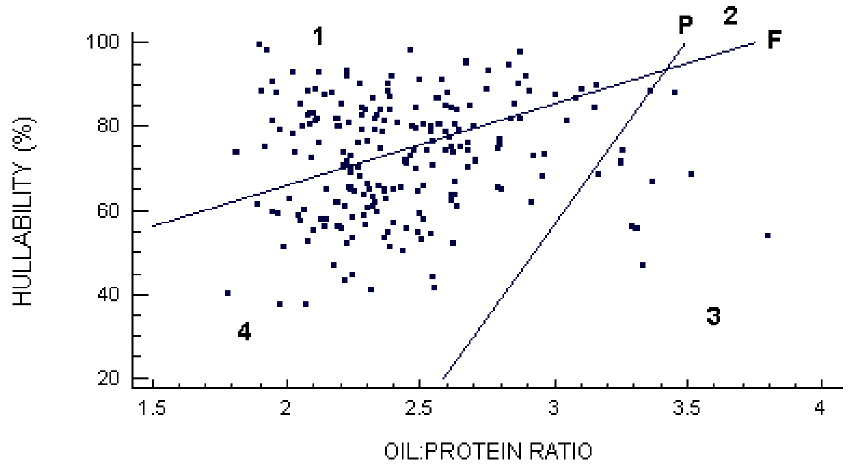

Figure 4 The relationship between hullability and the seed oil:protein ratio of sunflower seed (data points) and the threshold lines for an oil cake protein content of 444 g kg^{-1} (P) and a crude fibre content of 178 g kg^{-1} (F) assuming the oil cake contains no moisture and oil. Quadrant 1: oil cake protein ∃ 444 g kg^{-1}, fibre # 178 g kg^{-1}; Quadrant 2: oil cake protein < 444 g kg^{-1}, fibre # 178 g kg^{-1}; Quadrant 3: oil cake protein < 444 g kg^{-1}, fibre > 178 g kg^{-1}; Quadrant 4: oil cake protein ∃ 44.4 g kg^{-1}, fibre > 17.8 g kg^{-1}.

Conclusion

Manipulation of seed quality characteristics using agronomic practises such as plant population and nitrogen fertilisation, appears to be limited due to the relative small effects. A possible permanent solution will be the breeding of new cultivars with lower oil: protein ratios of approximately 2:1 and hullabilties in excess of 70%. To be acceptable however, the final processing monitory value of such cultivars should not be less than the high oil content cultivars currently being produced.

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