Sunflower Quality Report

BFAP
DATA DRIVEN INSIGHT

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Abstract

In 2014, the Bureau for Food and Agricultural Policy (BFAP) undertook a comprehensive sunflower value chain analysis for the Oilseed Advisory Committee (OAC). In the report, the importance of the oil content of the seed to ensure the economic sustainability of the industry was clearly articulated. Reference was also made to international markets, where price premiums are paid for sunflower seed with a higher oil content. Over the past season, the drastic decline in the oil content of sunflower seed has had a major adverse impact on the industry. Whereas the industry norm was typically the delivery of sunflower seed with an oil content of approximately 36% and higher, the oil content has dropped significantly, putting crushing margins and the overall competitiveness of the industry under pressure. In the light of this, BFAP has undertaken a study to provide a deeper understanding of the key drivers affecting sunflower seed quality, the impact of varying (lower) oil content on the industry, and potential interventions to achieve an upgraded state of the value chain.

In South Africa, yields and oil yield (t/ha) per hectare have been relatively stagnant over the past decade, managing to increase by an average annual growth of only 1% compared to maize yields, which have increased by an average annual growth of 2.5% over the same period. However, the oil content (%) of the seed simultaneously has decreased by an average annual growth of -0.6%. The oil content of sunflower seed produced in South Africa is also significantly lower than that produced in Argentina or the Balkan countries. Furthermore, cultivar trial data from international seed breeders shows that the same cultivar planted in South Africa yields a lower oil content than when planted under optimal conditions in Argentina. This research has clearly illustrated that seed yield and oil content are complex and quantitative traits that are not only controlled by many genes, but are also influenced to a great extent by environmental conditions, and both additive and non-additive genetic effects play an important role in the inheritance of seed yield and oil content.

Ample evidence exists that planting dates that are too early or too late have a negative effect on both the yield and oil content of sunflower seed, and the late plantings common in South Africa, where sunflower is mostly planted after the maize crop, may negatively influence the sunflower seed's oil production potential. The 2018 sunflower crop seems to be a typical illustration of this phenomenon, where exceptionally late plantings (in some cases as late as the first week in February) coincided with a sharp drop in the oil content of the delivered crop. In fact, all of the past five production season, except for 2017, had a late start, with the majority of plantings only commencing in late December and January in the major sunflower production areas. Sunflower seed production is the predominant cash crop in Argentina and the Balkan countries, whilst in South Africa it is maize. In South Africa, sunflower is often planted as a "catch crop" and preference is not given to the timing of production, such as optimal planting date, fertiliser applications, soil analysis or much of the required pest weed or disease programmes required for optimal production.

Thus, to achieve both high yields and a sufficiently high oil content as inherent in the genetic potential of the sunflower seed, the crop should be planted in areas with suitable climatic conditions (temperature and water stress) with optimal crop management (planting date, planting density, fertilisation). Currently, South African producers have a choice of 199 different sunflower seed varieties. Of these, 113 are classified as high oil hybrids with the potential of achieving higher than 40% oil content. All the 113 cultivars are GMO free, but some have speciality trials such as specific herbicide resistance (e.g. Clearfield or Clearfield Plus) or have specific fatty acid compositions (e.g. High Oleic).

From a seed breeding and plant sciences theoretical perspective, there should be a negative correlation between yield potential and oil content. However, based on a range of analyses undertaken on available data (the national cultivar trial database), this study could not find conclusive evidence that there was a negative correlation between yields and oil content. To some extent, these results could have been anticipated, given the wide range of external influences like the planting date and weather, which have a significant influence on both yields and oil content. Despite these inconclusive results, the fact remains that both higher yields (in the case of producers) and higher oil content (in the case of processors) are critical to boost the overall competitiveness of the industry. To this end, data from a recent pilot study undertaken by Syngenta and CEOCO was incorporated into this report. The pilot study, which involved the latest commercially sold high oil content variety, produced encouraging results, with sunflower seed being delivered to the crushing plant with an oil content well over 40% and average yields above 2 t/ha (in the 2020 season). During industry consultations, seed companies seemed to be confident that, with the correct cultivar selection, the average oil content of the South African sunflower crop could be improved significantly without compromising on yields in a meaningful way.

Consequently, this study explored the principles of an incentive system that rewards farmers for adopting high oil content seed that maximises oil yield per hectare, rather than just yields per hectare. This is not a new concept and is a sunflower contracting norm in international markets. To speed up the adoption of high oil content seed by producers, an incentive structure that stimulates uptake would be important to consider, especially if there might be a perception of a negative correlation between yields and oil content. Therefore, at the farm level, the incentive will translate into a gross margin trade-off between producing "high yield - lower oil content seed" and "low yield – high oil content seed". A summary of various international and domestic quality-based pricing models highlighted two options for the sunflower industry: a) Oil content-based price premium or oil content-based grading and b) Back-payment structure, by which the farmer gets to share in high quality-driven (high oil content) advantages at the crushing level.

The pilot study suggested the feasibility of a 1.5% premium, which would offer farmers a 0.24 t/ha "potential yield loss flexibility". In other words, this premium would be sufficient for farmers to achieve improved returns per hectare, up to a 0.24 t/ha yield loss (where the farmer would achieve returns equivalent to the average sunflower SAFEX price without yield loss). This study shows that the "potential yield loss flexibility" offered by such a price premium structure varies significantly with respect to yield, oil content and price premium level. The adoption of the high oil-yielding varieties would therefore also depend on the extent and likelihood of farmers consistently producing average oil content beyond 38%, which could be particularly difficult under the circumstances of shifting seasonal patterns. While the desire for crushers to procure higher oil content seed is well placed,[1] the uptake of new high oil-yielding seed varieties will also depend on the processors' appetite for and willingness to pay premiums that could compensate farmers for "potential yield sacrifices for high oil content seed". Again, this study has not found conclusive evidence of a negative correlation between yield and oil content.

Overall, it comes down to the farmers' willingness to adopt new high oil content seed and targeted agronomic practices to produce seed that consistently exceeds the threshold of 38%, preferably in excess of 40%, oil content, and the wherewithal of processors to pay premiums

[1] At a 0% "incentive added on the price", the five-year average crushing margin increases by R145 for each 1% increase in sunflower seed oil content.

that will sustainably stimulate high levels of high oil-yielding seed production, while competing with crude oil imports.[2]

Investigating the feasibility of testing the sunflower seed's oil content at silo level revealed that, firstly, the current sunflower seed-grading system does not explicitly define what constitutes a high or low oil content. Secondly, there is no standardised moisture content at which both yield and oil content are presented, i.e. representation at 9% moisture, which is mostly taken as the norm. Thirdly, although some silo depots have equipment to measure secondary quality characteristics (viz. NIR machines) and use it for measurements for grading purposes, this does not include the measuring of the oil content of sunflower seeds. In principle, oil content could be a measurement monitored at the silo level. However, since this currently is not a grading requirement and essentially a nice-to-have, it is consequently not measured, and machines are not necessarily calibrated for this. In addition, the roll-out of such a requirement will also require significant investment in order to make the equipment available at all silo depots.

The near-infrared reflectance (NIR) testing methodology could be the analysis of choice at both silo level and crushing plants due to the speed of the test, the ease of testing and its relative accuracy. However, not all silo depots currently have NIR machines available and, where they are available, a calibration for sunflower seed oil content would need to be purchased. Ring tests, however, as advocated by Agbiz Grain and SAGL, could go a long way to ensuring that oil content is measured accurately at all value chain nodes (silos, crushers, etc.), and some investment would be required to ensure that this type of testing equipment becomes more widely available.

Overall, one needs to also take cognisance of the fact that these relationships (pricing structures, profitability and farmer decisions) are by no means clearly defined cause-and-effect relationships when it comes to sunflower seed production in South Africa, as the causal relationships behind the performance of yield and oil content are not clear-cut, and the positioning of sunflower seed in the typical South African crop mix creates additional complexities.

[2] At a local oil content of 34.3% (five-year average), the cost to produce one tonne of crude oil from local seeds will be equivalent to the cost of imported crude oil.

Contents

1. Introduction

Sunflower has a broad value chain, which makes it an important crop in South Africa's agribusiness sector. Sunflower seed is used primarily for the manufacturing of sunflower oil, mainly for human consumption, and oil cake, which is used in the animal feed sector. Most of the seed produced is marketed locally to oil mills, animal feed manufacturers and for seed. In production volume, sunflower seed is the fourth largest grain crop produced in South Africa after maize, wheat and soybean. For the period between 2009 and 2019, an average of about 749.9 thousand tonnes of sunflower seed were produced per annum, while the gross value was approximated at R3.19 billion per annum.

To compete in a global economy, farmers and agribusinesses will have to be competitive in a value chain including producers, processors and refineries. In a study dating from 2011, Dennis found that the South African sunflower seed industry had a competitive advantage in its primary form (farm level); however, the value-added sunflower seed products (i.e. sunflower seed oil) showed a competitive disadvantage, which was opposite to that of Argentina's sunflower seed products. The analysis found that the South African sunflower industry is primarily driven by price. To increase the competitiveness of the local industry, crushing margins need to increase. One mechanism to achieve this is through higher sunflower oil and sunflower oil cake prices. However, South Africa trade in the global market and imports of cheaper sunflower crude and refined oils pose a major threat to the industry. Thus, policy must be put in place to avoid the dumping of cheaper crude vegetable oils as well as bottled cooking oils. Secondly, crushing margins could be increased by using sunflower seed with a high oil yield/content. Another option to investigate is value-added seed products for a higher price premium. Health issues are of great importance in the local as well as global market, and the production of a healthier vegetable oil with a desirable fatty acid content is an attractive option for the industry.

In 2014, BFAP undertook a comprehensive sunflower value chain analysis for the Oilseed Advisory Committee (BFAP, 2014). In the report, the importance of the oil content of seed to ensure the economic sustainability of the industry was clearly articulated. Reference was also made to international markets, where price premiums are paid for sunflower seed with a higher oil content. Over the past four seasons, the drastic decline in the sunflower seed oil content has had a major adverse impact on the industry. Whereas the industry norm was typically the delivery of sunflower seed with an oil content of 39% and higher, the oil content has dropped significantly, putting crushing margins and the overall competitiveness of the industry under pressure.

For the South African sunflower seed crushing industry to remain competitive in the international market, the price of sunflower seed must remain between import and export parity, or trend towards export parity. This is a simple function of supply and demand, although with the added impediment of competition from the import of unrefined sunflower seed oil and substitute products. For the crushers to remain profitable, it is important to have

- access to a sufficient quantity of sunflower seed to meet the demand, along
- with the right quality aspects in terms of:
    - oil content,
    - desirable fatty acid composition,
    - disease- and poison-free seed and
    - hull-to-seed ratio

Over the years, the sunflower seed industry has seen some shifts in terms of the importance of the crop within the cropping system, with sunflower having been replaced by soybeans. This has been the case in especially the eastern Free State and Mpumalanga. In the current predominant production region of the Free State and North West provinces, sunflower is secondary to maize, with sunflowers often planted on more marginal soils, often not within their optimum planting window, and they are frequently not well managed in terms of optimal fertilisation and pest, weed and disease management. Furthermore, as no premium is paid to farmers for oil content, cultivar choice for production is strongly driven by yield per hectare. As it is a known fact that there is a negative correlation between yield and oil content based on plant physiological factors, a decline in the oil content has been observed at the mill-gate. Figure 1 puts this into context using the yield figures of the National Crop Estimates Committee (CEC) and the oil content analysed by the South African Grain Laboratory (SAGL) from representative samples taken at silos.

This study aims to measure the impact of sunflower quality on the industry at large (Figure 2) and will include:

- An overview of the sunflower seed and sunflower oil supply, demand and consumption at the local and global level, with special references to trade flows and trans-fat policies.
- At the farm level, an analysis of historic South African sunflower yield trends and oil content, coupled with a comprehensive literature review of factors that drive oil content and comparisons with international sunflower quality.
- At the silo level, a discussion of the current grading system, together with the practicality of introducing a system that pays a premium for oil content.
- At the crusher level, a comparison of existing quality-driven oilseed pricing models.

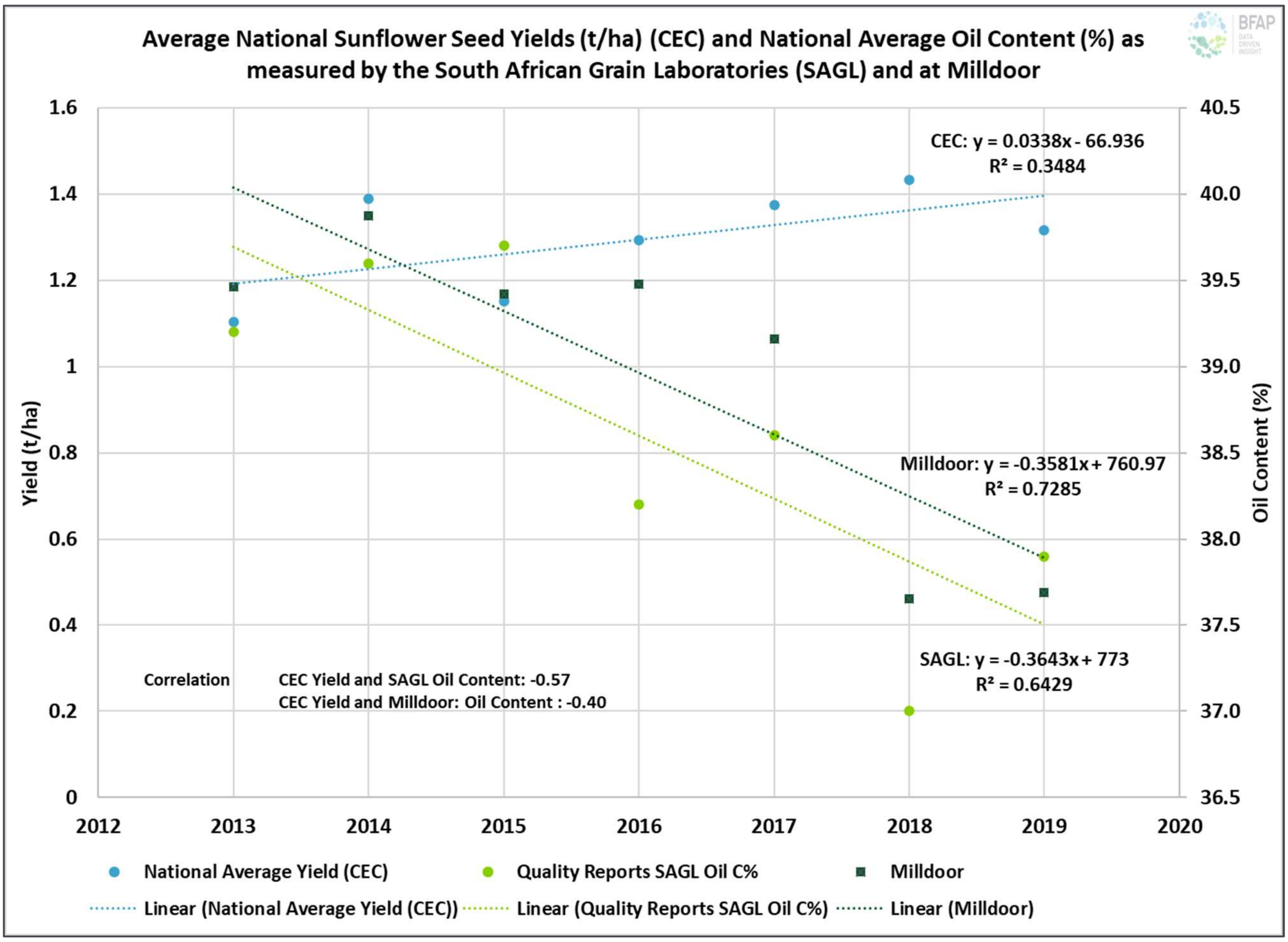


Figure 1 Average national sunflower seed yield (t/ha) (Source: National Crop Estimates Committee (CEC)) and the average oil content (%) (Source: South African Grain Laboratory (SAGL) and the average at mill door based on information from various crushers)

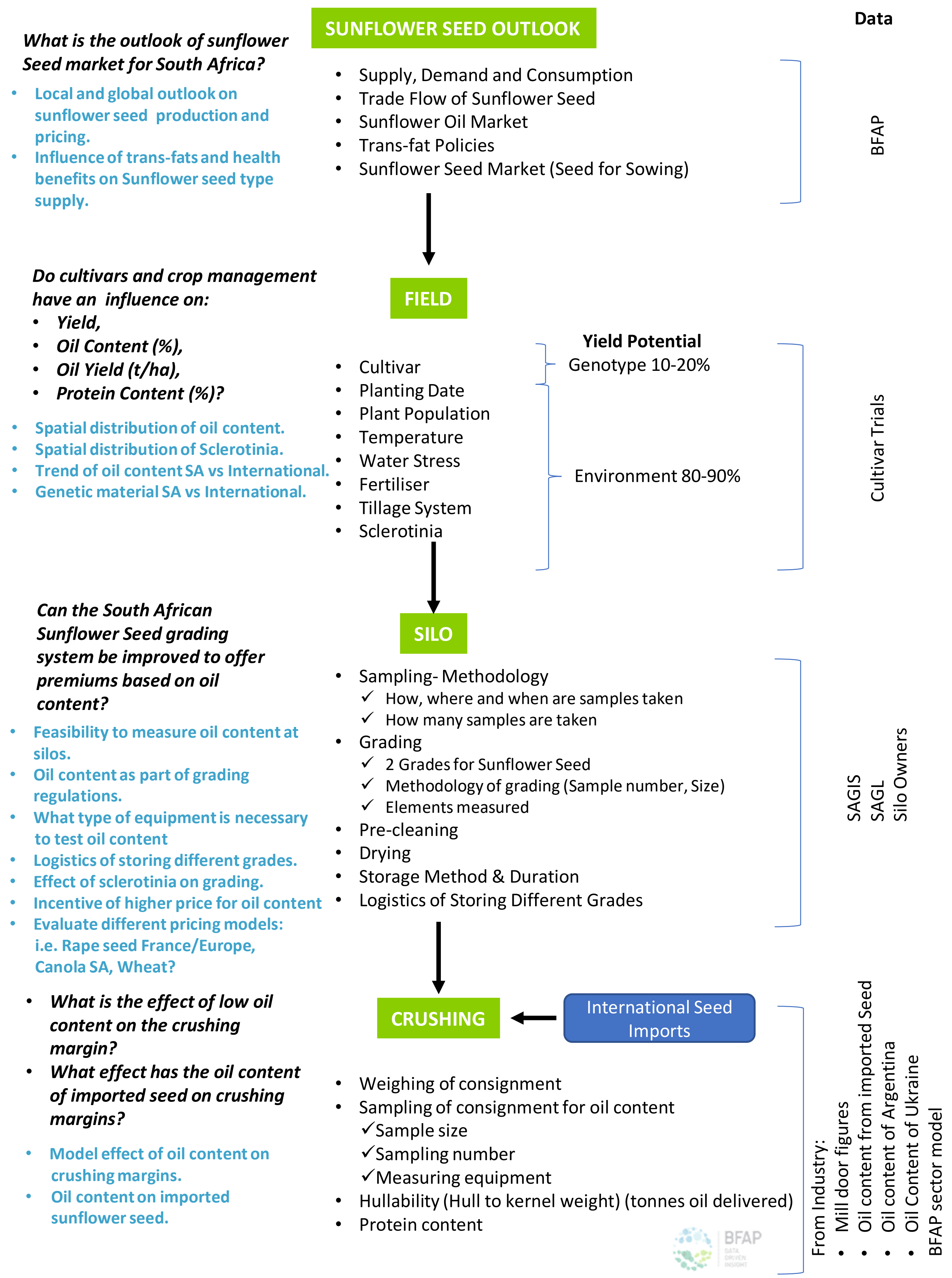


Figure 2 Overview of the research question

2. Global and Local Level: Sunflower Seed Outlook

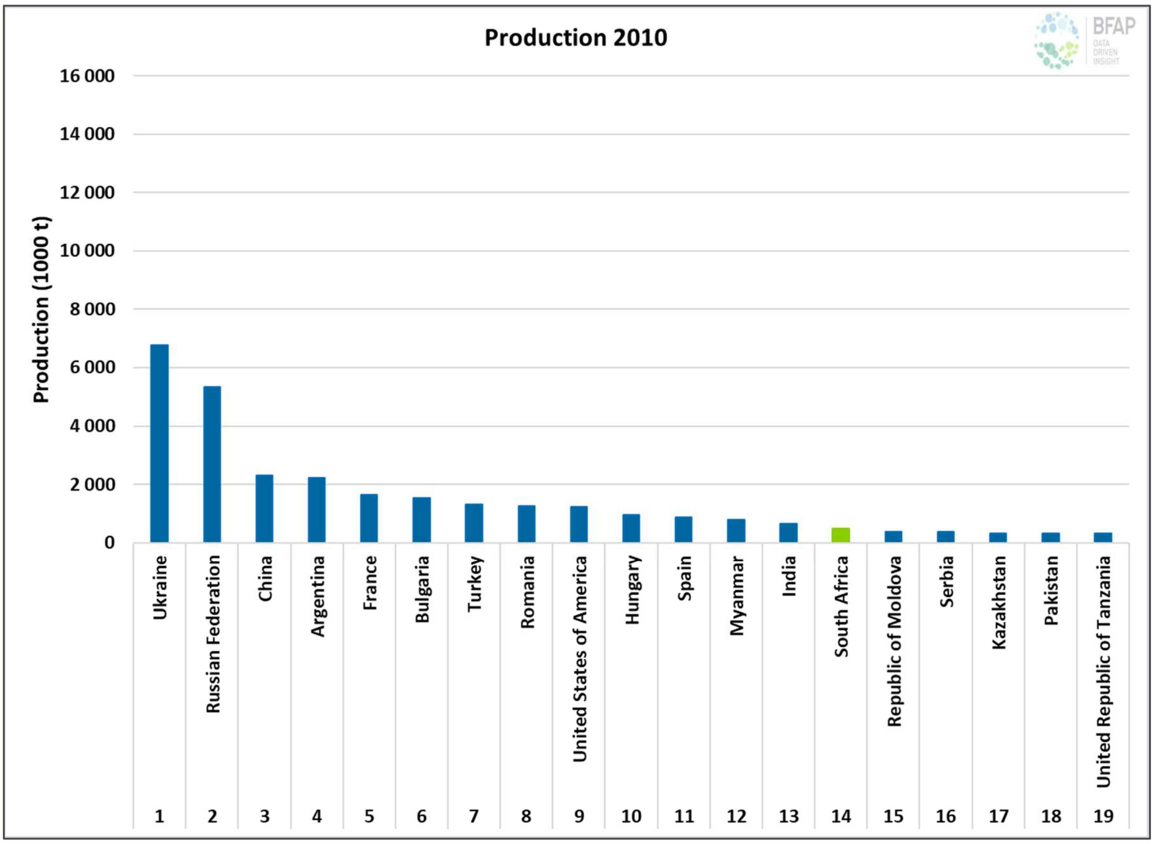
2.1. Sunflower Seed: Supply, Demand, Consumption and Outlook

Global sunflower seed production in the year 2018/2019 is estimated at 51.41 million tonnes, sunflower oil at 19.45 million tonnes, and sunflower meal at 20.90 million tonnes. Leading producers of sunflower seed are Ukraine, Russia and Argentina, while countries like Belarus, France, Hungry, Romania, Kazakhstan, Turkey, Tanzania, China and India produce relatively smaller quantity (Figure 3). The leading importers of sunflower oil are India, China, Iran, Iraq, Egypt, Turkey and the European Union. The leading importers of sunflower meal are China, Turkey, France, Netherlands, Belarus, Spain, Poland and India, among others.

Over the past decade, Ukraine has maintained its position as a leading producer and exporter of sunflower seeds and ranks first for sunflower oil consumption globally. Ukraine presently (2014 to 2018) holds a 26.2% share of total global sunflower seed production output, of 46.84 million tonnes. Russia and Argentina are currently ranked second and third respectively, with a share of 22.2% and 6.5%, followed by China, with 5.5%, and Romania, with 5.1%, of the global sunflower seed production output (Figure 3). South Africa ranked only 14th in 2010 and 13th in 2018, with an average of only 1.7% of market share averaged over the period 2014 to 2018 and ranking 13th globally. What is interesting to note is that, of the other African countries, the United Republic of Tanzania, which only held the 19th place in terms of production in 2010, has since increased production and held the 12th place in 2018, which is one ranking higher than South Africa. In terms of average global market share averaged over the period 2014 to 2018, the United Republic of Tanzania holds 3.6% and ranks 9th (FAOSTAT).

Globally, the area planted to sunflower seed production has increased significantly, from just over 22 million hectares in 2000 to 27.5 million hectares in 2018 (FAOSAT). Global average yield also has increased significantly, and the average yield for the past five years (2014 to 2018) was 1.74 t/ha. However, sunflower seed, as any crop planted under dryland conditions, is vulnerable to a changing climate. Changes in climatic conditions can reduce oil content and alter fatty acid concentrations, thereby affecting the quality of sunflower oil extracted from such seeds. Also, the effects of climate change have influenced production in Eastern Europe. For instance, in the 2007/2008 season, sunflower production plummeted by nearly one-third, or 3.67 million tonnes, due to historical drought and the highest temperatures of the last 80 years (Kaya *et al.*, 2008).

South African commercial sunflower seed production has been variable over the past 19 years (Figure 3), with the highest production in 2002, with just over 900 thousand tonnes. The lowest delivery – only five years later, in 2007 – was just a third of the all-time high: 300 thousand tonnes. However, average production for the past five seasons (2014 to 2018) was just under 800 thousand tonnes, which included the drought of the 2015/2016 season. Sunflower seed production in that season was still high, as many farmers chose to cultivate sunflowers as they could planted late in the season and still deliver relatively good yields, which could contribute positively to cashflow. In total over the past five seasons (2014 to 2018), the Free State and North West contributed up to 86% of total national sunflower seed production.



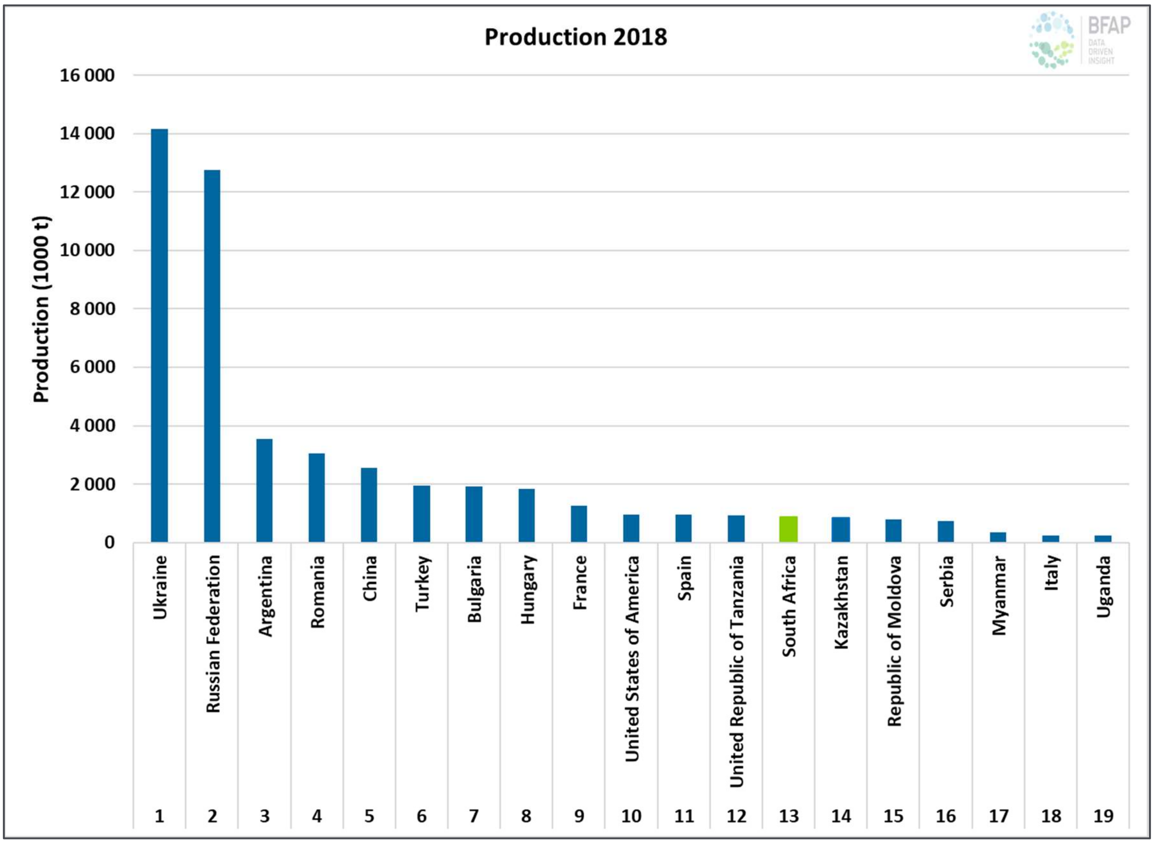


Figure 3 Ranking of sunflower seed-producing countries for a) 2010 and b) 2018, Source: FAOSAT

In South Africa, the variation in sunflower seed production is driven mainly by variations in area planted to sunflower seed. Most of the sunflower plantings are produced under dryland conditions, with only 1.2% of total national plantings being irrigated. Over the past 20 years, there seems to have been a slight increase in area, but due to the large variability this is not significant. The median area planted to sunflower seed over the period is 547 000 ha, with a 25th percentile at 463 000 ha and 75th percentile at 628 500 ha. Yields are also highly varied, with a slightly decreasing but insignificant trend. The median yield for the past 20 years was 1.28 t/ha, and that for the period 2015 to 2018 was 1.25 t/ha. The average yield of 1.25t/ha for the recent period is 28% lower than the world average over the same period. A 25th percentile yield of 1.15 t/ha, a 75th percentile yield of 1.37 t/ha and a CV of 11.5% are indicative of very little variability in sunflower yields over time (Figure 4).

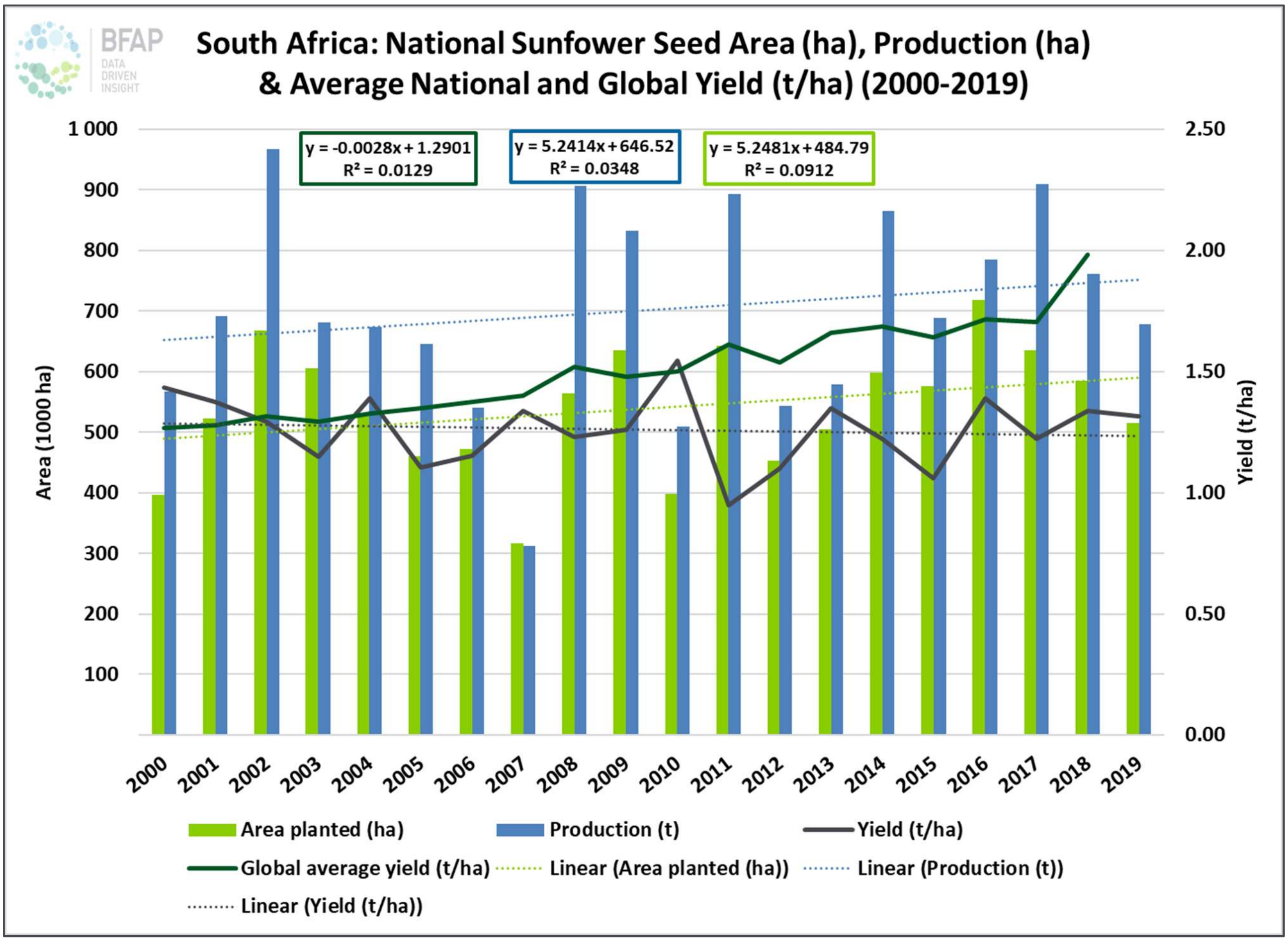


Figure 4 South African national sunflower seed production area (ha) and average yield (t/ha) for the period 2000 to 2019 (Source: DALRRD, n.d.)

In 1999, the area planted to sunflower seed reached its peak, with 828 000 ha planted and an average yield of 1.14 t/ha in that season. Up until 2004, South African sunflower seed yields were comfortably on par with the average yields obtained by the four largest sunflower producers and exporters in the world (Ukraine, Russia, EU-28, Argentina) (Figure 4). However, since 2004, the area under production has declined and South African yields have not followed the same increasing trend as in the rest of the world. In fact, the five-year average yield (2014 to 2018) for the top four producing countries equals 2.08 t/ha, compared to 1.25 t/ha in South Africa.

It seems that the sunflower hybrids that are currently available in the South African market have the genetic potential to produce higher yields that are more in line with the international trends: The national cultivar trials indicate that a yield gap exists between the potential of the plant under trial conditions (average of 2.1 t/ha from 2015 to 2018) and the actual yields that are obtained in the field (Figure 5). Although yield trial data will always produce higher yields on small plots compared to actual full-scale production, it does, however, illustrate that there is potential for higher yields. Higher yields can be achieved by implementing:

- optimum planting dates,
- conservation agriculture, and
- introducing advanced sunflower breeds, i.e. Clearfield Plus.

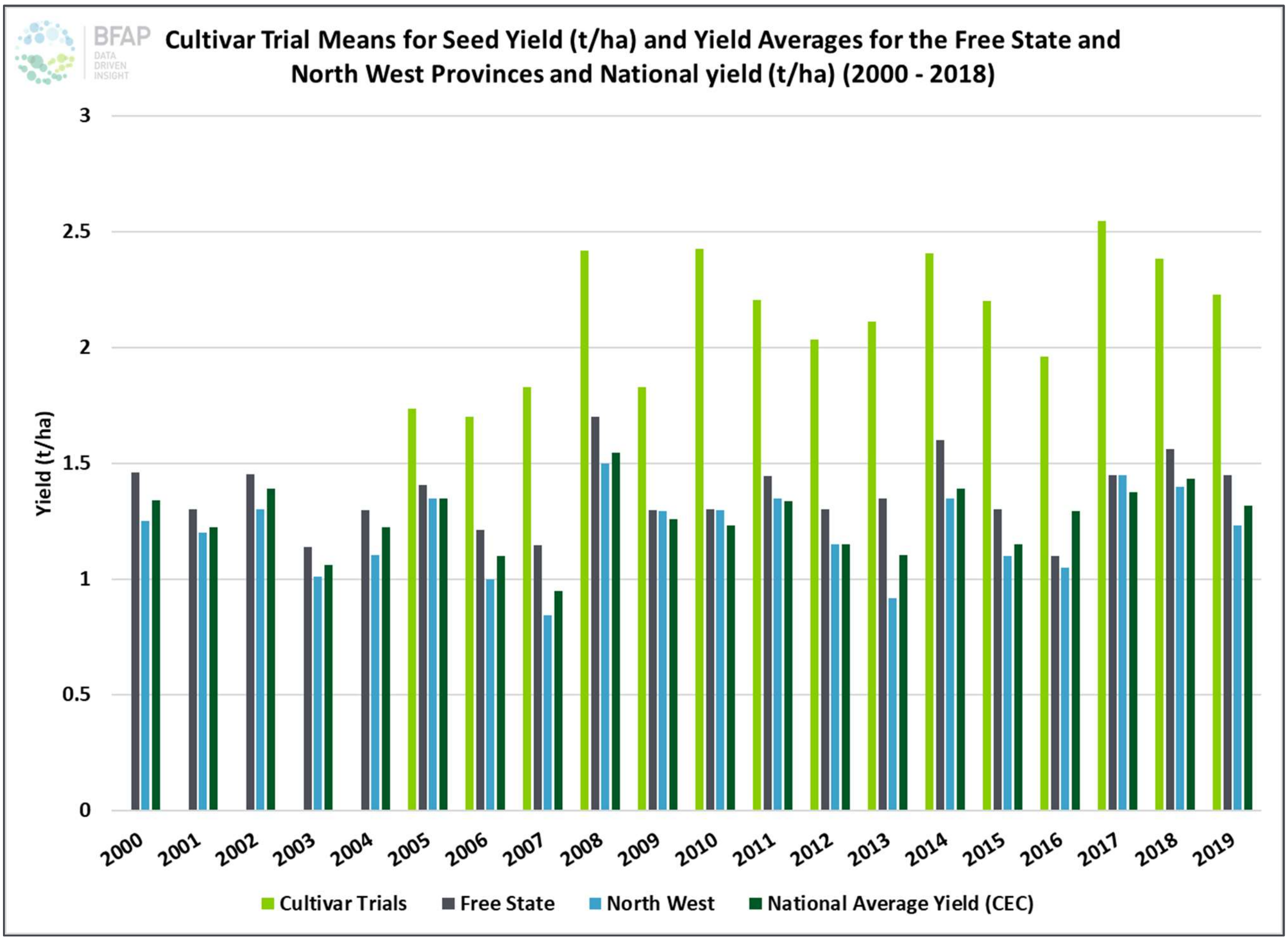


Figure 5 Yield comparison between cultivar trial means and Free State, North West and national yield averages (Source: National Crop Estimates Committee) for the period 2000 to 2018

The market for sunflower seed is expanding due to rapidly growing global sunflower oil consumption, which is mainly a result of rising health consciousness among consumers, as for example in India and Mexico. Due to negative effects on health resulting from the adoption of a modern lifestyle, consumers now prefer light edible oils in order to remain healthy. In 2018, the U.S. Food and Drug Administration (FDA) provided an indirect boost to consumer confidence that sunflower oil is a healthy product. Effective June 18, 2018, the FDA banned food manufacturers from adding mostly partially hydrogenated oils to foods. The agency estimated that the new ban could prevent thousands of heart attacks and deaths in the United States each year. Sunflower oil is naturally free from trans-unsaturated fatty acids (trans-fats) and is low in saturated fatty acids. The FDA ban opened new demand for sunflower oil because it is naturally stable and does not need to be hydrogenated. As a result, the share of sunflower oil in the total edible oil consumption is rising year on year (also see the section on trans-fat policies).

Furthermore, the demand for sunflower seed has escaped the trade war that has adversely affected international soybean exports. Although sunflower-crushing capacities in Russia and Ukraine have impeded exportable sunflower supplies, sunflower oil production and exports are gradually increasing year by year. Turkey is the largest importer of sunflower seed in Eastern Europe and has a market share of approximately 30% of the world's sunflower seed trade. Ukraine is the largest sunflower oil exporter in the world, followed by Russia. In Argentina, the deregulation of the agricultural market and relaxed export taxes have motivated farmers to gear up production with an aim to serve export markets, making it the fourth largest sunflower oil exporter after the EU27 countries.

The sunflower seed produced in South Africa is used mainly for either human consumption, animal feed or oil and oil cake (

Table 1). South Africa has established capabilities in the crushing, refining and manufacturing of oil-based products, but imports a balance of oilseeds and edible crude oil, mainly from Eastern Europe and South America. The capacity to crush sunflower seed is about 1 700 000 tons, with an additional dual capacity of 700 000 tons (Soybean or Sunflower Duals). The combined crushing capacity of sunflower and soybean is approximately 3.5 million tonnes (Meyer and Van der Burg, 2015). The USDA's grain report for 2018 thus estimated the crushing capacity for sunflower seeds in South Africa at around one million tonnes per annum (USDA, 2018).

In years of lower sunflower seed production, the activities at crushing plants are reduced and the refineries import more crude sunflower oil, as it is more cost effective than importing sunflower seed. Sunflower meal, a by-product of the oil-extraction process, is sold to local animal feed manufacturers. Sunflower meal is generally regarded as a low-value product that does not compare well to soya bean meal in terms of nutritional value, protein and fibre content. As a result, broiler rations cannot include more than 7% sunflower meal. However, a 7% inclusion in poultry rations is a significant volume and sunflower meal is more widely used as feed in the dairy and beef industries (DALRRD, 2018).

The sunflower seed marketing season in South Africa commences on 1 March and ends on 28 February. The South African Grain and Oilseeds Supply and Demand Estimates Committee (S&DEC) was established by the National Agricultural Marketing Council in 2013 and releases regular updates on supply and demand figures that guide the industry.

Table 1 Number of sunflower seed processors and the amount (t) processed for different usage categories (Source: SAGIS, 2020)

Sunflower seed processed	2019/2020[1]		2018/2019[2]		2017/2018[3]	
	Number of processors	Tonnes	Number of processors	Tonnes	Number of processors	Tonnes
Human Consumption	2	1 228	2	1 331	1	1226
Animal Feed	50	4 548	58	4 406	53	4958
Oil and Oil cake	10	549 841	12	768 810	11	717 250
Total		555 617		774 547		723 434

[1] 2019/2020: Mar 2019 to Dec 2019
[2] 2018/2019: Mar 2018 to Dec 2018
[3] 2017/2018: Mar 2017 to Dec 2017

Table 2 Supply and demand for sunflower seed; national (South Africa) versus international figures for the 2018/2019 marketing season, with projections for the 2019/2020 season (Source: SAGIS, 2020)

	SAGIS[a)]	NAMC (S&D)[b)]	International (USDA)[c)]	
Marketing year	Mar - Feb		Sept - Aug	
	Final: 2018/2019[1] 1 000 t	Projection: 2019/2020[1] 1 000 t	Final 2018/2019[2] Mt	Projection: 2019/2020[2] Mt
Opening stocks	154.8	120.2	2.9	2.8
Production	863.2	680.9	50.6	54
Imports	1.3	0.5	2.6	2.5
Processed	905.9[3]	712.2[3a]	50.3	53.4
Exports	0.5	0.6	3	2.8
Closing stocks	120.2[4]	91.3[4]	2.8	3.1

[a)] SAGIS South Africa Grain Information service
[b)] NAMC (S&D) National Agricultural Marketing Council (Supply and Demand)
[c)] USDA United States Department of Agriculture
[1] Source: SAGIS - 31 Dec 2019 & NAMC: S&DEC - 14 Jan 2020
[2] Source: USDA - 27 Jan 2020 Marketing
[3] Including producer withdrawals, seed and end users ([2] 5 865 t – [2a] 4 850 t)
[4] All stocks, regardless of ownership thereof, in commercial structures

Internationally, oilseed prices are projected to stabilise around the 400 USD per tonne mark (Figure 6). In line with historic norms, sunflower prices are projected to be marginally higher than those of soybeans but are expected to trade largely sideways over the medium term, despite growing livestock production. In the case of vegetable oil, a modest increase is projected to 2020, but in the medium term, petroleum prices are not expected to increase to levels that would induce a substantial switch to biofuels. Consequently, prices should stabilise in line with the underlying oilseed prices. In the case of sunflower and soybeans in South Africa, projected price gains are insufficient to offset the reduction in production volumes, resulting in a decline of 24% and 1% in gross production value respectively in 2019 (BFAP, 2019).

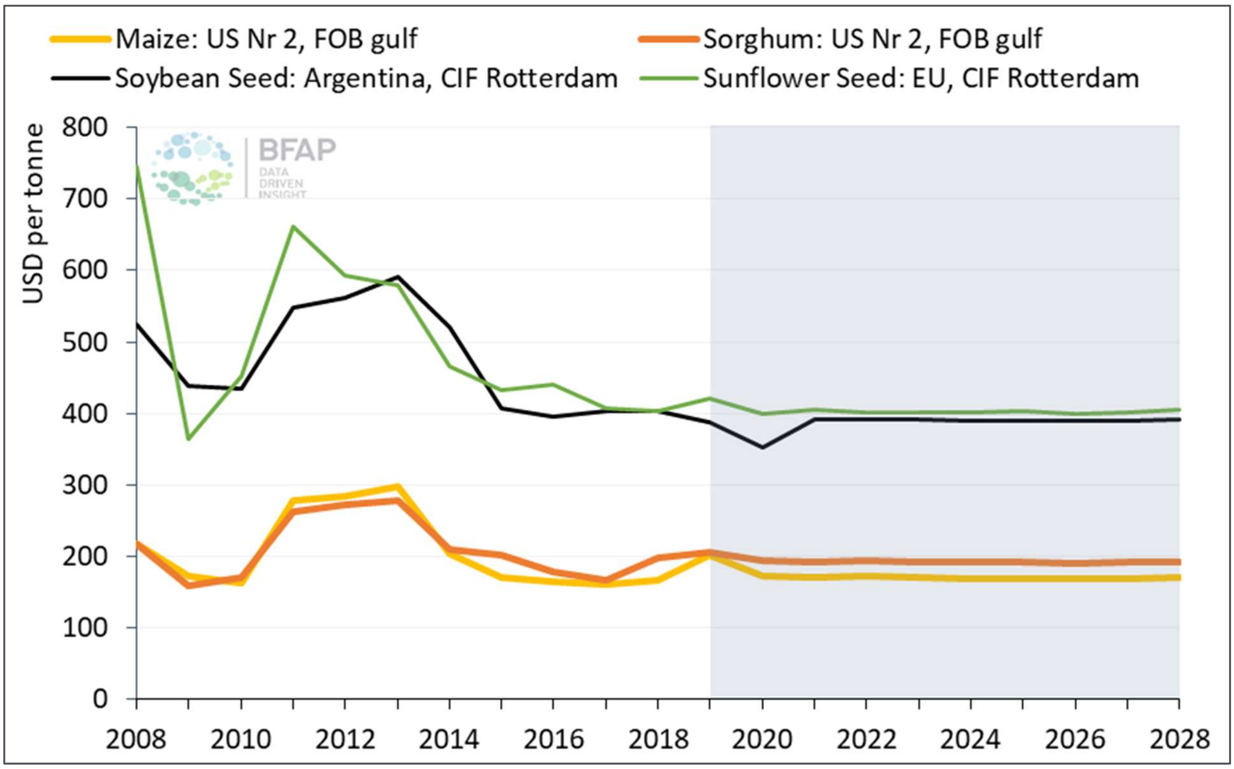


Figure 6 International summer crop prices (Source: BFAP & FAPRI 2019)

Since the drought in 2016, the area under sunflower has decreased by 10% year on year, and the projection is that this trend will continue (Figure 7). For the coming decade, projections indicate fairly consistent yield growth, with quicker gains for white maize and sunflower seed, despite a decline in total area. The removal of more marginal areas supports greater average yield gains (BFAP, 2019). Figure 7 illustrates that, on average, the local sunflower seed price (SAFEX) has traded between import and export parity levels. The price in South Africa is driven mainly by the price of oil cake and oil. Since South Africa is a net importer of these commodities, their prices are determined mainly by import parity prices. The competition that the local industry is facing from imported seed, oil and oil cake is to some extent softened by the *ad valorem* import tariff (9.4% on sunflower seeds, 4.95% to 6.6% on sunflower cake, and 10% on oil; see Table 3) that is charged on the FOB (free on board) prices of the imported products. There is a fine balance between the price at which the South African farmer can sustainably produce a tonne of sunflower and the price that crushing plants can afford to pay for the seed and still be able to compete with imported oil and cake (BFAP, 2019).

Table 3 Sunflower seed and product tariffs

Trade description	Exporting region	*Ad valorem* tariff
1206 – Sunflower seeds, whether broken or not	General	9.4%
	EU	Free
	EFTA	9.4%
	SADC	Free
	MERCOSUR	9.4%
230630.30 – Sunflower oilcake	General	6.6%
	EU	Free
	EFTA	6.6%
	SADC	Free
	MERCOSUR	4.95%
1512.1 – Sunflower seed or safflower oil and fractions thereof (crude & other)	General	10%
	EU	Free
	EFTA	10%
	SADC	Free
	MERCOSUR	10%

Source: SARS, 2020

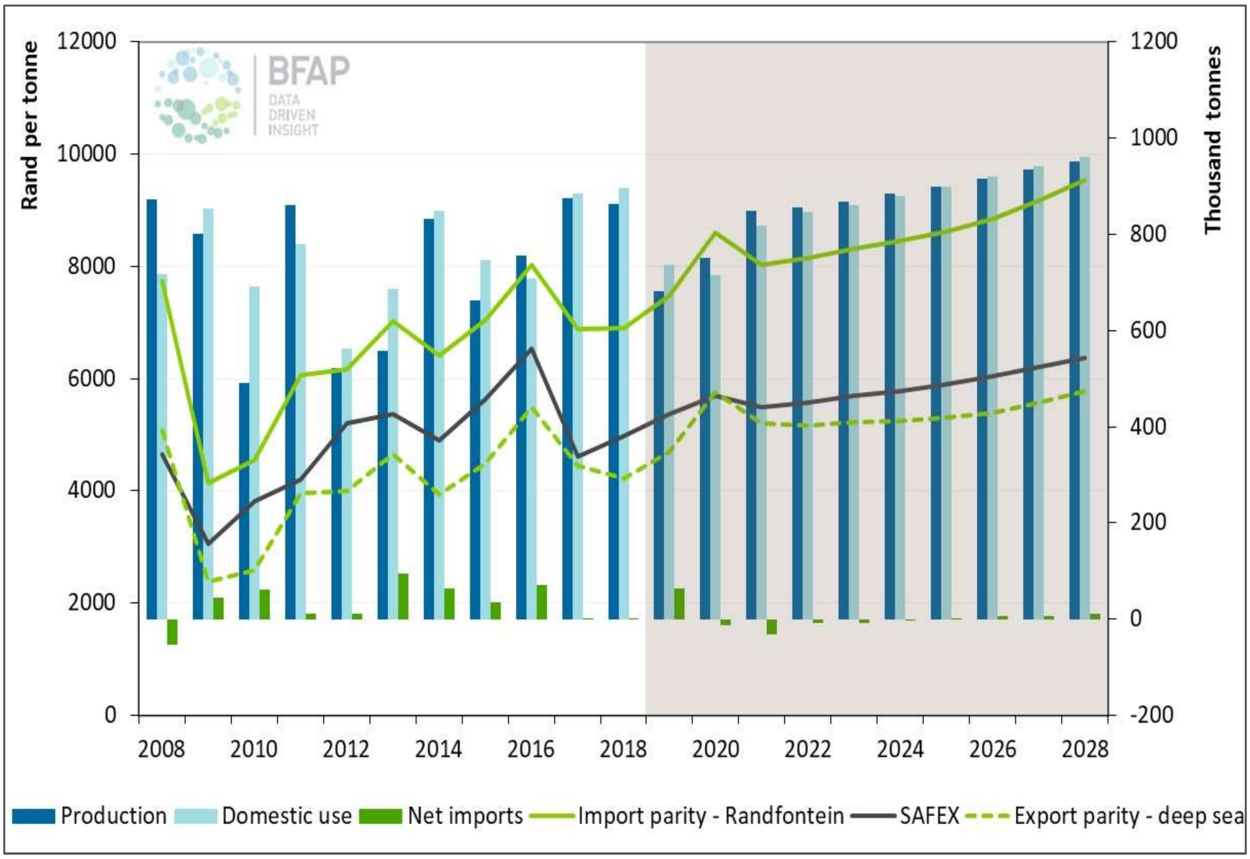


Figure 7 Sunflower seed production, consumption, trade and prices: 2008 to 2028 (Source: BFAP, 2019)

Sunflower seed consumption is closely linked to crushing capacity and the consumption of sunflower oil and oil cake. The Asia-Pacific region dominates the global sunflower oil market in terms of consumption, holding a 30% share in the global market. The market in this region is driven by higher disposable incomes and increased health consciousness. Consumers of edible oil in India are increasingly turning to sunflower oil, which has witnessed a five-fold increase in its consumption over the past 15 years. For example, the Solvent Extractors' Association of India (SEA) noted a steady rise in sunflower oil imports, from 973 000 metric tonnes in 2015/2016 to 1 516 000 metric tonnes in 2017/2018 (Mordorintelligence, 2019).

In Russia, sunflower seed processing reached a record 12.5 million tonnes in 2019, which was approximately two million tonnes more than in the previous season. The sharp increase in the volume of sunflower seed processed in Russia in 2019 can be attributed to good production, as well as the high worldwide demand for sunflower oil and meal. In Ukraine, total oilseed processing reached approximately 18 million tonnes in 2019, of which approximately 86% was sunflower seed (Strydom, 2020). It is expected that Turkey's sunflower seed imports could increase sharply between February and June 2020 due to the discount on the import levy that comes into effect. However, most of these increased imports are expected to come from Russia (Strydom, 2020).

In Africa, the imports of sunflower oil into Ethiopia almost tripled in 2019 to 149 000 tonnes, due to the decline in palm oil imports. There is an international shortage of palm oil, which has strongly supported the price of palm oil. Sunflower seed oil is relatively cheaper than other vegetable oils available for import by Ethiopia, which explains the imports shift from palm oil to sunflower seed oil (Strydom, 2020).

The South African oil-processing industry has grown in leaps and bounds with respect to crude oil production (by crushing plants) as well as oil refinement and has become a dominant player in supplying Southern African Development Community (SADC) countries. For example, although the republic of Tanzania is the 12th largest global producer of sunflower seed, local processors meet only 40% of the national cooking oil requirements (Zhihua Zeng, 2017). In South Africa, sunflower seed crushing is finely balanced with sunflower seed production from a profitability perspective (pricing structure and crushing margins). In most years, production meets crushing requirements at a price between import and export parity, which incentivises farmers to plant sunflower seed. However, if production is higher, prices can drop to export parity, which makes sunflower seed production less profitable for farmers, while crushers also need to find a balance between lower input cost and lower output (e.g. oil cake) prices (BFAP, 2019).

In the last two decades, the average consumption of oils and fats in South Africa has increased from nearly 15kg/head/annum to around 25kg/head/annum (Becker, 2019). In South Africa, domestic consumption of sunflower oil is projected to increase by an average of 2% per annum through the next decade, reaching an annual consumption of 486 000 tonnes by 2025. South Africa is expected to remain a net importer of sunflower oil throughout the baseline period, with imports projected to account for approximately 30% of domestic consumption by 2025, totalling 134 000 tonnes (BFAP, 2019).

One of the drivers of increased consumption of fats in South Africa is the banting diet, which manifested mainly in the higher income sector and has helped to boost demand for healthier edible oils such as olive oil or canola oil. B-Well, a canola oil brand, is focused on educating consumers on the health benefits of canola oil. Over the last years, the price gap between sunflower oil and canola oil has also closed. However, the majority of South Africans are less concerned with health benefits when buying edible oils and instead focus on products that offer value for money. Most consumers are under severe economic pressure and therefore remain loyal to well-known brands and traditional sources of fat, as they do not want to risk wasting their money. They usually purchase the more affordable sunflower or sunflower oil blends that are marketed as vegetable oil and look and taste similar to pure sunflower oil (Euromonitor, 2019).

Within the edible oil industry there is some brand loyalty, based mainly on targeted advertising. However, in-house brands also do well among edible oils in South Africa, viz. Shoprite, Checkers and the Spar Group. Thus packaged (bottled) sunflower oil continues to see strong growth in value, despite economic problems, but taste, price, health, wellness and convenience are the key sales drivers. Supermarkets constitute the dominant distribution and sales channel, but they are getting strong competition from mixed retailers. There is modest growth within the foodservice industry maintained by this industry's ability to meet the demand for convenience (Euromonitor, 2019).

2.2. Sunflower Seed: South African Trade Flow

South Africa's Industrial Policy Action Plan (IPAP) 2011–2017 and Agricultural Policy Action Plan (APAP) 2014–2019 do not have a specific strategy for oilseeds and edible oils. Oilseeds are not identified as a 'strategic commodity' in the IPAP. This may be because the main oilseeds (sunflower, canola, groundnuts and soya beans) are not labour-intensive commodities and employ fewer than 0.01 persons per hectare. IPAP interventions focus mainly on labour-intensive agricultural sub-sectors, such as fruit, poultry and milling (DALRRD, 2018).

South Africa imports (exports) sunflower seed from (to) various countries in different regions. However, both imports from and exports to the various global regions have been variable over the years. The main region of origin for imports has been the Balkan States of Europe and some African countries, like the Republic of Malawi and Botswana. The past three years (2017 to 2019), however, have seen an increase in imports from South America (countries like Argentina and Chile). Going forward, net imports are projected to remain positive but below 10% of crush demand (DALRRD, 2018).

Regarding exports, phytosanitary requirements and quality standards must be adhered to and a certificate must be obtained from the Perishable Products Export Control Board (PPECB). Besides the large volumes of export to Europe and Asia in 2008, the main export is to other African countries.

South Africa applies *ad valorem* tariffs of up to 9.4% on sunflower seed imports in general (see Table 3). However, sunflower seed originating from trading partners, including Romania, Bulgaria (the EU countries), Argentina (MERCOSUR) and Malawi (SADC), are traded at a zero rate linked to the indicated trade agreements. Up to 25% *ad valorem* tariffs apply to exports from South Africa to other countries (DALRRD, 2018).

2.3. Sunflower Oil Market: Supply, Demand, Consumption and Outlook

By nature, the sunflower seed market is closely linked to the manufacturing of sunflower oil. The size of the global sunflower oil market is forecast to grow by USD 4 billion from 2019 to 2023, according to a new report by Technavio, progressing at a compounded annual growth rate of close to 5% during the forecast period.

The sunflower oil market is driven by factors such as the utilisation of the sunflower oil for frying food products such as bakery products and confectionery and for cooking food. As already mentioned, the demand for sunflower oil is increasing, as it is promoted as being good for the heart and skin by keeping cholesterol in check. Sunflower oil is also used in the manufacturing of cosmetic products for the protection, moisturising and recovery of skin from bruises and other skin problems. In pharmaceuticals, sunflower oil is used as an active ingredient carrier and in creams and gels for fast absorbance (Transparencymarketresearch, 2020) (Figure 8).

The global market for sunflower oil is a competitive one, with many local and multinational manufacturers. As a result, the concentration within the sunflower oil market is very low. The top five individual manufacturers account for less than a quarter of global market share in terms of production. For example, Kernel, from Ukraine, the largest sunflower oil manufacturer in the world, held an estimated market share of only 9.23% in 2015. Some of the key players in the global sunflower oil market value chain are: Archer Daniels Midland Company, Cargill Incorporated, Colorado Mills, CHS Inc., Oliyar Production Company, Delizio, Macjerry sunflower oil, PPB Group Berhad, ConAgra Foods, Inc., Marico and Rein Oil CC. These companies are expected to expand their business by enhancing their product portfolio and are projected to frame strategies for the future in order to gain a competitive advantage in the global sunflower oil market until 2025 (Transparencymarketresearch, 2020).

The above companies are expected to achieve this by launching new products. Several market players are focusing on launching chemical-free processed sunflower oil using a patented chemical-free process to retain natural vitamins during processing. Other companies are launching new premium brands to increase the overall sales of sunflower oil and drive the growth of the market and claim these to be unadulterated, untainted, and chemical-free.

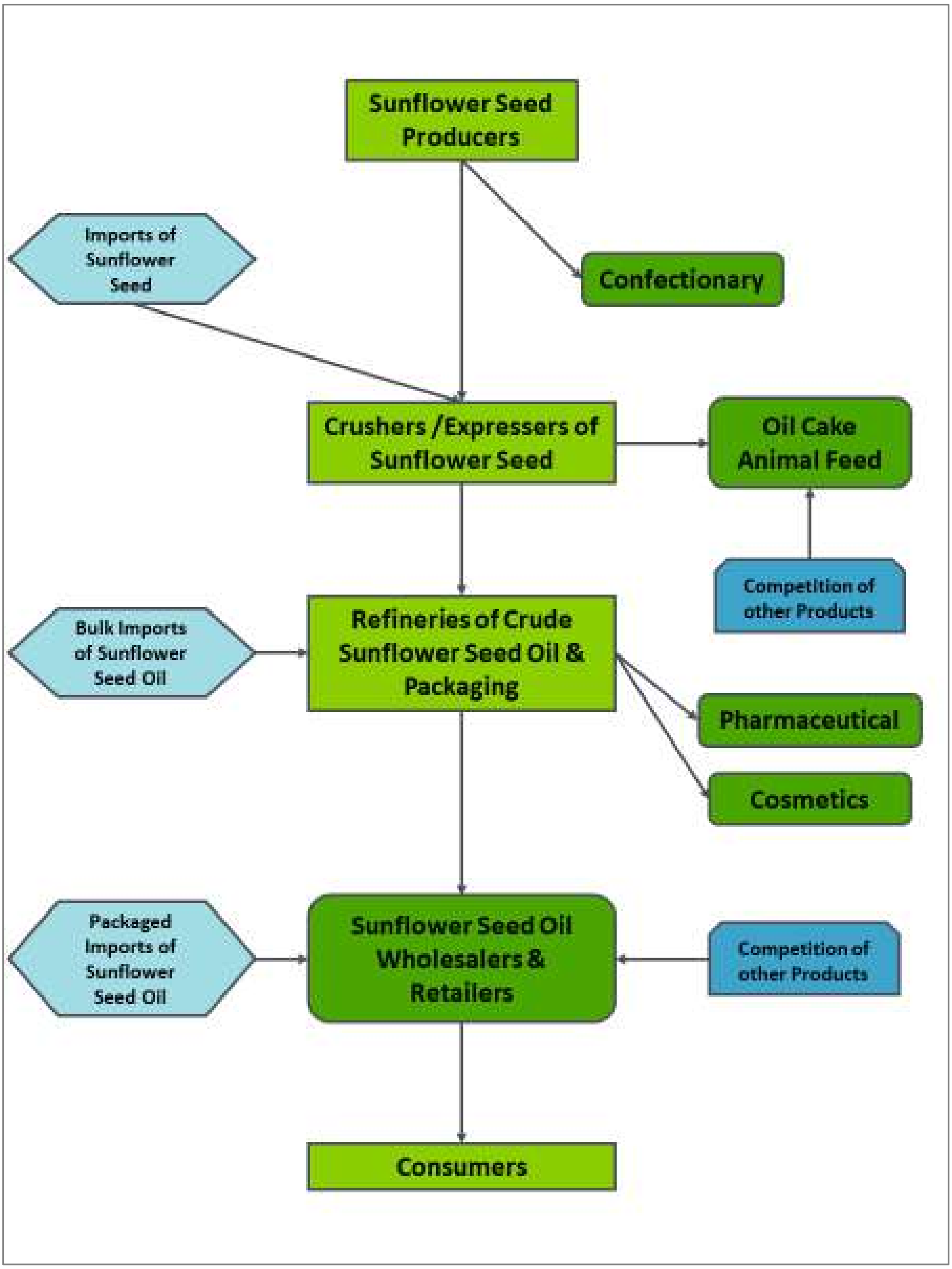


Figure 8 Sunflower seed market value chain

Ukraine is the number-one global supplier of crude sunflower oil. In 2015, the global market share of Ukraine was 30.1% in terms of sunflower oil production. The second largest producer was Russia, with a market share of 24.25%, followed by the EU-27 and Argentina, which accounted for 20% and 8% of market share of global sunflower oil production in 2015 respectively.

Drivers that can provide growth opportunities for sunflower oil manufacturers are:

- the increasing population,
- increasing preference for healthy food ingredients in certain countries,
- the increasing demand for fried food products using healthy oils,
- stagnating growth in the palm oil industry due to limited available supplies from Malaysia and Indonesia. Indonesia has adopted a nationwide B30 biodiesel blending mandate which will have a negative impact on the country's palm oil exports, and
- negative sentiment toward palm oil due to deforestation of rainforests for production.

The demand for sunflower oil imports is rising in many countries, such as Iraq, India and China. Sunflower oil exports from Ukraine to Iraq tripled from 2016/2017 to 2017/2018. Overall, sunflower oil exports to India increased by more than 20% from January 2018 to January 2019. From 2017 to 2018, the total exports of sunflower oil from the Russian Federation registered an increase. Likewise, the overall exports of sunflower oil from Ukraine increased in 2018. Hence, a continuous rise in the exports of sunflower oil can have a positive influence on the global sunflower oil market during the forecast period.

The threat to sunflower oil and meal, however, is that it can be substituted by other products, such as palm, soya and canola oil in the case of South Africa. The imports of palm oil by South Africa have increased to such extent that they now make up the largest share of all vegetable oil imports (Figure 9). Simultaneously, domestic production of soybean, sunflower and canola oil has increased and is projected to increase further over the outlook period (Figure 9). Palm oil has replaced sunflower and soya oil in the commercial market, such as in the take-away industry. Palm oil, however, does not pose a threat to the household consumption market. The challenge that the sunflower industry (and other oilseed crops) faces with palm oil is that palms produce much higher yields per hectare at much lower costs than any other oilseed and can thus be produced sustainably at very low prices.

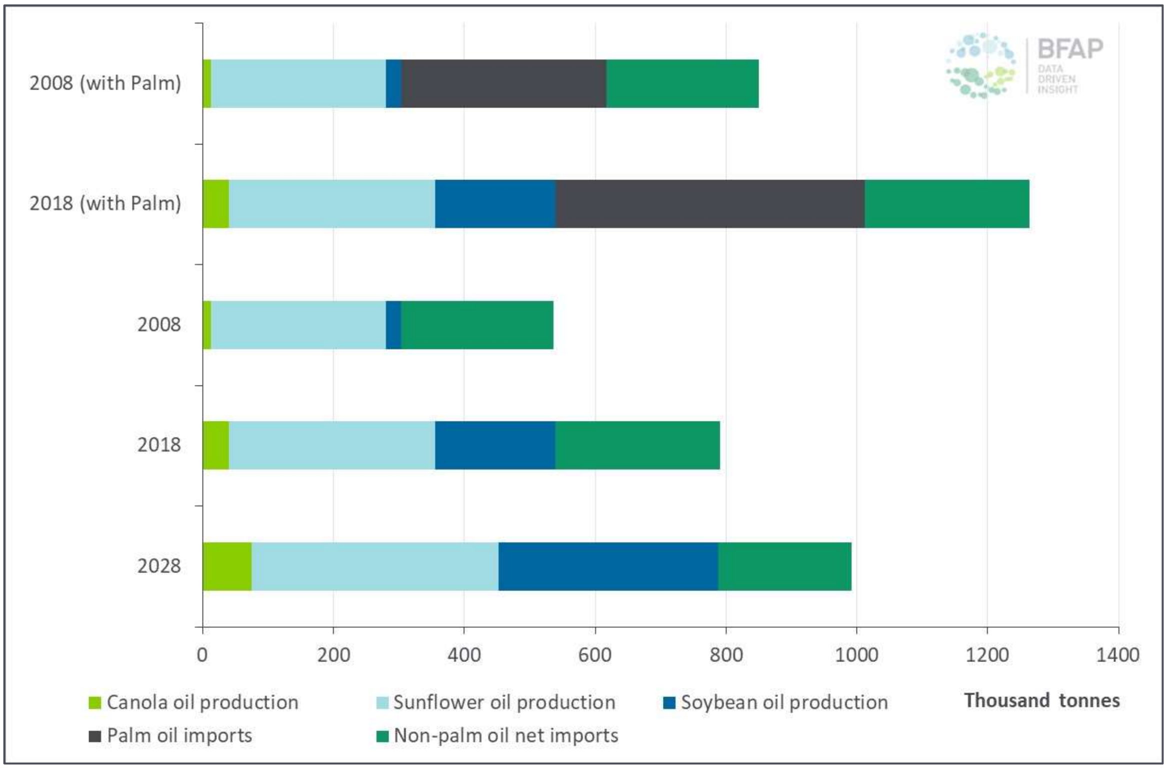


Figure 9 Oilcake supply and demand in South Africa: 2008 to 2028, Source: BFAP, 2019)

2.4. Trans-Fat Policies

Policy, regulations and legislation have an influence on consumers' decision-making. Around the world, changes in governments' policies have altered edible oil buyer preferences (Figure 10). Trans-fats and concerns about their effect on health at least partially explain the recent dynamics in the edible vegetable oil market (Li *et al.*, 2019).

Trans-fatty acids develop when an oil is hydrogenated. Partially hydrogenating oils moderately saturates them and makes them more stable; however, the process also creates artificial trans-fat. Trans-fat may increase bad cholesterol, decrease good cholesterol, stimulate inflammation, interrupt blood vessel cell responsiveness and encourage insulin resistance. The discussions of trans-fat and limitations on it have extended throughout the world. The World Health Organization has called for the complete elimination of trans-fat from food. Globally, many countries have made commitments to reduce the use of trans-fats. A few European countries and one Southeast Asian country have adopted national trans-fat bans. Countries in North America, South America and Asia have implemented national labelling standards. In September of 2003, the US Food and Drug Administration announced that all packaged food products must include the amount of trans-fatty acids on the product label by January 1, 2006, with Canada enforcing similar labelling requirements that starting in December 2005. Products containing less than 0.49 grams of trans-fat per serving may round down to 0 grams according to the Food and Drug Administration.

The most recent South African regulations relating to trans-fats in foodstuffs – Regulation 249 – were signed into law in February 2011. According to South African legislation, the trans-fat content of any oils and fats may not exceed two grams per 100 grams. Products with higher trans-fat levels are prohibited from entering or being sold in the country. The regulations also require any product labelled as 'trans-fat-free' to contain less than one gram of trans-fats per 100 grams (WHO, 2018) (see Appendix A). There are, however, still countries, especially in Africa, with no or unknown trans-fat policies.

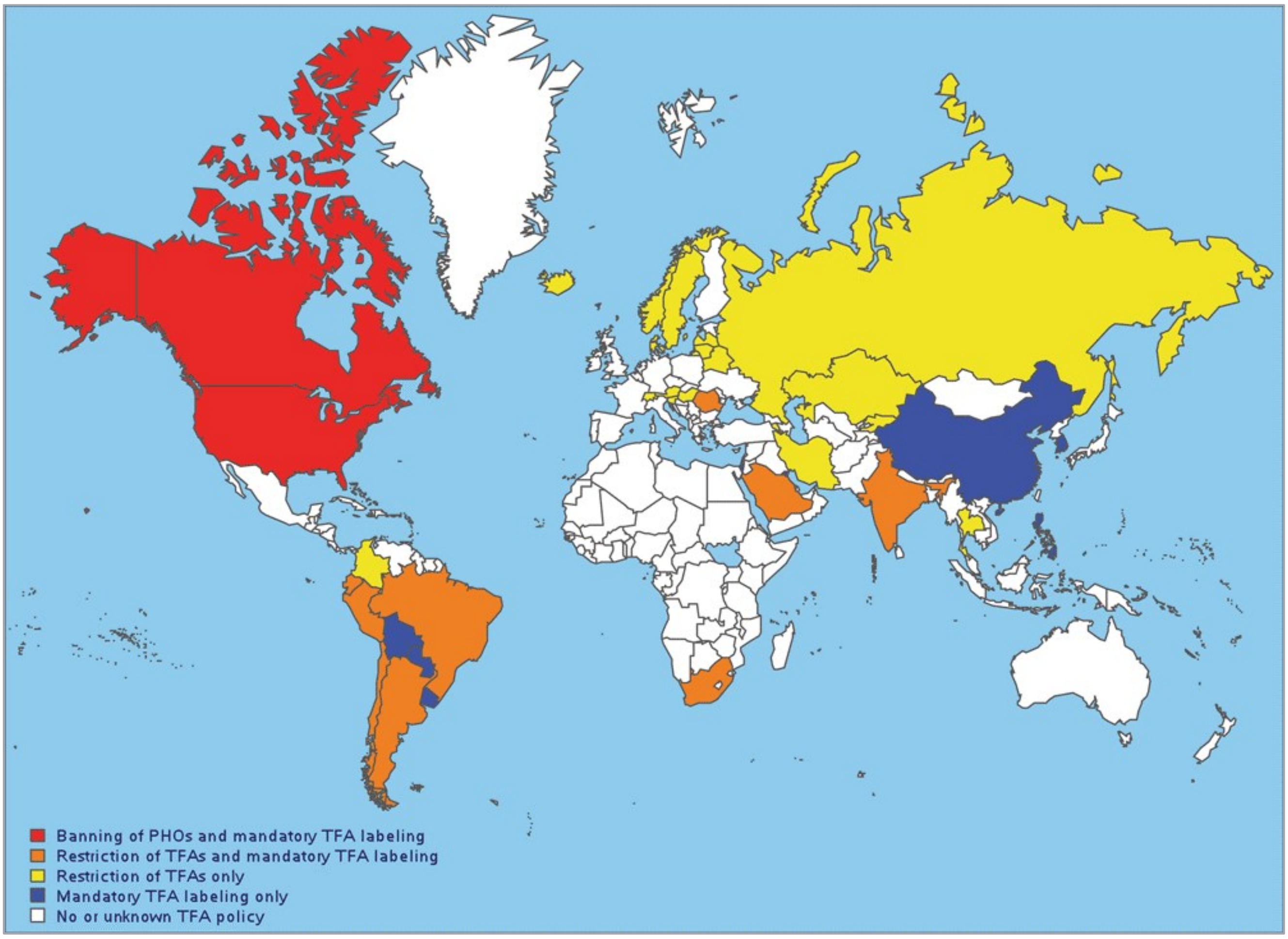


Figure 10 Countries with policies or regulations on industrially produced (artificial) TFAs. Data source: World Health Organization (WHO, n.d.). Abbreviations: PHO, partially hydrogenated oil; TFA, trans-fatty acid (Source: Li *et al.*, 2019)

2.5. Sunflower Seed (Seed for Sowing) Market

The increasing area of sunflower crop and increasing demand for vegetable oil is driving the growth of the sunflower seed market for sowing purposes. The sunflower seed market (seed for sowing) has witnessed unprecedented vertical growth in recent years and is highly consolidated. The market value is projected to grow from USD1 337.0 million in the year 2018 to USD 2 017.8 million by 2024, showing a compound annual growth rate of 7.1% during the forecasted period from 2019 to 2024 (Mordorintelligence, 2019). The market for sunflower seed used for sowing purposes forms a small part of the sunflower seed commodity industry and accounts for only 2% of the market share. The major sunflower seed companies are focusing on developing sunflower seeds that have traits such as high oleic acid (also see Section 3.2.2 on page 26), high-performance sunflower hybrids that are tolerant to biotic stress (also see Section 3.2.5 on page 41) and disease-tolerant hybrid seeds. Thus, farmers are able to choose from the seed types, i.e. confectionary, conventional oil types, high oleic or NuSun – a mid-oleic type, each of which may have a speciality trait. Examples are Clearfield, Clearfield Plus and Express Sun.

Companies are adopting strategies, such as forming joint ventures and entering into agreements, to exploit the current demand for sunflower seed. Syngenta has acquired 100% of the sunflower seed business unit of the Monsanto hybrid sunflower seed activities, including all germplasm and the development and breeding activities of hybrid sunflower seeds. Syngenta also has acquired Sunfield Inc., a US-based company. With this the company is strengthening its supply chain capabilities and its expansion into new geographies (Mordorintelligence, 2019).

In South Africa, the organisation that regulates seed certification is the South African National Seed Organization (SANSOR). SANSOR annually publishes data of seed sales of different agricultural commodities. The seed sales for field crops are divided into three groups, viz. Hybrids non-GMO, GMO and open pollinated (Figure 11).

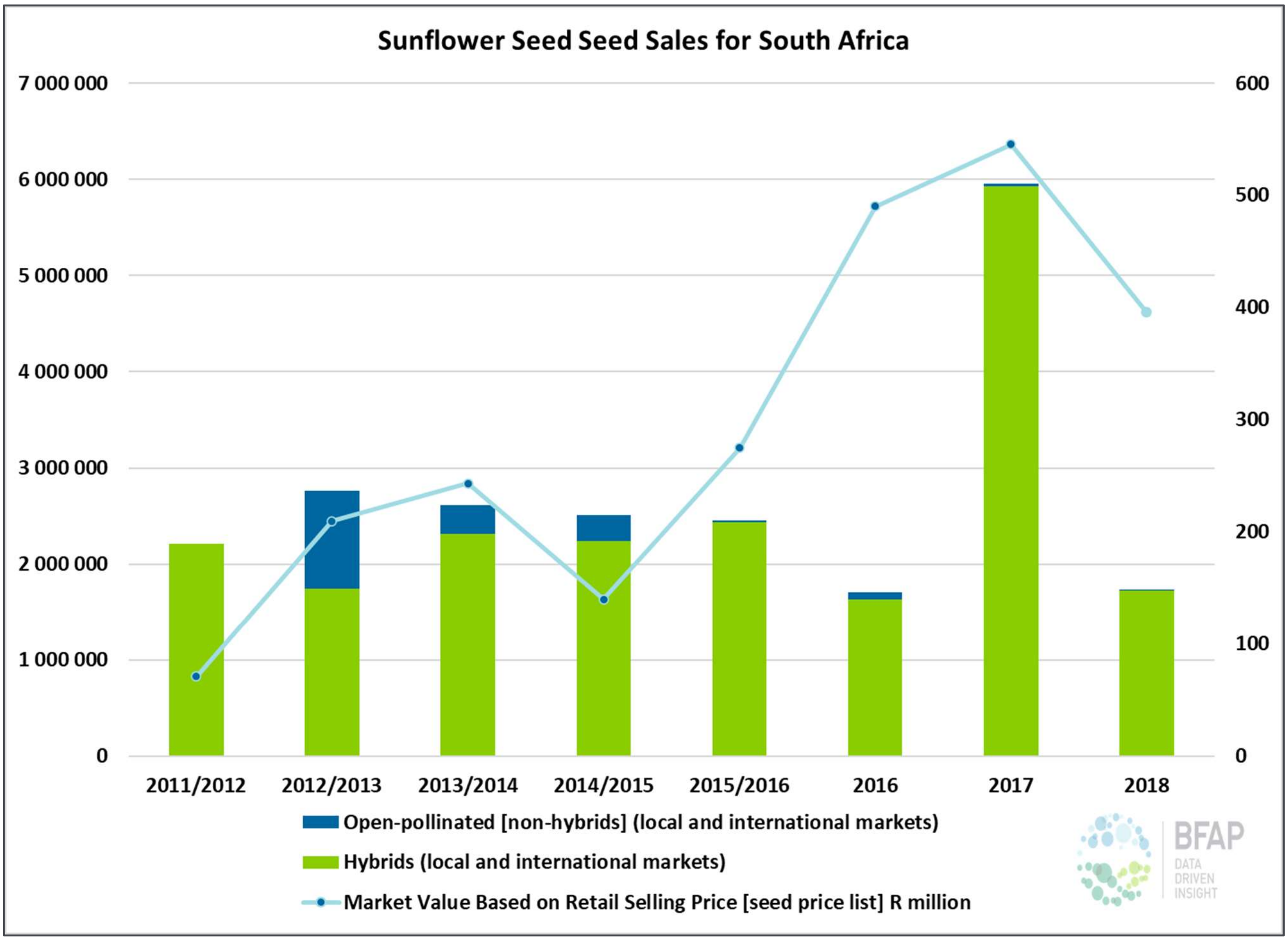


Figure 11 Market value and sunflower seed sales by type for South Africa (Source: SANSOR)

2.6. Summary

Globally, a total of 51.41 million tonnes of sunflower seed are produced on average annually. This in turn, leads to the annual production of about 19.45 million tonnes of sunflower oil and 20.9 million tonnes of sunflower meal. The leading producers (and exporters) of sunflower seed include Ukraine, Russia and Argentina. In South Africa, average production over the past five seasons (2014 to 2018) was just under 800 thousand tonnes on an average area of between 500 and 600 thousand hectares. Up until 2004, South African sunflower seed yields were comfortably on par with the average yields obtained by the four largest producers and exporters of sunflower in the world (Ukraine, Russia, EU-28, Argentina). However, since 2004, the area under production has declined and South African yields did not follow the same increasing trend as was the case in the rest if the world. In fact, the five-year average yield (2014 to 2018) for the top four producing countries equals 2.08 t/ha, 66% higher than the five-year average sunflower yield of 1.25 t/ha in South Africa. Although one could argue that the key sunflower production regions in South Africa have experienced exceptionally adverse weather conditions over the past five years, the growth in local yields has not been able to keep pace with trends in global yield growth.

It seems that the sunflower hybrids that are currently available in the South African market do have the genetic potential to produce higher yields that are more in line with international trends: The national cultivar trials indicate that the potential of the plant under trial conditions reached 2.1 t/ha on average between 2015 and 2018. Farm management practices, environmental factors and the fact that sunflower is most often not the first-choice crop on South African farms are among factors that likely contribute to this yield gap.

The sunflower price in South Africa is driven mainly by the price for oil cake and oil. Since South Africa is a net importer of these commodities, their prices are determined mainly by the import parity prices. There currently is no price incentive related to the quality of sunflower seed in South Africa and therefore the primary characteristic by which farmers select seed varieties is total yield.

The competition faced by the local industry from imported seed, oil and oil cake is to some extent softened by the *ad valorem* import tariffs (see Table 3) that are charged on the FOB (free on board) prices of the imported products. There is a fine balance between the price at which the South African farmer can sustainably produce a tonne of sunflower and the price that crushing plants can afford to pay for the seed and still be able to compete with imported oil and cake.

South Africa has an estimated crushing capacity of one million tonnes per annum and has a well-established capacity for refining and manufacturing oil-based products. While sunflower oil is destined for human consumption, sunflower oil cake is generally regarded as a lower-valued product compared to soya bean meal in terms of nutritional value, protein and fibre content. As a result, broiler rations typically cannot include more than 7% sunflower meal. Therefore, sunflower meal is mainly used as feed in the dairy and beef industries.

The threat to sunflower oil and meal in South Africa is that they can be substituted with other products, such as palm, soya and canola oil. Imported palm oil has replaced sunflower and soya oil in the commercial market, such as the take-away industry. Palms produce much higher yields per hectare at much lower costs than any other oilseed and can thus be produced sustainably at very low prices, leading to cheap imports into South Africa.

Trans-fats and concerns about their effect on health explain the recent dynamics of the edible vegetable oil market globally, with higher demand for high oleic seed varieties. South Africa has instituted policies similar to those of other higher-income countries, although other African countries are yet to institute such policies. South Africa's sunflower industry could benefit from niche health-conscious product markets and capitalise on exporting surpluses of refined vegetable oil products to other African markets.

3. Field Level: Genotype and Environment Influences on Sunflower Seed

3.1. Introduction

Drivers affecting sunflower seed quality have been researched worldwide in an attempt to improve the quality. Sunflower seed quality can be defined in terms of several characteristics, such as seed oil and protein contents, along with seed hullability (Nel, 2002). The amount of money being spent on sunflower research, both public and private, is dwarfed by the amount being spent on other field crops such as maize and soybeans. There have, however, been recent developments, with a focus on the:

- Creation of oil hybrids (with high seed and oil yield) resistant to dominant diseases and with drought tolerance.
- Creation of hybrids with different oil quality (high oleic acid content and changed tocopherol content).
- Creation of hybrids tolerant of certain groups of herbicides (imidazolynes and tribenuron-methyl) (Jocic *et al.*, 2015).

The main direction of sunflower breeding is the creation of hybrids with high genetic potential for seed yield (over 5 t/ha) and an oil content in seed (> 50%) that gives high oil yield per hectare (> 2.5 t/ha). These aspects are important to the cost of production and will allow sunflower seed to maintain or increase its existing world market share among oilseeds. It is not expected that sunflower will be genetically modified in the near term.

3.2. Genotype Influences on Sunflower Seed Quality

3.2.1. Yield

Seed yield is a complex and quantitative trait that is not only controlled by many genes, but also influenced highly by environmental conditions, so both additive and non-additive genetic effects play an important role in the inheritance of seed yield. Seed yield consists of three main components:

- number of plants per hectare (for European standards the optimal number of plants ranges from 55 000 plants/ha to 75 000 plants/ha and for South Africa this is 30 000 to 45 000 plants/ha, depending on maturity group and leaf position on the stem)
- seeds per plant (1 500 to 2 000 seeds), and
- 1 000-seed weight (up to 80 g) (Kaya, 2016)

Weight (hectolitre weight (50 to 55 kg/hl) is another important component and is closely related to low husk levels (< 25%) and high oil content in seeds (50% to 55%). There is, however, a diverse correlation between the two traits.

Seed yield is the most important characteristic for sunflower breeders formulating a model of selection schemes for efficient photosynthesis. The effect of heterosis in sunflower hybrids is based on using inbred lines, such as cytoplasmic male sterility (CMS), female and restorer male lines, to obtain high-yielding hybrids. This is achieved mainly using single crosses, since heterosis decreases frequently when using two-way or more crosses.

Hybrids are genetically narrower than varietal populations, so it is necessary to develop hybrids that are highly adaptable to each agroecological region (Škorić, 2012). In addition to high seed yield and high oil content in seeds, sunflower hybrids should have resistance to some important diseases and weeds integrated into them.

Theoretically, the genetic variability of cultivated sunflowers presents the possibility to develop hybrids with a genetic potential for seed yields of over 6 t/ha and seed oil content of over 55% (Škorić *et al*., 2007; Škorić, 2012). However, the current production range of sunflower seed is only 1.5 to 3.0 t/ha, which is mainly attributed to environmental factors. Škorić (2012) indicated that only 10% to 20% of the yield potential of sunflower plants comes from its genetic capacity, and that general phenotypic variance is determined by genetic factors such as leaves and roots and environmental conditions such as soil fertility and climate. In breeding to remove or reduce environmental factors, yields of at least 4 t/ha should be attainable.

After the change in the Common Agricultural Policy in the EU in 1992, the question arose whether recent sunflower varieties showed any genetic gain over old varieties (Vear, 2016). Comparisons with varieties planted from 2000 on showed that the potential yield of the leading varieties was at least 150% that of the Russian cultivar *Peredovik* and the other varieties grown from 1960 to 1970 (Salvi and Pouzet, 2010; Vear and Muller, 2011). Škorić *et al*. (2007) indicated that farm yields in the central parts of France reached 4 t/ha and suggested that it would be possible to obtain 6 t/ha. However, yields in France have rarely exceeded 2.5 t/ha. With the trend of planting fewer sunflowers under irrigation, there has been little change in mean yield (2015: 2.1 t/ha). Thus, national yield figures may be skewed due to expansion, the contraction of plantings under irrigation and the displacement of sunflower planted on high-potential soils with other crops with a higher income potential, leaving a larger proportion of sunflower seed planted in the more marginal areas. The shifts in sunflower seed production systems imply that there is a need to breed genotypes that maintain good yields in stressed/dryland production conditions (Vear, 2016). This task has become easier using new techniques and technologies such as genomics, phenotyping and crop models.

In South Africa, genetic improvement of seed yield and oil content in sunflower cultivars was initiated in the early 1970s. To test cultivars under different environments, the national sunflower cultivar trials – coordinated by the Agricultural Research Council (ARC) – were started in 1975 (Birch *et al*., 1978). These annual trails continue to date, with trials throughout the sunflower growing regions.

In 2012, Chigeza *et al*. investigated seed yield and associated trait improvements in sunflower cultivars over four decades of breeding in South Africa using data from the cultivar trials (Figure 12). Two datasets were used in the study: (1) side-by-side evaluation of historical and current sets of popular cultivars in the same environment under one set of trial management practices; and (2) yield trends in commercial farmers' fields based on annual production estimates. The absolute genetic gain (yield increase per year) for seed yield in the side-by-side trials ranged from 18 to 32 kg/ha^{-1} year^{-1}, with a mean of 24 kg ha^{-1} year^{-1}. In contrast, the absolute increase in seed yield under commercial production was 12 kg ha^{-1} year^{-1}. The estimated relative genetic gain for seed yield based on side-by-side trials was 1.5% year^{-1}, and the relative gain in seed yield per year under commercial production was 1.9%. The contribution of new cultivars to total progress in seed yield for sunflower was 56.3% for the period 1970 to 1989 and 23.9% from 1990 to 2009, and the mean over the four decades under consideration (1970 to 2009) was 41.6%.

Although not using the same methodology as Chigeza *et al*. (2012), the average seed yield according to the national cultivar trials for the past 10 seasons (2010 to 2019) indicates a slight but not significant (R^2 = 0.0174) increase in yield taken over all cultivars and environments tested for the season (Figure 13). This correlates well (0.57) with the increase in national yields estimated by the Crop Estimates Committee, which also indicates, although also not significantly so (R^2 = 0.2148), an increase in yield. The ± 1.0 tonne yield difference between the cultivar trials and the national average yield indicates that there is potential to increase commercial yield (Figure 5).

Using the year of release of the data from 2005 to 2019, the average, yield, oil yield, protein and oil content percentage were calculated for the period 2005 to 2010 (six seasons) and 2011 to 2019 (nine seasons) for all the cultivars that were in the trials for more than two seasons (Table 4).

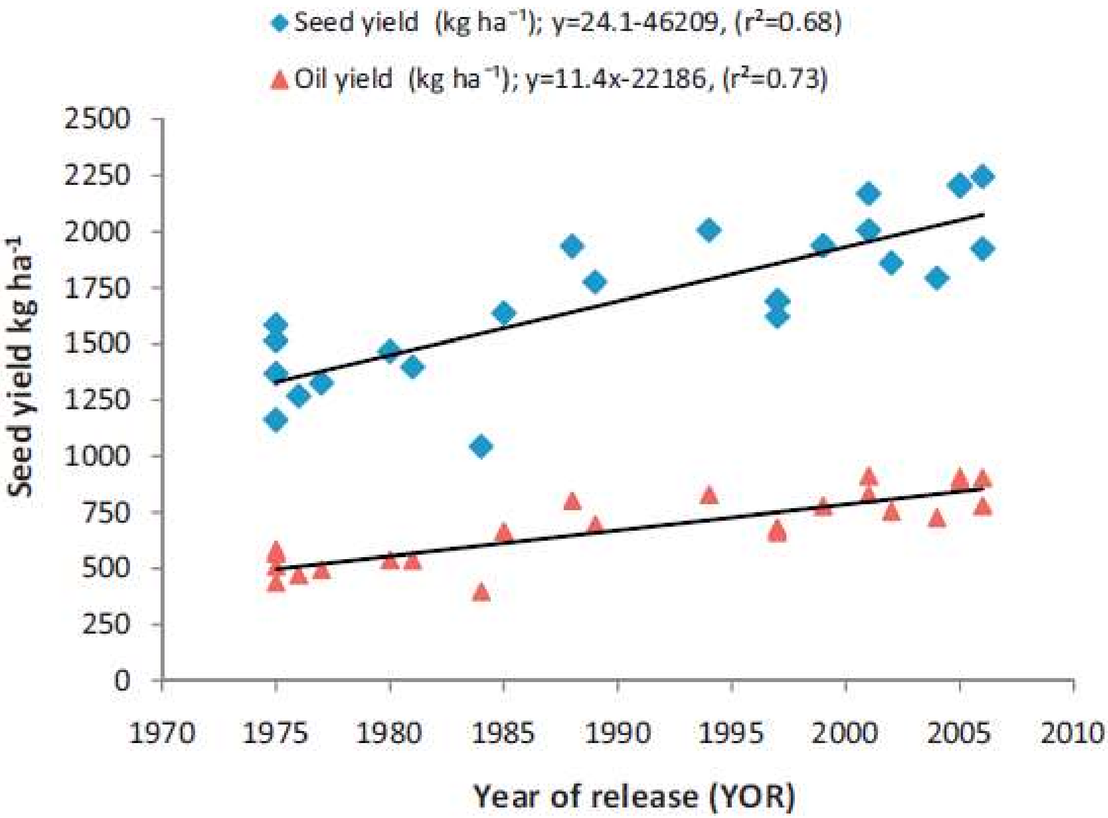


Figure 12 Absolute genetic gain in seed yield and oil yield across all environments. Seed yield for each cultivar over four environments was regressed on year of release (YOR). Source: Chigeza *et al.*, 2012

Table 4 Averages of yield, protein content, oil content and oil yield for the cultivars based on their period of release – 2000 to 2009 and 2010 to 2019, as well as the % change between the two periods

Year	Yield (t/ha)	Protein content (%)	Oil content (%)	Oil yield (t/ha)
2000 – 2009	2.01	17.91	43.81	0.86
2010 – 2019	2.29	17.81	42.51	1.01
increase/decrease (%)	13.92	-0.57	-2.96	17.28

The average yield of the cultivars based on the year of release indicates that there was an increase in yield of ± 14% between the two periods (decades). This is in conjunction with the findings of Chigeza *et al.* (2012) and provides an indication of diminishing % contribution of cultivars in the breeding for higher yields.

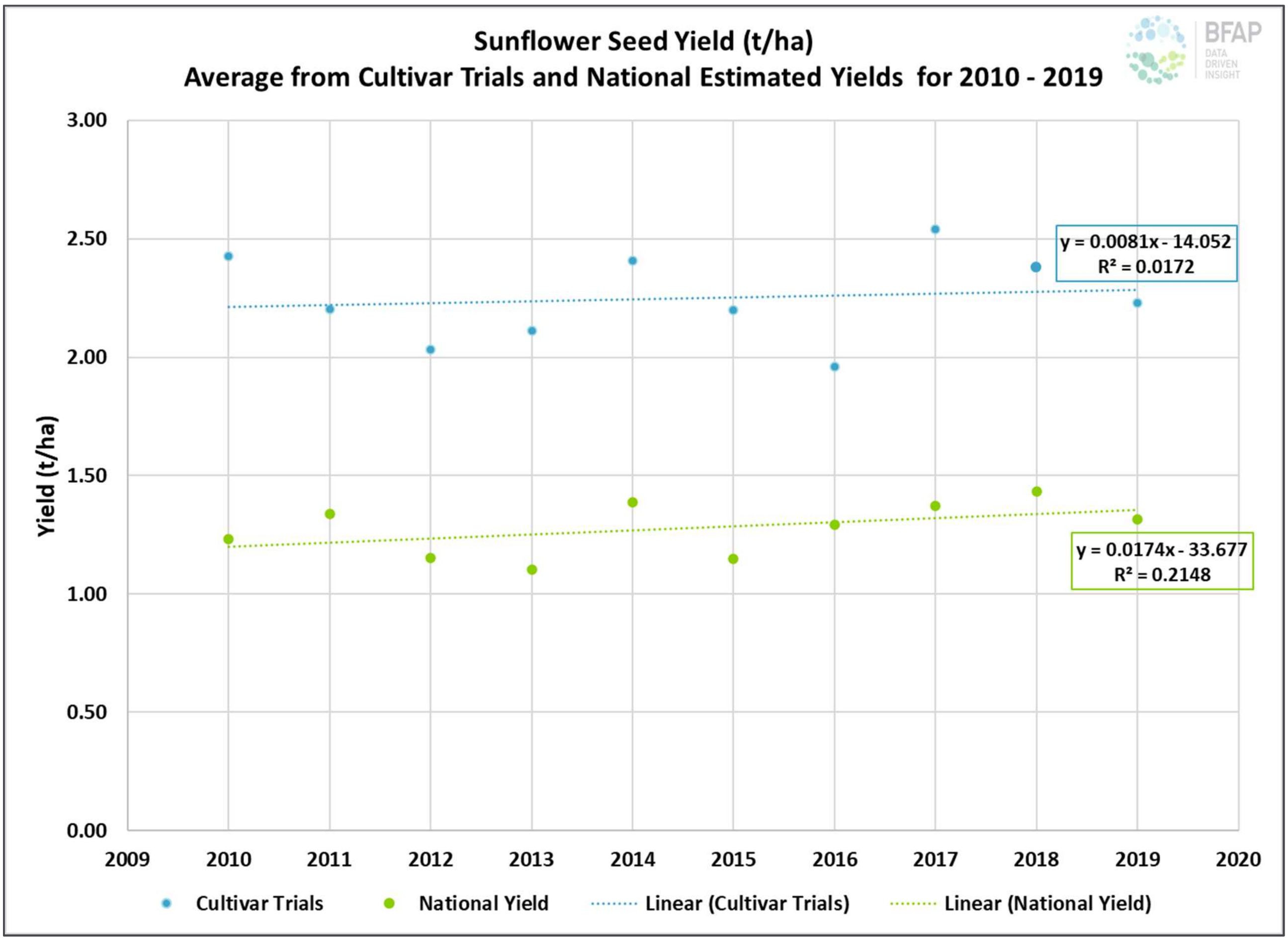


Figure 13 Sunflower seed yield based on cultivar trials and national yields (2010 to 2019).

3.2.2. Oil Content

A systematic literature review (SLR) was performed to identify and summarise key concepts in the existing literature on factors influencing sunflower seed oil content. Table 5 displays a summary of the key drivers explored in the literature.

Table 5 Summary of SLR of existing literature on key drivers affecting sunflower seed oil content

	Driver	Effect on oil content	Number of sources
External / Control factors	Earlier planting dates	↑	3
	N rates fertilisation	↓	3
	Hybrid/ Genotype/ Cultivar	!	12
	Environment	!	3
	Planting density	↑	2
	Water deficit	↓	4
Internal correlation	Yield	↓	3
	Seed characteristics		1
Additional research fields	RIL's QTLs		3
	Beneficial microbes	↑	1

↑ : Increase; ↓ : Decrease; ! : Critical

Since the work of Pustovoit, high seed oil content has always been a breeding objective (at least for oilseed sunflower; for confectionary, a low oil content is required) (Vear, 2016). Up to about 1970, it was necessary to press seed to determine oil content, but with the development of very rapid, non-destructive measurement using nuclear magnetic resonance (NMR) spectroscopy, the oil content, which is highly heritable, has become one of the easiest characters for the breeder to determine. Up until just before World War II, conventional sunflower yielded only 18% oil. However, under good field conditions, modern varieties regularly yield over 50% oil. The maximum possible oil content is probably about 60%. This may, however, be too high to obtain under the best combinations with other characters such as high yields per hectare. Oil requires more energy per gram produced than cellulose, so that the highest yielding genotypes often do not have very high oil contents (Vear, 2016).

Genotype–environment interaction may be significant for the percent oil content, stem height and stem diameter. These traits are readily affected by environmental factors. For example, oil content in the seed is affected by factors such as moisture availability at seed fill, duration of seed fill, and mean daily temperatures above 25°C (Škori , 1992).

For the producer, oil yield per hectare is important, whilst crushers are more interested in the oil content as this relates directly to plant efficiency. The oil content can be expressed via three approaches (according to the cultivar trial reports):

- as is, with no compensation for the moisture content of the seed (current practice of SAGL and industry),
- adjusted for a moisture content of 9%, which is mostly taken as the norm from a trading perspective.
- moisture free, implying zero percent moisture.

These differences in calculation may lead to unequal comparisons (not comparing apples with apples) and contribute to confusion regarding the oil content averages and trends, as the method often is not stated in reports. The percentage differences may not seem to be big (1% to 4%), but when this makes the difference between profitable and unprofitable crushing margins, these differences become important (see Figure 15). A summary of the methods used to present the oil content by the two major data sources, viz. cultivar trials and SAGL quality reports, are presented in Table 6. Both the cultivar trials and the SAGL quality report data do not publish detailed moisture content data for accurate standardisation calculations. The data is used as is and thus, in context, the trend is more important than absolute figures (with little certainty that the two can be compared on face value). One recommendation to be made to the industry is to standardise the data representation of both the yield and oil content to a set standard of moisture content for direct comparability, e.g. 9%, which is mostly taken as norm. This must be communicated to all parties collecting, reporting on and analysing data representing sunflower seed in South Africa.

Table 6 Methodology used to measure the oil content in data from the Cultivar trials and SAGL quality reports

Year	Methodology to measure oil content	Calculation/reporting oil content
Data collected through the cultivar trials (National Cultivar Trials)		
2005	Pretern DA7000 infra-red analyser on dry solid base	No information
2006-2007	NIR	Moisture free
2008	No analysis done	
2009-2012	NIR	Moisture free
2013-2019	SAGL in-house method 024 with Soxhlet extraction apparatus	Moisture free
Data collected from silos (SAGL Quality Reports)		
2013-2019	SAGL in-house method 024 with Soxhlet extraction apparatus	As is

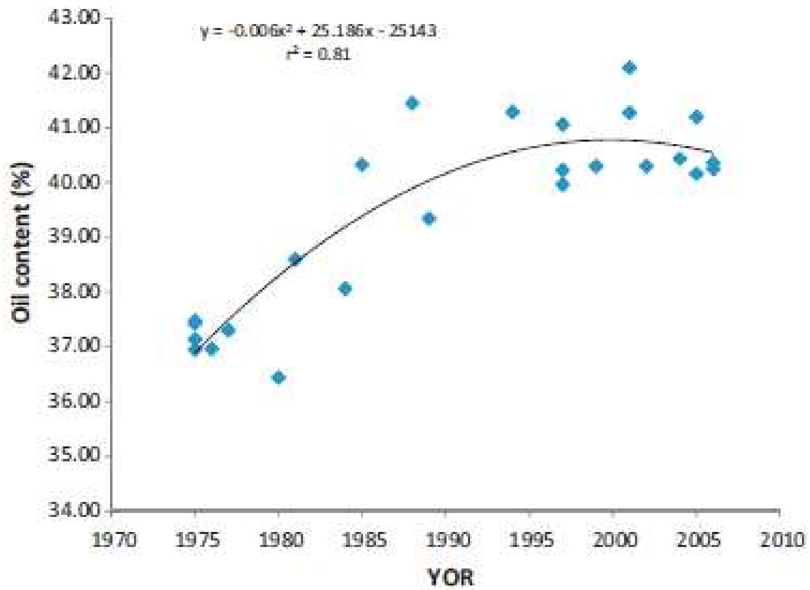


Figure 14 Absolute genetic gain in oil content across all environments, where YOR refers to year of release. A quadratic model was fitted, rather than a bilinear model (Source: Chigeza *et al.*, 2012)

Chigeza *et al.* (2012) say that, when plotting the mean oil content of the cultivars in the year of release (YOR), a fitted quadratic model showed an increase in oil content in cultivars up to the 1990 breeding decade, and a levelling off of the increase in content in the 2000 breeding decade (Figure 14). This decrease in the oil content seems to be a pattern that continued over the next decade, as shown by the analysis of data from the cultivar trials and the SAGL (Figure 15).

Before working with an average oil content of the various cultivars enrolled in the national cultivar trials, caution must be taken to differentiate between cultivars that are commercially sold and those that are enrolled as new or future market entrants. Table 7 below shows a comparison of the average yield and oil content of varieties that are sold commercially (as indicated by seed companies) and those that are not sold commercially. The yield for commercially sold varieties is marginally higher (0.1 t/ha, 4.5%) and the oil content for commercially sold varieties is 0.58% lower than the other enrolled varieties. However, since these differences are very small (almost negligible) on average, the research report will continue to analyse the averages of all varieties that were part of the cultivar trials.

Table 7 Comparing commercially sold varieties with others enrolled in the national cultivar trials

	Average yield (t/ha)	Average oil content (%)
Varieties commercially sold	2.33	43.25
Other enrolled varieties	2.23	43.83

Figure 15 illustrates the oil content by year for the cultivar trial data, reported on a moisture-free basis on the left, and compares the oil content for the SAGL quality reports (data from silos) measured on an as-is basis with the cultivar trial results and reworked to a 9% moisture content basis on the right. The results of the cultivar trial suggest a turning point in the decline in oil content in 2016 (see estimated hyperbolic curves). The same trend, however, is not observed in the national oil concentration data from the South African Grain Laboratory (SAGL), in which a downward trend is still indicated (Figure 15). Given that cultivar trials include most of the newest cultivars available in the market, along with the lag in acceptance (sales) of newer varieties in the commercial market, there is some potential that the oil content may increase over the next few years as producers change to newer, higher oil and higher yielding cultivars. We therefore conclude that there is some scope for an improvement in sunflower seed oil content based on the available cultivars (also see Box 1 at the end of the section).

As represented in Table 4 on page 24, the sunflower seed oil content (%) of cultivars based on the year of release decreased by ± 3% between the two decades (2000 to 2009, 2010 to 2019). As can be expected, there is a high correlation (0.86) between sunflower seed yield and sunflower seed oil yield per hectare (Figure 16). Sunflower seed oil yield per hectare shows a slight increase over the last decade.

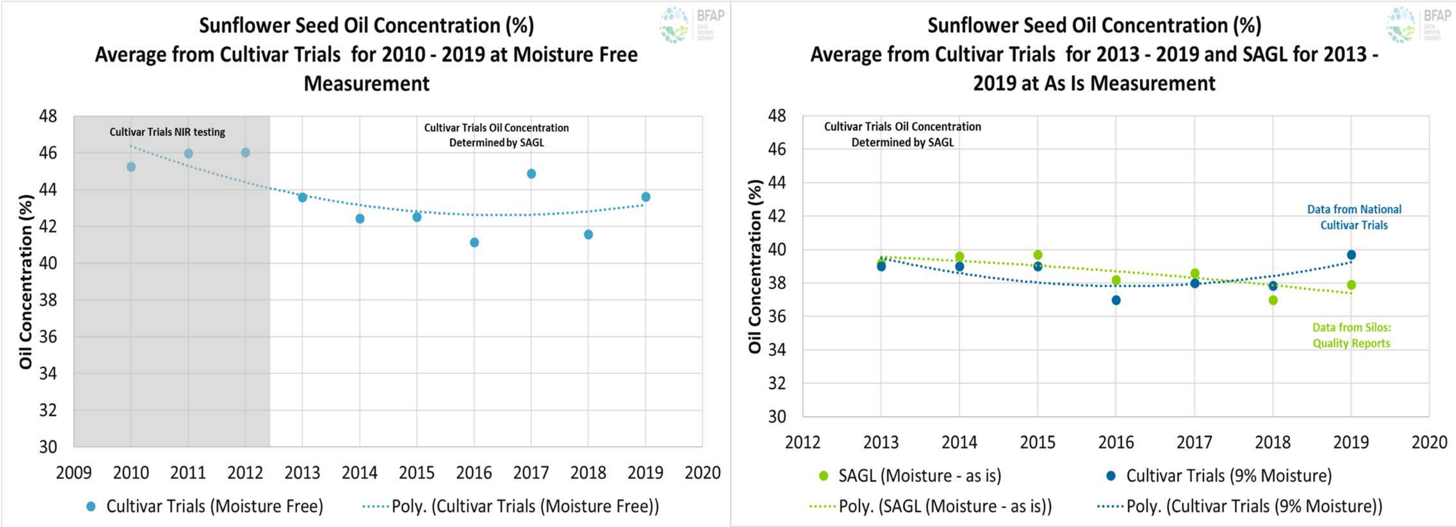


Figure 15 Sunflower seed oil concentration based on the cultivar trials and SAGL results to illustrate differences in the way oil content is presented, i.e. "as is", moisture free or at 9% moisture content.

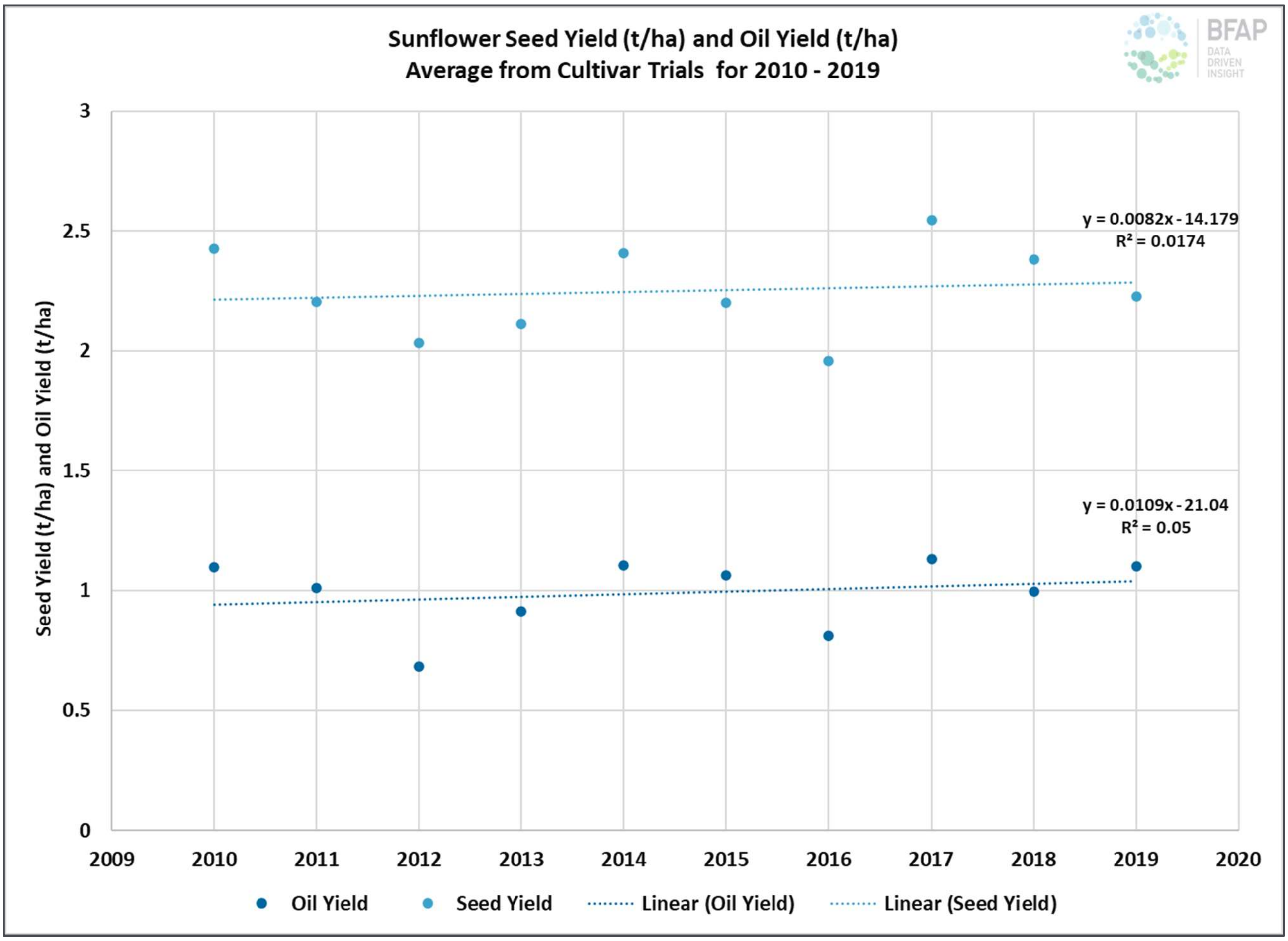


Figure 16 Sunflower seed production yield (t/ha) and oil yield (t/ha), average from the cultivar trials for 2010 to 2019

According to the registrar of plant improvement, there were 119 different sunflower seed varieties available to producers in December 2019 (DALRRD, 2019). Of these varieties, 113 are hybrids classed as high oil, two are high-oil open pollinated, three are low-oil hybrids and one is low oil-open pollinated. Most seed suppliers make some reference to seed type or trait through some of their own naming conventions, e.g. CL – Clearfield, CLP – Clearfield Plus, HO – high oleic. After discussions with South African seed companies, it was clear that certain genetic seed backgrounds yield consistently higher oil content over various planting dates and other environmental variables. Therefore, a high-oil content trait can be bred, and a 40% oil content achievement is perceived as a high-oil content-yielding cultivar from a breeding perspective. From the correlation analysis below, as well as the different advertisements for sunflower seed featuring oil content in South Africa compared to abroad, it is clear that cultivars in South Africa are expected to yield up to 10% lower oil content. On the other hand, some South African cultivars have been planted overseas (in Argentina) and, while this controls for seed quality and genetic differences, the same cultivar yielded on average 6% to 10% higher oil content and up to 1 t/ha higher yields in Argentina than in South Africa (see Table 8). These disparities, as well as information in the sections to follow, point not only to cultivars and technologies as drivers for oil content in sunflower seed, but also indicate that environment and agronomic practices are crucial.

Table 8 Comparison of cultivar performance in Argentina and South Africa

Cultivar	Country	Yield (t/ha)	Oil content (%)
Cultivar 1[3] – commercially sold in Argentina and South Africa	Argentina	2.58	52.7
	South Africa (av. 2016 to 2019)	1.77	42.3
Cultivar 2[4] in Argentina vs. Cultivar 3 in South Africa	Argentina	2.51	50.4
	South Africa (av. 2016 to 2019)	1.88	40.0

Source: National cultivar trials in South Africa & Argentina: Corteva, 2020

Table 9 presents a review of a selection of cultivars with agronomic trails with information derived from seed companies' websites and those obtained over different seasons in the cultivar trials. The correlation between the information on the South African seed companies' websites and that obtained over different seasons in the cultivar trails for day to flower was low (0.065), whilst there was some correlation for oil content (%) (0.413). The index of agreement was 0.486 and 0.775 for day to flower and oil content respectively (Figure 17). This indicates that, for the selected cultivars in cultivar trials, the cultivars deliver the advertised oil yield, whilst there was not such strong agreement on when 50% flowering was reached. Oil content (%) is a fairly accurately measurable trait, whilst time to 50% flowering is somewhat arbitrary. Thus, it is expected that the index of agreement will be lower. For days to 50% flower, some of the cultivars took longer, whilst others flowered earlier. The cultivar trials mostly yield a higher oil content than advertised, indicating that the cultivars in the trial reach their genetic potential in the environment. Whilst the average advertised sunflower seed oil content (%) was between 38% and 46% for the South African cultivars, an analysis of advertisements by seed companies supplying the Russian, Ukrainian, Hungarian and Argentinian markets indicate advertised oil yield in the range of 45% to 54% (Table 10). This is significantly higher than the advertised yield for cultivars available to South African producers.

[3] Also used in the pilot study presented in Box 1 at the end of this section.

[4] Cultivar is of South African origin and was moved to Argentina since it could not outperform Cultivar 3, the winning Corteva cultivar in terms of yield in South Africa.

Given this, it may very well be possible to import sunflower seed with a higher oil content for processing purposes than what South African producers currently can achieve using the available genetic material.

Table 9 Review of a selection of cultivars in agronomic trails with information derived from seed companies' websites and those obtained over different seasons in the cultivar trials

			Information from the Internet			Cultivar trials	
Cultivar	Supplier	Type	Relative days to flowering	Relative days to harvest maturity	Oil content (%)	Days to 50% flowering	Oil content %
AGSUN 5101 CLP	Agricol	Clearfield	65-72	130-140	38-44%	71	40
AGSUN 5102 CLP	Agricol	Clearfield	64-70	130-140	38-43%	70	40
AGSUN 5103 CLP	Agricol	Clearfield	65-73	130-140	38-44%	72	40
AGSUN 5106 CLP	Agricol	Clearfield	65-73	130-140	38-44%	72	40
AGSUN 5270	Agricol	Conventional	62-70	130-140	40-44%	67	44
AGSUN 5273	Agricol	Conventional	65-72	130-140	38-43%	69	41
AGSUN 5278	Agricol	Conventional	65-72	130-140	38-43%	67	42
AGSUN 8251	Agricol	Conventional	65-72	130-140	38-43%	68	42
CAP 4000	Capstone Seeds	Conventional			42-46%	66	43
DKF 68-22	Klein Karoo Seed Marketing	Conventional	68	130 - 140	Very high	72	43
NK Adagio CL	Syngenta	Clearfield	66	130-140	Very high	65	43
P 65 LL 02	Pioneer	Conventional	72		42.6 East 43.4 West	70	44
P 65 LL 14	Pioneer	Conventional	68-72		39.4 East 43.5 West	69	44
P 65 LP 54	Pioneer	Clearfield	72		37.7 East 39.9 West	67	42
PAN 7033	Pannar	Conventional	75	150-155	41	68	42
PAN 7049	Pannar	Conventional	75	150-155	41	66	43
PAN 7057	Pannar	Conventional	77	150-155	43	66	43
PAN 7080	Pannar	Conventional	77	150-155	40	68	43
PAN 7095 CL	Pannar	Clearfield	75	150-155	40	66	42
PAN 7100	Pannar	Conventional	76	150-155	43	68	43
PAN 7102 CLP	Pannar	Clearfield	75	150-55	43	66	66
PAN 7156 CLP	Pannar	Clearfield	77	150-155	40	70	42
PAN 7158 HO	Pannar	High Oleic	70	135-140	40	72	41
PAN 7160 CLP	Pannar	Clearfield	77	150-155	42	72	41
SY 3970 CL	Syngenta	Clearfield	69-72	125-130	44-46	69	47
SY 4045	Syngenta	Conventional	62-65	130-150	High	63	43
SY 4200	Syngenta	Conventional	64-68	140-160	Very high	67	46

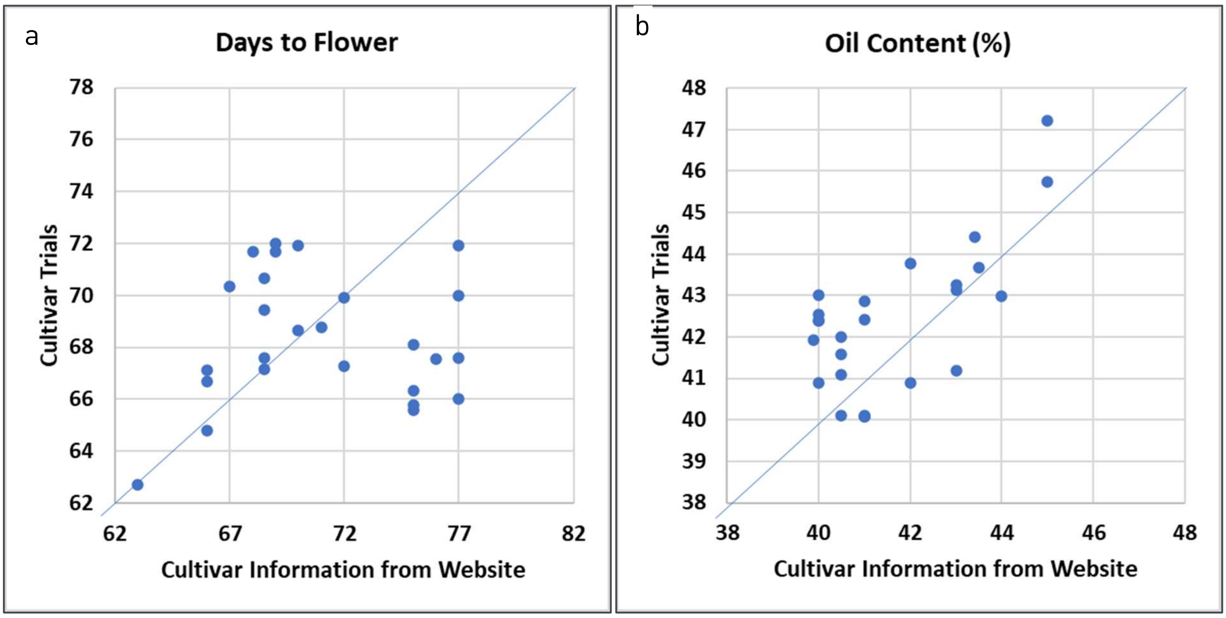


Figure 17 1:1 graph of a) days to flower and b) oil content (%) between the seed companies' websites and data obtained over different seasons in the cultivar trials

Table 10 A review of the length of the growth season and oil content of a selection of cultivars advertised by a selection of sunflower seed suppliers for a selection of countries

Cultivar	Supplier	Type	Growth season	Oil content (%)
Ukraine (https://alfa-seeds.com/our-products/nasinnya-sonyashnika/)				
Alzan	Alfa Seed own production under licence from the originator – Euralis Semences (France)		101	50
Antsilla	Alfa Seed own production under licence from the originator – ISEA (Italy)		105-110	54
Cookson	Alfa Seed own production under licence from the originator – PANAM Semences (France)		110	54
Vincenzo	Alfa Seed own production under licence from the originator – ISEA (Italy)		108	54
Michelle	Alfa Seed own production under licence from the originator – ISEA (Italy)		108	54
Theo	Alfa Seed own production under licence from the originator – PANAM Semences (France)		115	54
Russia (https://euralis.ru/catalogue/sunflower/es-genezis)				
EU GENIS CLP	Euralis	Clearfield	102	48
EU MALES	Euralis	Conventional	Very early	49
EU REGATTA	Euralis	Conventional	Medium	52
ES PETUNIA	Euralis	Conventional	Mid-season	49
EU SAVANNA	Euralis	Conventional	Early	51
EU NOVAMIS SL	Euralis	Clearfield	Early	49
ES GENERALIS SL	Euralis	Clearfield	Mid-season	51

Cultivar	Supplier	Type	Growth season	Oil content (%)·
EU YANIS	Euralis	Clearfield Plus	Mid-early	47
ES KAPRIS SLP	Euralis	Clearfield Plus	Mid-early	49
ES ARGENTIK	Euralis	hybrid express	Mid-season	50-51
ES ARKADIA ARE	Euralis	hybrid express	Early	47
Argentina (https://www.kws.com/ar/es/productos/girasol/)				
KWSOL 362 CL	kws- Argentina	Clearfield	Intermediate	51-53
KWSOL 480	kws- Argentina	Clearfield	Intermediate-long	50-53
Hungary (https://www.kws.com/hu/hu/termekek/napraforgo/)				
KWS APACHE CL	kws- Hungary	Clearfield	Mid-season	45-48
KWS ACHILLES CLP	kws- Hungary	Clearfield Plus	Mid-season	45-50
IT NAUTILUS CLP	kws- Hungary	Clearfield Plus	Mid-season	48-50
KWS ACER CL	kws- Hungary	Clearfield	Early	48-51
HYSUN 231 HO CL	kws- Hungary			
Ukraine (https://www.syngenta.ua/product/seed/alkantara)				
Alcantara	Syngenta Ukraine	Conventional	Medium early	49
The Bosphorus	Syngenta Ukraine	Conventional	Medium early	49
THE SHOP	Syngenta Ukraine	Conventional	Medium late	52
COLOMBIA	Syngenta Ukraine	Clearfield &HO	Medium early	48
NK ADADŽÍO	Syngenta Ukraine	Clearfield &HO	Medium late	49
NK BRÍO	Syngenta Ukraine	Conventional	Medium	52
NC DELFI	Syngenta Ukraine	Conventional	Medium early	52
NC CONDY	Syngenta Ukraine	Conventional	Medium	54
NC YEARS	Syngenta Ukraine	Conventional	Early ripe	53
YOU ARE ARIZONA	Syngenta Ukraine	Conventional	Medium	54
YOU ARE EDISON	Syngenta Ukraine	Conventional	Medium	54
YOU ARE THE CODICS	Syngenta Ukraine	Conventional	Medium early	49
You're shopping	Syngenta Ukraine	Conventional	Medium	53
WELCOME	Syngenta Ukraine	Conventional	Medium	52
United Kingdom, Russia, Ukraine (https://www3.nuseed.com/eu/product/nhk12m010/)				
NHK12M010	Nuseed	Clearfield &HO	Mid-late	46-49
COBALT 2	Nuseed	Clearfield &HO	Early	47-49
N4HM411	Nuseed	Clearfield &HO	Mid-late	46-49
CAMARO 2	Nuseed	Clearfield	Mid-late	48-52
IMPACT	Nuseed	Clearfield	Mid-late	45-48
N4LM408	Nuseed	Clearfield	Mid-late	49-51
X4219	Nuseed	Conventional	Mid-early	48-50

· Oil content presented as published on the websites

Box 1: Pilot study by Syngenta and CEOCO

Syngenta (through Sensako as seed distributor) and CEOCO (sunflower oilseed crusher) undertook a pilot study in the 2020 season as a proof of concept for the industry at large that the production of sunflower seed with a high oil content can boost the relative competitiveness and profitability of the industry. The pilot study had the following principles:

- Through Sensako, Syngenta distributed a sunflower hybrid (SY 3970 CL) with a high oil content to producers in the Wesselsbron and Bultfontein areas. Only these producers (planting this hybrid) were eligible to enrol in this pilot study and participation was completely voluntary.
- A sunflower seed contract was offered (through JVD trading) to producers who decided to participate in this quality evaluation, for the harvest of the SY 3970 CL cultivar.
- The contract offered producers a SAFEX price premium of 1.5% for every 1% of oil content exceeding 38% on delivery of the SY3970 CL sunflower seed to CEOCO, Boksburg or other silo nominated by CEOCO. No penalties were specified for deliveries with an oil content below 38%.
- The oil content for each load of SY3970 CL delivered to CEOCO was measured by CEOCO and their results were final.

Despite the late initiation of this pilot project, which meant that large percentages of the sunflower seed crop were already contracted, the stakeholders described it as a success:

- Of the sunflower seed delivered to CEOCO, oil content was measured at 46% to 48% (as measured by Syngenta as reference check).
- Based on an average sunflower price of R5 887/tonne, producers would have received price premiums of between R706 and R883/tonne (that is 12% to 15%).

On top of the improved price, farmers that took part in the pilot reported average yields of 2t/ha.

3.2.3. Fatty Acids

A further important quality character of sunflowers (and other oil crops) is the proportion of the different fatty acids in the oil. Sunflower seed can be divided into four types based on the oleic content present in the oil after extraction (Figure 18 and Table 11). Sunflower oil also contains a high content of vitamin E and is low in saturated fats. Along with these properties, it also contains tocopherols, carotenoids and waxes. The fatty acid composition of sunflower seed determines its uses and health effects on humans, while the oil content determines the price paid to producers.

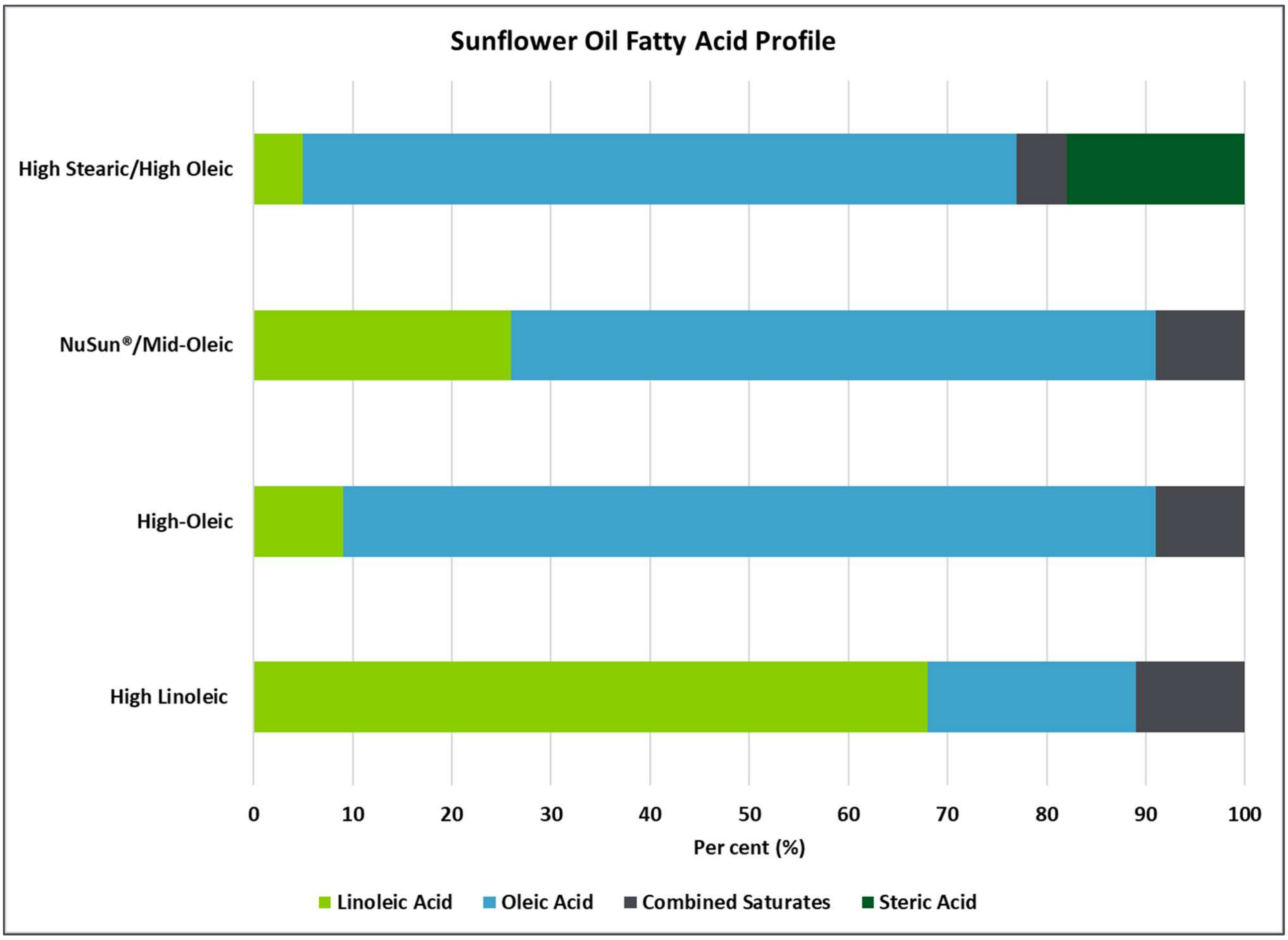


Figure 18 Sunflower oil fatty acid profile (Source: National Sunflower Association Fact Sheet, n.d. (a))

Table 11 Description of the four main sunflower seed types regarding fatty acid profile (Source: National Sunflower Association Fact Sheet, n.d.(a))

Type	Description
High linoleic	This is the traditional type of sunflower oil that has been produced for many years. Production, especially in the USA, has decreased because of its limitations in fried foods. In South Africa, however, it is the predominant type found on most grocery store shelves. A typical fatty acid ratio is 68% linoleic acid, 21% oleic acid and 11% combined saturates.
High oleic	This type was developed through traditional breeding methods. The initial patent on the seed and oil has expired and there are now several firms producing high-oleic sunflower oil, which is marketed as a premium sunflower oil with high mono-unsaturated levels. Oleic levels generally start at 82%. There are some hybrids that produce an oleic level of 90%. The advantage of high-oleic sunflower oil is added stability and a general neutral taste profile. Because it contains less than 10% saturated fats, it does not need hydrogenation and therefore does not contain trans-fats. A typical profile is 82% oleic, 9% linoleic and 9% combined saturates.
NuSun®/Mid-oleic	This type also was developed through traditional breeding methods. It is the largest volume of sunflower oil produced in the USA and Canada. The oil has a good shelf life and is a preferred frying oil, with excellent stability and a neutral taste profile. A typical fatty acid ratio is 65% oleic acid, 26% linoleic acid and 9% combined saturates.

Type	Description
High stearic/high oleic	This is the newest member of the sunflower family. The development was also through traditional breeding methods. The hybrid seed is under patent and the oil produced from the seed is marketed as Nutrisun™. The advantage is that it can be used as a replacement for partially hydrogenated oils or tropical oils with a higher saturate level. The fatty acid profile is 18% steric acid, 72% oleic acid, 5% linoleic acid and 5% other saturates.

Linoleic sunflower seed oil is the original sunflower oil and, until recently, has been the most common type of sunflower oil. It is a polyunsaturated oil with low levels of saturated fat, a clean, light taste and is high in Vitamin E. This type of sunflower oil is predominantly (65%) polyunsaturated. The type of polyunsaturated fat it contains is linoleic acid (an omega-6 acid), which is one of two essential fatty acids that our bodies require but cannot make and thus must be supplied by food sources. The balance of this sunflower oil is monounsaturated fats (oleic) at 21%, and other low saturated fats at 11%. Linoleic sunflower oil is a healthy and delicious vegetable oil. Besides its use as a liquid salad or frying oil, it is used in the production of margarine and shortening. Because of the high levels of polyunsaturated fats in linoleic sunflower oil, the oil is susceptible to oxidation during commercial usage, especially frying. Like other highly polyunsaturated oils, such as soybean and canola, it can be hydrogenated to a more stable form. This, however, as already mentioned, may lead to the development of trans-fats (National Sunflower Association, n.d. (b)).

In the last decades, many new lines of sunflower with modified fatty acid composition have been developed through conventional breeding methods. One of the most successful was the production of mutants with very high levels of oleic acid (HO), which kept the other properties of regular sunflower oil intact. This oil has a fatty acid composition similar to that of olive oil and is more stable than most seed oils used for frying and storage. Based on legislation this type of oil is usually purchased by cafes, restaurants and canteens in many countries. For instance, in the EU and USA, certain legislative restrictions were imposed on the application of particular types of oils, especially trans-fats. Thus, the cultivation and consumption of high-oleic sunflower oil is steadily increasing. These oil types have been broadly accepted by the industry and consumers, as a higher intake of monounsaturated fat may raise high-density lipoprotein (HDL) cholesterol without raising low-density lipoprotein (LDL) cholesterol. The patent on high-oleic sunflower oil and seed has expired. Consequently, more companies are becoming involved in producing and merchandising this oil type. It was estimated in 2017 that the global demand for such oil is around 2.5 million tonnes per year, with the EU having the largest share – 800 000 tonnes. In that year, this oil was 13% more expensive than standard sunflower oil.

In anticipation of a change in labelling laws for manufactured food, the US sunflower industry in 1995 started developing a mid-oleic sunflower oil known as NuSun™ (Kleingartner, 2002). It was anticipated that the Food and Drug Administration would require the labelling of trans-fatty acids. Mid-oleic NuSun sunflower oil is one of several oil choices that can be used to replace hydrogenated oils. The NuSun™ sunflower oil fatty acid profile has oleic values of 55% to 75% and saturates of 9%, while the remainder is linoleic acid. The oil has been rigorously tested in numerous frying mediums and has become the 'gold' standard in conducting fry-test comparisons. NuSun™ provides a very pleasing flavour in most food uses. Human and animal testing indicates the NuSun™ can lower LDL (bad) cholesterol. The US sunflower industry made the switch to NuSun™ to gain greater value for producers and the industry.

In more recent years, a second generation of modified sunflower oils has been developed. The fatty acid composition of these new lines differs much more from that of regular sunflower, displaying high levels of stearic acid in a high oleic background, with a high potential for industrial applications. The high stearic–high oleic oil can be fractionated to produce fractions with high levels of solids and different melting profiles that can be used in a broad variety of food formulations, including fillings, spreads, coatings and confectionary products.

During the 2008/2009 season, high-oleic oil totalled about 5% of world sunflower oil production, whilst in 2011/2012 it represented approximately 10% of the global sunflower oil market (APK-Inform, 2011). Currently, the world's largest producers of high-oleic crops are USA and the EU countries: France, Portugal, Spain, Italy and Austria. These countries have the highest percentage of arable lands planted with these crops. For instance, in the USA, this figure is 100%, while it is 60% in France and 41% in Portugal. Leading exporters of high-oleic sunflower oil are Netherlands (22%), Great Britain (19%), Italy (16%) and Spain (13%) (Bakertilly, 2017).

The high-oleic sunflower seed oil market is thus well developed, and the potential for growth is still huge, as the demand for such oil is increasing steadily. This demand may be satisfied by countries with substantial potential for the development of a high-oleic crop industry, such as Ukraine, Argentina and the CIS countries (Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, and Uzbekistan).

It was estimated in 2017 that only 2% of Ukrainian fields were planted to high-oleic sunflower seed types. However, Syngenta forecasts that Ukraine can become the largest exporter of high-oleic sunflower oil in the global market. In 2014/2015, Ukraine planted 110 thousand hectares to high-oleic cultivars and increased this almost twofold, to 260 thousand hectares, in 2016/2017. In terms of high-oleic sunflower oil, production has nearly doubled – from 225 thousand tonnes in 2014/2015 to 473 thousand tonnes in 2016/2017. This, however, has had direct consequences for Argentina. In 2014/2015, 29% of sunflowers in Argentina were high-oleic hybrids, but the figure increased to 50% a year later. However, in 2016, Black Sea countries had a record production of high-oleic sunflower seed and, as a result, their exports of high-oleic sunflower seed oil, together with those from Argentina, flooded the market This oversupply caused a reduction in demand, a decrease in price and a loss of interest by Argentinian farmers to plant this seed type. Consequently, the area under high-oleic sunflower in Argentina was significantly reduced in 2016/2017 (Castaño, 2018). According to FAS-USDA, Argentinean producers continued to plant more high-oleic sunflower varieties in the 2019/2020 season to capture price premiums in this niche market. The producers are working closely with the government to ensure the proper segregation of seed varieties for high-, mid- and low-oleic sunflowers.

Turkey is also positioned to have considerable potential for oleic-type sunflower oil, since 600 t to 700 t of the worldwide sunflower oil consumption of around 10 million t is consumed by Turkish people. In European countries, and in America, Asia and Malaysia, there is an active trend to replace the usage of palm oil with high-oleic oils.

High-oleic oil also fits perfectly within the global trend of healthy eating. As in the USA in 2014, several EU countries introduced new labelling standards and forbade the use of trans-fat acids. In 2016, they also adopted the obligatory indication of saturated fat content in products. Thus, Europe has already gone through the process of substitution of palm oil with high-oleic oil. As a result, the large volume of sunflower oil in Italian and Spanish shops today is high-oleic. In many countries with trans-fat policies, manufacturers of food products are actively searching for a replacement for palm oil. As already stated in section 2.4, high-oleic sunflower oil can become such a replacement thanks to its outstanding nutritional and taste qualities.

Furthermore, the high-oleic-type sunflower oil, in contrast to the traditional linoleic type, also conforms to the EU Biodiesel Standard of EN 14214 due to its lower iodine value.

From 2017 to 2020, the consumption of high-oleic oil worldwide was expected to increase by up to 8.1% and up to 10.2% in the EU. Every year, the variety of by-products with a high concentration of oleic acid was expected to increase by 19%. The market for blended oils also appears to ensure price and proposition flexibility. The premiums for high-oleic sunflower oil remained high (200 to 250 USD/t) in the 2019 harvesting season.

Although the regular sunflower oil as sold worldwide has a very high omega-6 to omega-3 ratio (330:1), it contains a considerable amount of oleic acid and can contribute significantly to the dietary intake of monounsaturated fatty acid. Percentagewise, South African sunflower oil contains a comparable amount of oleic acid (23% to 33%) in relation to that in other sources of fat, such as commercial lard (37%) and butter (26%) (Opperman *et al.*, 2016). Oils with linoleic acid levels above 2% (sunflower is 0%) tend to develop off-flavours because the linoleic acid oxidises quickly and must be hydrogenated to enhance the product's shelf life.

For continued profitable sunflower seed production it will be key to find value niches in the marketplace that will pay a premium over most other vegetable oils, and thus provide a better return to the farmer. This is especially important when farmers have several crop choices and turn to the market in their planting decisions, as is the case in the price-driven South African market. These choices by farmers will be based on crop rotational requirements, cost of production, labour and capital required to produce the crop, access to markets and, finally, potential economic return per hectare.

Planting high-oleic and mid-oleic sunflower seed types could be mechanisms implemented by farmers to find value over and above conventional sunflower seed production. For sunflower oil to keep competing in the world market as a low-priced vegetable oil that can compete with soybean and palm oils is in most instances not viable. Producers, and especially South African producers, could market their sunflower oil as a premium oil with enhanced value to the consumer, i.e. trans-fat free, non-GMO and, if it is the case, as high-oleic. However, the production of high-oleic sunflower oil has not been as successful as anticipated, with only a limited number of producers specialising in this market (Farmers Weekly, 2019).

As of the 2018/2019 season in South Africa, the SAGL has included an analysis of fatty acid profile of 20 composite crop samples representing different production regions as well as 20 cultivar samples from different localities.
Table 12 presents the fatty acids in the profile analysis. This is the start of a database to collect such information. The reason why these analyses were initiated was that a large seed oil producer in South Africa contacted Precision Oil Laboratories and SAGL to determine if an unexpected variation in one of the fatty acids in a sunflower seed batch was acceptable (SAGL, 2019). After extraction of the sunflower oil, it was rejected by a food-processing company, indicating that one of the fatty acids was not within their specification. A literature review and the American database proved that wide ranges were acceptable for the specific fatty acid, since specific factors, including drought, could lead to the fatty acid having increased acceptability ranges. The seed containing the fatty acid, which was out of range, was from a particularly dry season's production, which explained the wide range. If a national database had been kept and maintained, time and money lost by the industry because of rejected batches could have been avoided (SAGL, 2019).

It is important for South Africa, as a sunflower seed-producing country, to develop and maintain a national fatty acid profile database to the benefit of the (sunflower seed) oilseed industry. The annual analysis of crop and cultivar samples will ensure that the natural variation caused by different cultivars, as well as the influence of climate and locality, are included in the database values. Seasonal variations will also be addressed. Recording all variation applicable to the crops in the database will enable the annual review of the specified ranges (SAGL, 2019).

Fatty acid composition, together with a better capturing of yield, oil content and other variables, such as climate, soil type and crop management, could enable data scientists to help breeders select cultivars and varieties that are well suited to a certain environment or exhibit stability across a wide range of diverse environments.

Table 12 Fatty acids in the SAGL profile analysis

Fatty Acid	Name
C14:0	Myristic acid
C16:0	Palmitic acid
C16:1	Palmitoleic acid
C17:0	Margaric acid
C17:1	Ginkgolic acid
C18:0	Stearic acid
C18:1	t trans Oleic acid
C18:1	c cis Oleic acid
C18:2	t trans Linoleic acid
C18:2	c cis Linoleic acid
C18:3n6 n6	Linolenic acid
C18:3n3 n3	Linolenic acid
C20:0	Arachidic acid
C20:1	Eicosenoic acid
C20:2	Eicosadienoic acid
C21:0	Heneicosanoic acid
C22:0	Behenic acid
C22:1	Erucic acid
C24:0	Lignoceric acid
C24:1	Nervonic acid

The samples gathered for the purpose of the annual national sunflower crop survey could be utilised further for future research to the benefit of the industry by including the following analyses and results in the newly created database:

Sterol and tocopherol

The problem of adulteration of food is not new and methods of detecting it were described as far back as 1820. Adulteration in the oilseed industry is a reality and blends are often made intentionally to increase the profit margin of the oil by blending it with a lower cost oil (also see Section 2.4 on page 18).

Although the fatty acid profile is the most important test for the adulteration of oil, it can be circumvented. The standard ranges laid down for the fatty acids of pure oils are very wide in order to accommodate natural variation. When blends are made, the natural variations of the constituent oils are superimposed. This makes identifying different oil samples more complex. It is possible to blend several oils to make it look like a pure oil with respect to the standard ranges of the fatty acid composition.

Fatty acid profile alone is not sufficient information for discrimination when blends of oils are involved. The inclusion of tocopherol and sterol patterns in a data basis of oils has been proven not only to discriminate between authentic and adulterated oils but can also be used to determine which oils are present in a blend and what proportions were blended.

Free fatty acids
The free fatty acid value of oil is an indicator of hydrolytic deterioration. The free fatty acid value is an important quality parameter of oilseeds and is directly correlated with the effective drying of the seeds as well as storage temperatures. High free fatty acid values lead to significant oil losses during refining of the oil. Factors aggravating hydrolytic deterioration are moisture, heat and enzymatic activity. If seeds are not dried properly, the free fatty acid value increases. It is important to update the national database with the free fatty acid value for seed oils. This will ensure that correlations can be made between free fatty acid value and harvesting conditions, as well as free fatty acids and storage temperatures. The information gathered will assist in lowering free fatty acid values and prevent oil losses (SAGL, 2019).

3.2.4. Protein Content

Sunflower seed processing produces two principal products: oil, mainly for human consumption, and oil cake (meal), for animal feed. Table 13 presents the reported composition ranges of sunflower seed on a dry basis.

Table 13 Reported composition ranges of sunflower seeds on dry basis (Source: González-Pérez, 2015)

Component	Dehulled seed (%)	Whole seed (%)
Protein	20.4 – 40.0	10.0 – 27.1
Peptides, amino acids, and other nonprotein nitrogen	1 – 13	
Carbohydrates	4 - 18	18 - 26
Lipids	47 – 65	34 – 55

Two main processing variants exist in the crushing industry: oil extraction from whole seeds and oil extraction from partially dehulled seeds. In the first process, the resulting meal is of low protein content (27% to 29%). In the second process, the resulting meal has a higher protein content (36% protein content is a standard quality for this type of meal) and reduced fibre. The use of sunflower protein for human consumption is limited due to protein denaturation and the discoloration of the protein due to the extraction processes.

Oil cake is a source of protein for animal feed blends. Sunflower oil cake, however, contains lower nutritional value (protein content) compared to other oil cakes like soybean due to its high crude fibre content. The value of sunflower oil cake is equivalent to approximately 72% of the value of soybean oil cake, depending on the diet in which it is included. The higher fibre level of sunflower oil cake restricts the amount that can be included in feed blends for poultry and pigs.

Considerably large genotypic and phenotypic variations occur in the protein levels of sunflower. There is a reverse relationship between oil and protein concentration. Genotype effects on protein concentration are largely ascribed to the hull-to-kernel ratio. Thus, the feed value of sunflower oil cake can compare well with that of soybean oil cake if it is improved through more efficient dehulling (Bekker, 1996). Ideally, sunflower oil cake should have a crude fibre content of less than 14% and a protein content above 40%. However, Smith *et al.* (1989) analysed South African 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 having a protein content of more than 40% (more recent research on this topic was not found during the literature review).

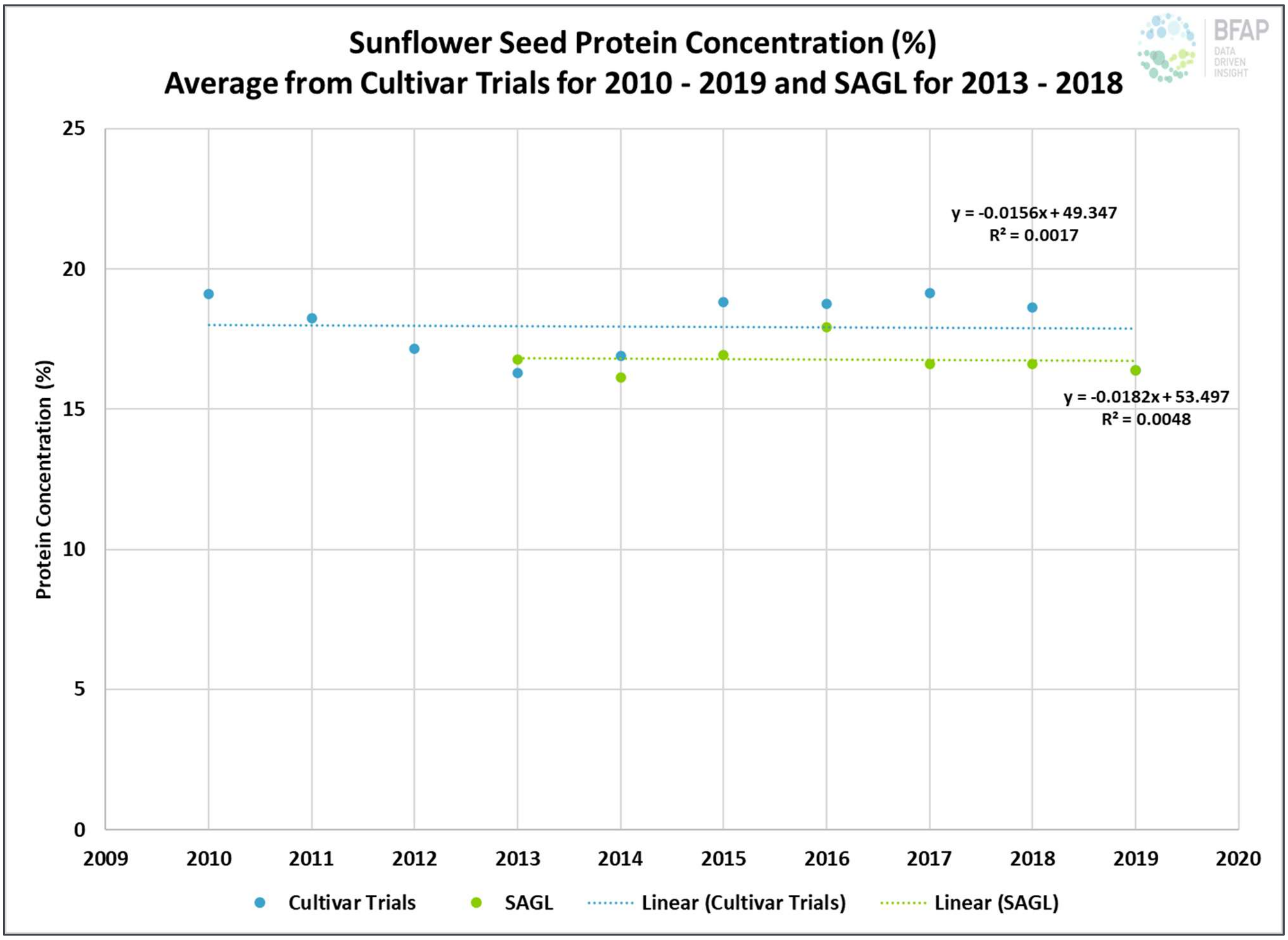


Figure 19 Sunflower seed protein concentration averaged for cultivar trials and the SAGL

As expected, the average protein concentration found by the SAGL was 1% lower than that of the yield trials (Figure 19). Whilst the sunflower seed protein concentration varied between years due to environmental conditions in the both the cultivar trials and the SAGL data, the trend did not indicate much variation and was almost linear.

3.2.5. Herbicide and Disease Resistance

Weeds are a major production problem in sunflower seed cultivation. Sunflower is a poor competitor during the early growth stages until canopy closure. Therefore, weeds compete successfully during these growth stages for light, water and nutrients. The limitation of the available herbicides, especially herbicides to control broadleaf weeds, causes considerable yield losses for sunflower producers. Clearfield®, an herbicide-resistant sunflower, was introduced by the BASF Corporation and allows farmers to control most weeds in a single post-emergent herbicide application (BASF, 2012). The Clearfield technology was developed in sunflower to allow the use of imidazolinone herbicides as a post-emergence weed-control option. The mode of action of imidazolinone herbicides is the inhibition of the enzyme acetohydroxy acid synthase (AHAS). While conventional sunflower is sensitive to imidazolinone herbicides, Clearfield sunflower hybrids have been modified to survive an otherwise lethal application of these herbicides.

The original Clearfield trait in sunflowers – the ImiSun trait – is based on a natural acetohydroxy acid synthase (AHAS) mutation discovered in a wild sunflower growing in a soybean field in the United States in 1996. In 2000, a research and development programme was initiated with Nidera Semillas S.A. to deliver a more efficient single-gene breeding system, producing sunflowers seed plants with greater tolerance to environmental stresses and improved weed control, oil content and grain yield. By 2006, BASF confirmed the improved trait, which was developed through traditional breeding techniques and resulted in an elite cultivated sunflower line, Clearfield Plus. Like the original Clearfield sunflowers, Clearfield Plus sunflowers are classified as non-transgenic (BASF, 2012).

The Clearfield Plus sunflower production system was launched in Argentina in 2010 and was registered in countries around the globe from 2012 onwards. The trait has been developed further and the seeds are sold in partnership with many seed companies worldwide.

The first commercially available Clearfield hybrids introduced into South Africa were NKAdagio CL (Syngenta), AGSUN 5181 CL (Agricol) and PAN7063CL (Pannar). Cultivar trials in 2009/2010 indicated that the mean yield of the two Clearfield cultivars on trial – AGSUN5181 CL and NKAdagio CL – were 15% lower than the non-Clearfield cultivars.[5] Besides the fact that their yields were lower, the cultivars also did not show high yield reliability (Meyer and Van der Burg, 2015). The advanced Clearfield Plus line of sunflower breeds became commercially available in South Africa in the 2014/2015 production season. Seed breeders are including the Clearfield Plus traits in their cultivars, but at an additional cost, as BASF holds the exclusive rights for the use and re-use of the genes. However, the regular Clearfield patent has expired. Consequently, the cost of reproducing and selling seed has decreased.

Herbicide-tolerant hybrids, in turn, are divided into two different classes: tolerant to imidazolinones (IMI) and tolerant to tribenuron methyl or sulfonil urea (SU). Hybrids tolerant to IMI are marketed under the Clearfield trademark, whereas those resistant to tribenuron methyl are marketed under the Express Sun trademark

Application of Clearfield Herbicide-resistant sunflower, its use and the herbicide application (post-emergence).
According to the NSDU (2007), BEYOND (Imazamox) is applied as a post-emergence herbicide to Clearfield sunflower varieties from the two- to eight-leaf stage and controls most annual grass and broadleaf weeds. It is further argued that Clearfield sunflower may boost no-till sunflower production. The South African version is called Euro-Lightning and is distributed by BASF, which also holds the Clearfield Plus genes.

Alternative to Clearfield
EXPRESS (tribenuron) is applied as a post-emergence herbicide to Express Sun sunflower varieties and will control annual broadleaf weeds. It will not control grass weeds. It is applied early post-emergence to Express-resistant sunflower in the one-leaf stage, but prior to bud formation. Broadleaf weeds should be three inches or less in height. A 70-day pre-harvest interval is allowed. Express Sun application may help facilitate no-till sunflower production (NSDU, 2007).

[5] Note that the national cultivar trials do not apply customised crop management practices for speciality-trait cultivars and, as a result, the improved weed management that herbicide-resistant cultivars might have (e.g. Clearfield and Clearfield Plus, which are resistant to Euro-Lightning) is not realised during the trials.

Progress is also being made in identifying disease-resistant breeding lines. The Agricultural Research Service of the United States Department of Agriculture has released several lines resistant to Sclerotinia head rot. This is especially important for rotations that might include other broadleaf crops, like soybean. There also are cultivars with immunity to the strains of downy mildew. Breeding for pest, weed and disease resistance will be important aspects to keep sunflower seed competing with other crops.

3.3. Speciality Traits and Spatial Trends

To set the scene, Figure 20 depicts a density map indicating the main sunflower seed planting areas in South Africa based on satellite imagery crop-type classification for the main production provinces. However, over the years, as stated in the introduction (Section 1 on page 1), the sunflower seed industry has seen some shifts in terms of the importance of the crop within the cropping system, where sunflower has been replaced by soybeans. This has been the case especially in the eastern Free State and Mpumalanga (Figure 21a & b). The area under sunflower seed production has remained relatively stable in the North West, although Limpopo has seen a significant increase in plantings over time (2000 to 2017) (Figure 21c & d).

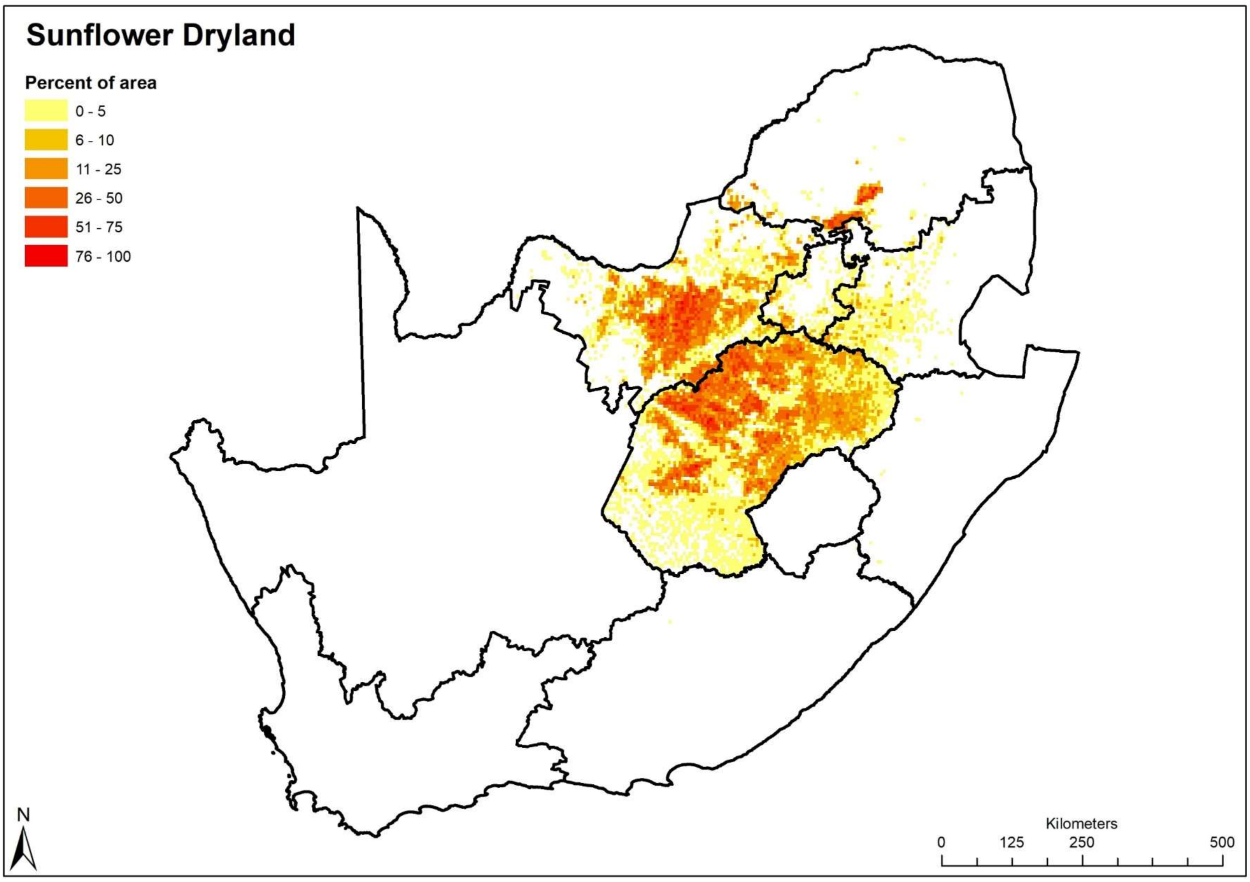


Figure 20 Density map of potential sunflower plantings within a 5 km grid based on satellite imagery crop-type classification (2006 to 2016) and various other sources, such as the Producer Independent Crop Estimates System (PICES) and the crop census (Source: BFAP, own calculation)

a

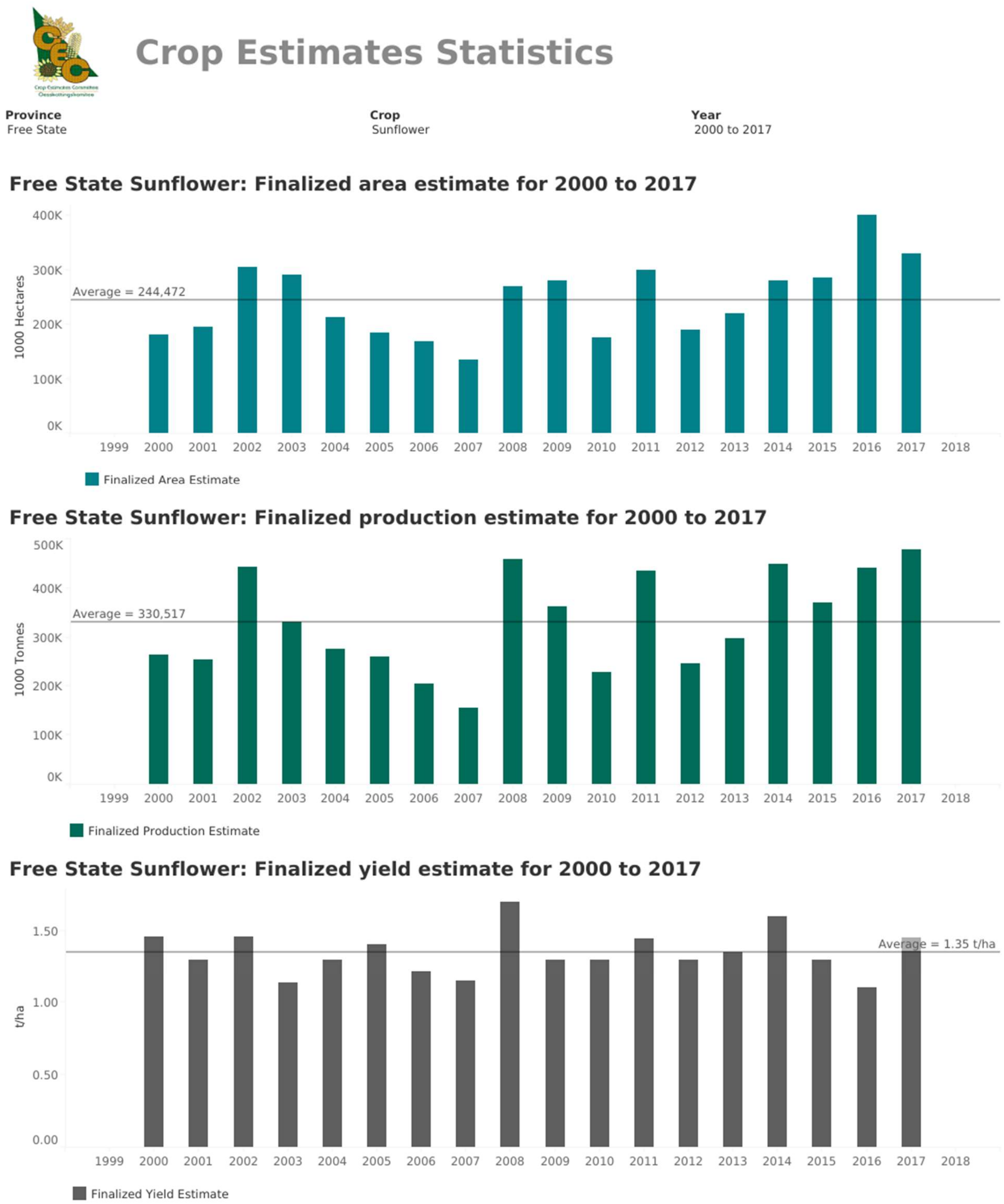


Figure 21 (continued on the next page)

b

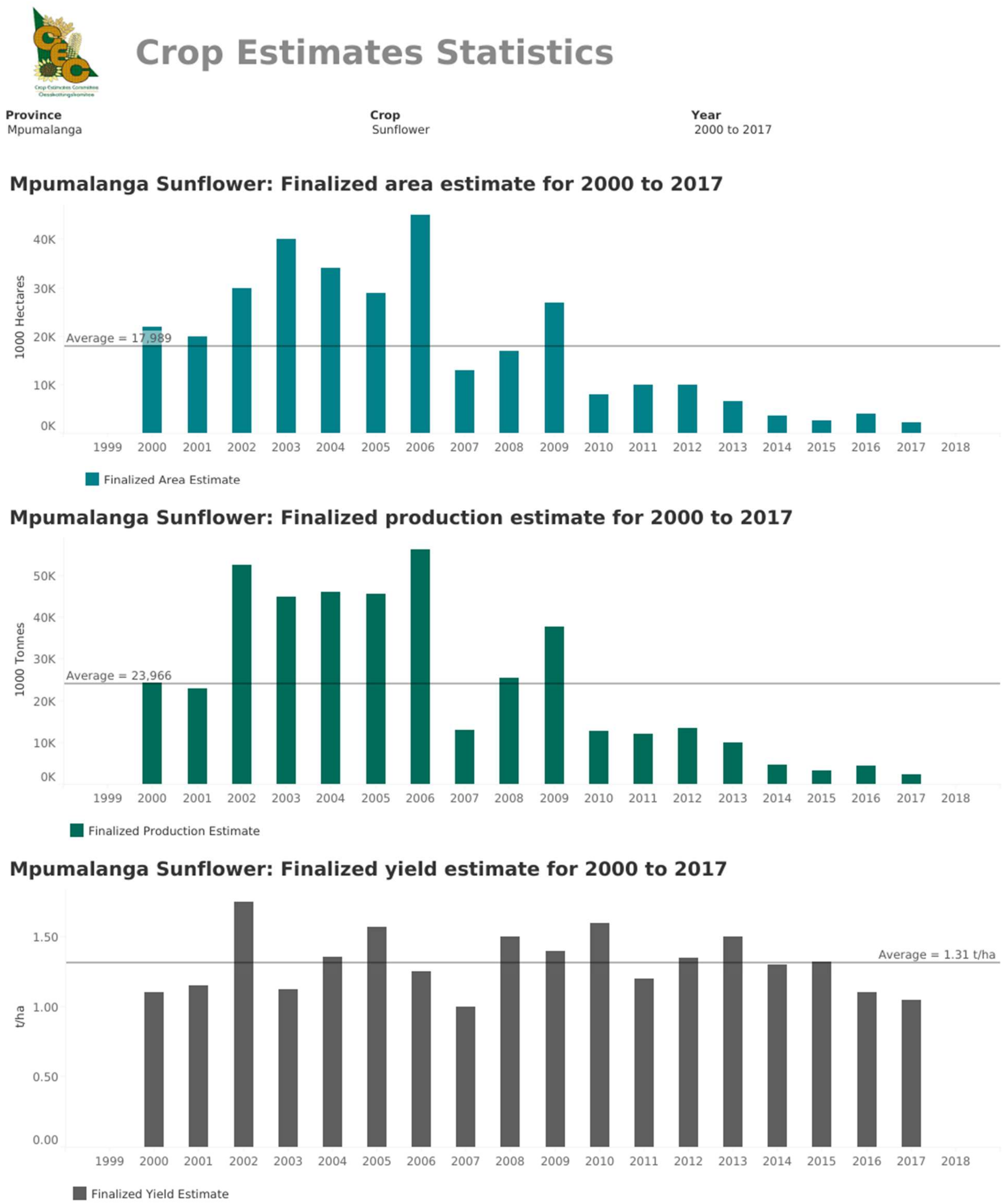


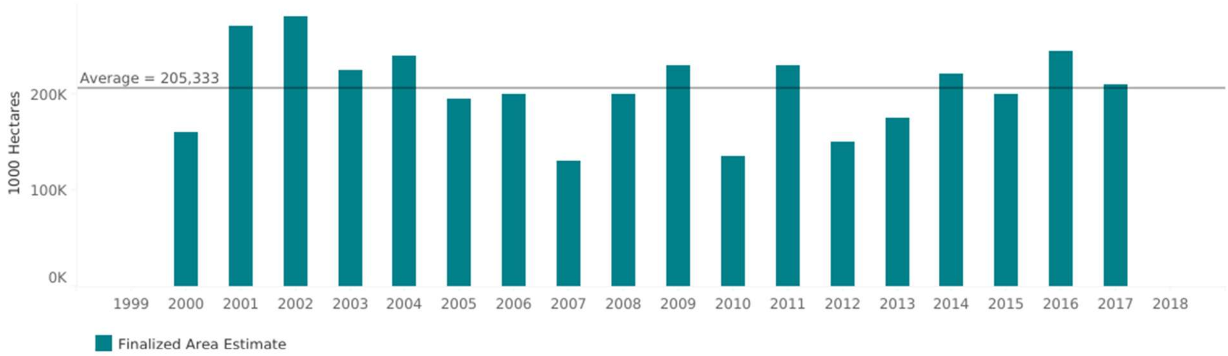
Figure 21 (continued on the next page)

Crop Estimates Statistics

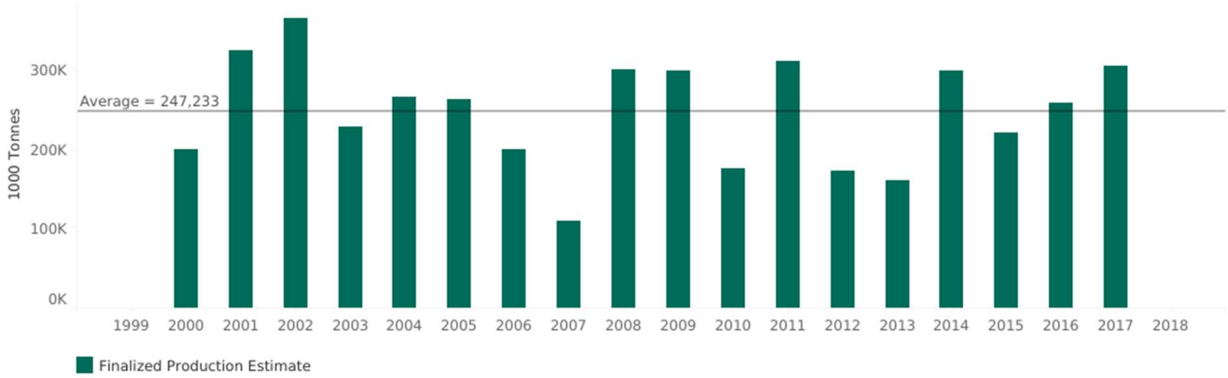
Province North West | **Crop** Sunflower | **Year** 2000 to 2017

c

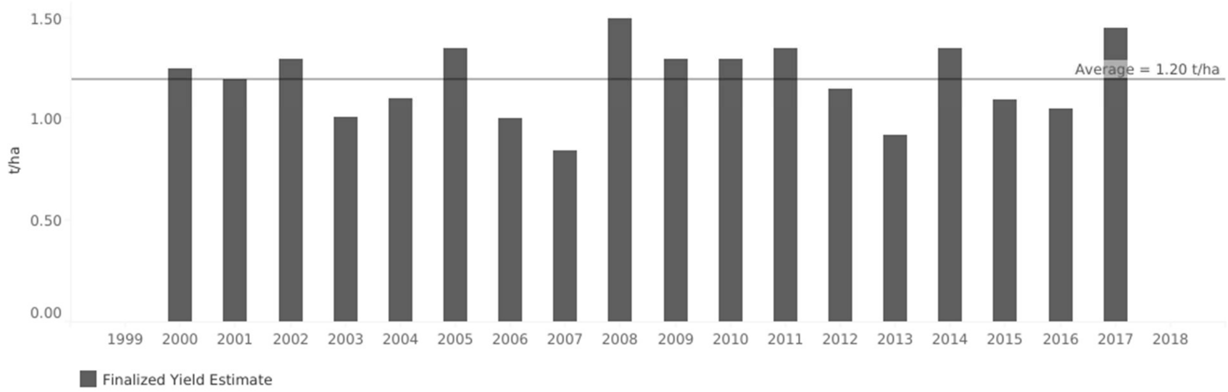
North West Sunflower: Finalized area estimate for 2000 to 2017



North West Sunflower: Finalized production estimate for 2000 to 2017



North West Sunflower: Finalized yield estimate for 2000 to 2017



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d

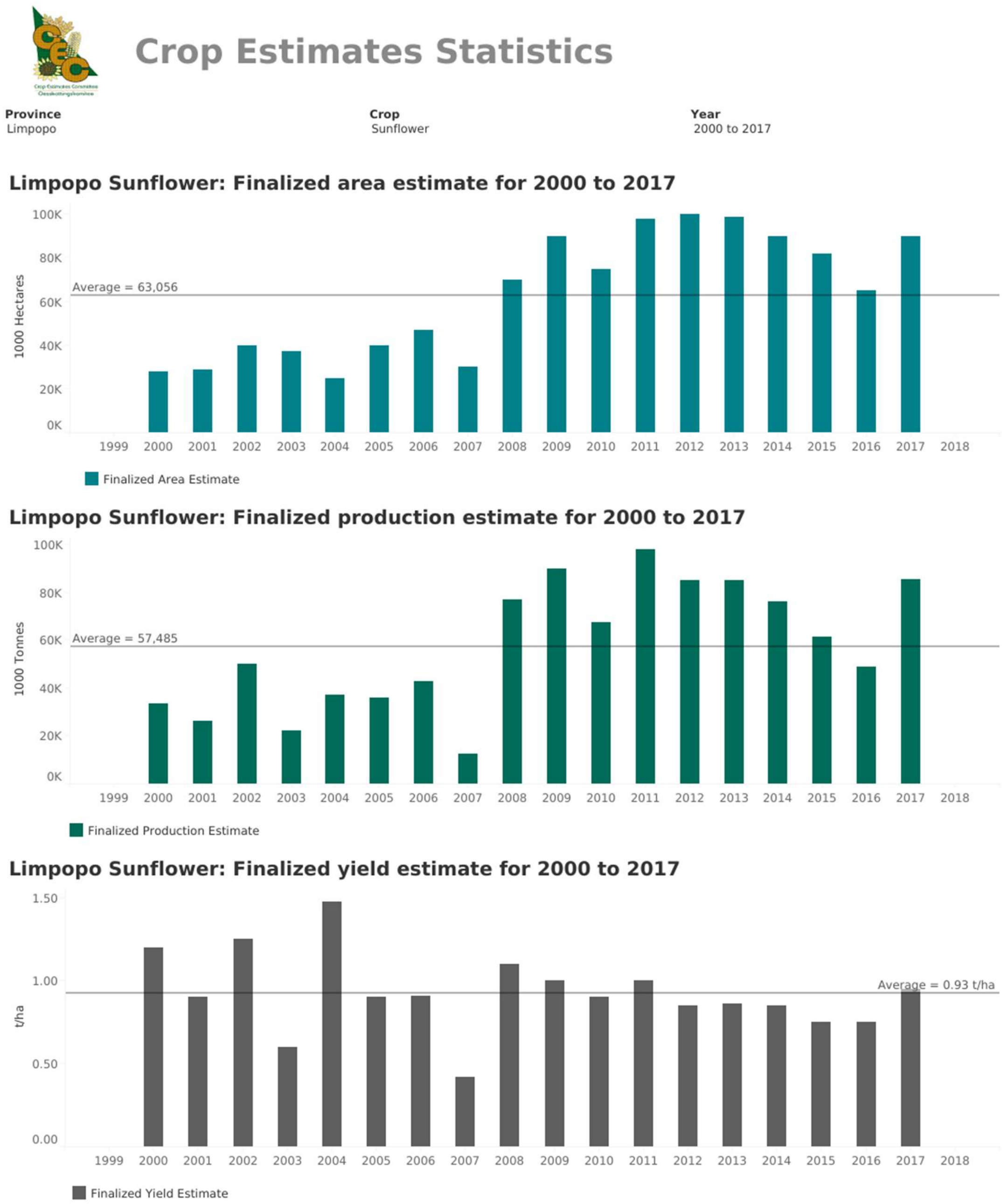


Figure 21 Area (ha), production (t) and yield (t/ha) of sunflower seed for a) the Free State, b) Mpumalanga, c) North West and d) Limpopo for the period 2000 to 2017 (Source: Crop Estimates Committee)

Over the years, the choice of cultivars available to farmers has included speciality traits, such as herbicide tolerance included in the Clearfield and Clearfield Plus types or having a higher oleic fatty acid content. The question arose whether there is a strong negative correlation between yield and oil content in the cultivation of these cultivars, as producers are constantly selecting cultivars for higher yield. Table 14 presents the correlation between a) yield and oil content, b) yield and oil yield and c) oil content and oil yield, calculated from the cultivar trial data for two time periods – i) 2005 to 2019 and ii) 2014 to 2019 – over all locations, and for 2014 to 2019 for all trials located in Potchefstroom. Counter-indicative of what was expected and what is also presented in Table 14, there was no negative correlation between yield and oil content over all cultivars, locations and the time period from 2005 to 2019. Even though a positive correlation was found, it was not strong (< 0.25). This means that a higher yield does not necessarily imply a lower oil content. A higher oil content with higher-than-normal yields was also observed during the Syngenta-CEOCO pilot study in 2020 (see Box 1 in section 3.2.2). However, for the Clearfield types and the high oleic types, a negative correlation between yield and oil content was estimated from the data, implying that higher yields of these cultivar are associated with a lower seed oil content. However, it should again be mentioned that the data for both the Clearfield and high oleic types did not cover all seasons, and fewer of these types than conventional hybrids were included in the cultivar trials.

Table 14 Correlation coefficients based on cultivar trail data between yield and oil yield components taken over different time frames for all locations and Potchefstroom

	Yield – Oil content	Yield – Oil yield	Oil content – Oil yield
All years (2005 – 2019)			
All cultivars	0.14	0.85	0.10
Hybrids	0.23	0.84	0.18
Clearfield and Clearfield Plus	-0.06	0.90	-0.04
High oleic	-0.48	0.66	-0.44
Selected years (2014 – 2019)			
All cultivars	0.64	0.79	0.79
Hybrids	0.68	0.80	0.81
Clearfield and Clearfield Plus	0.43	0.79	0.64
High oleic	-0.97	-0.82	0.93
Potchefstroom, selected years (2014 – 2019)			
All cultivars	-0.01	0.96	0.23
Hybrids	0.28	0.96	0.48
Clearfield and Clearfield Plus	-0.09	0.90	0.33
High oleic	-0.46	0.86	0.06

To unpack the effects of these speciality traits on yield (t/ha), oil content (%) and oil yield (t/ha), a simple type 1 analysis of variance (ANOVA) was calculated. The ANOVA is based on the law of total variance, where the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether two or more population means are equal. Fisher's least significant difference (LSD) method was used in ANOVA to create confidence intervals for all pairwise differences between factor-level means, while controlling the individual error rate to a specified significance level (P = 0.1).

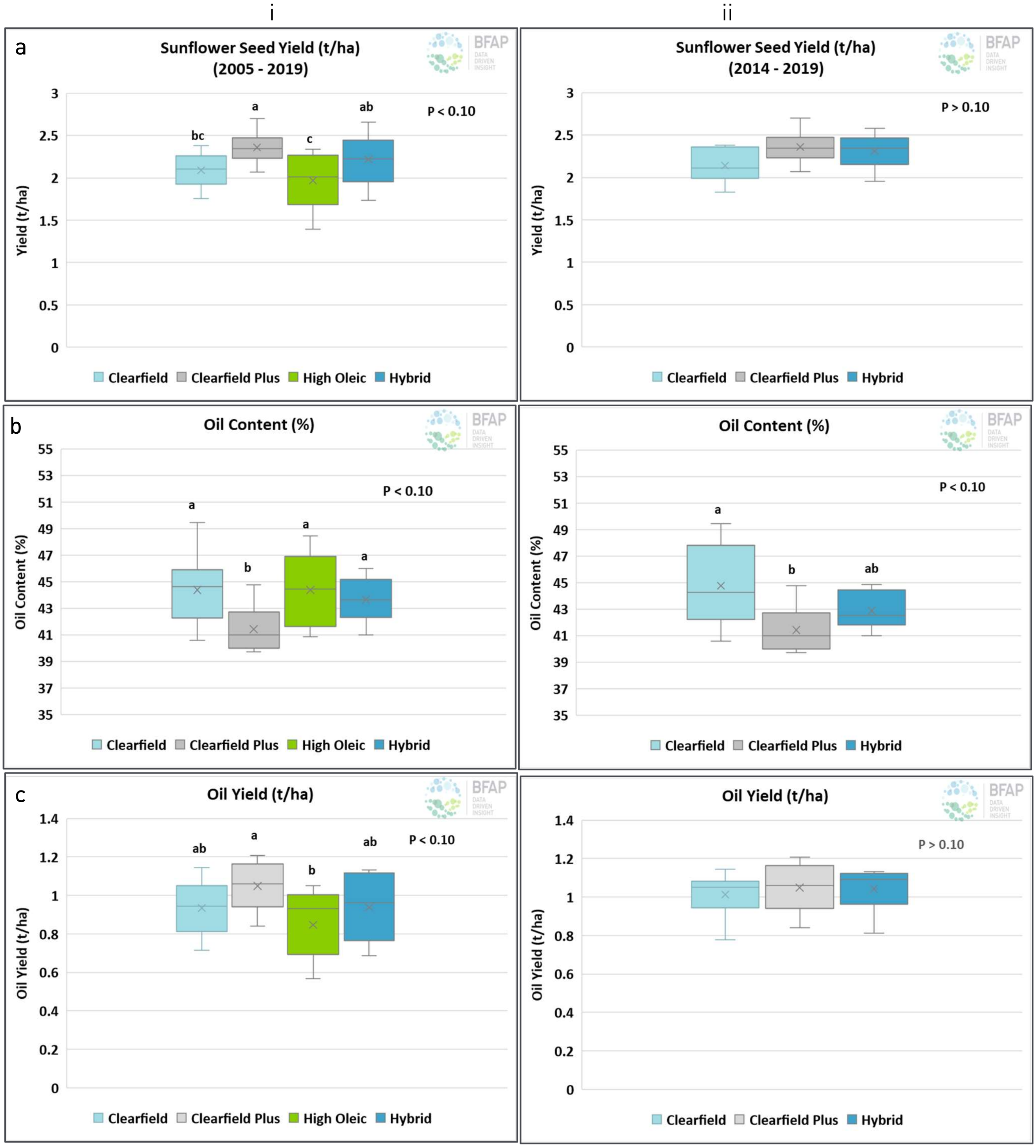


Figure 22 Boxplots of a) yield (t/ha), b) oil content (%) and c) oil yield for the different sunflower seed trait types: i) average for the period 2005 to 2019 and ii) 2014 to 2019, where x denotes the mean and the notation refers to Fisher's least significant difference calculated at the 10% level.

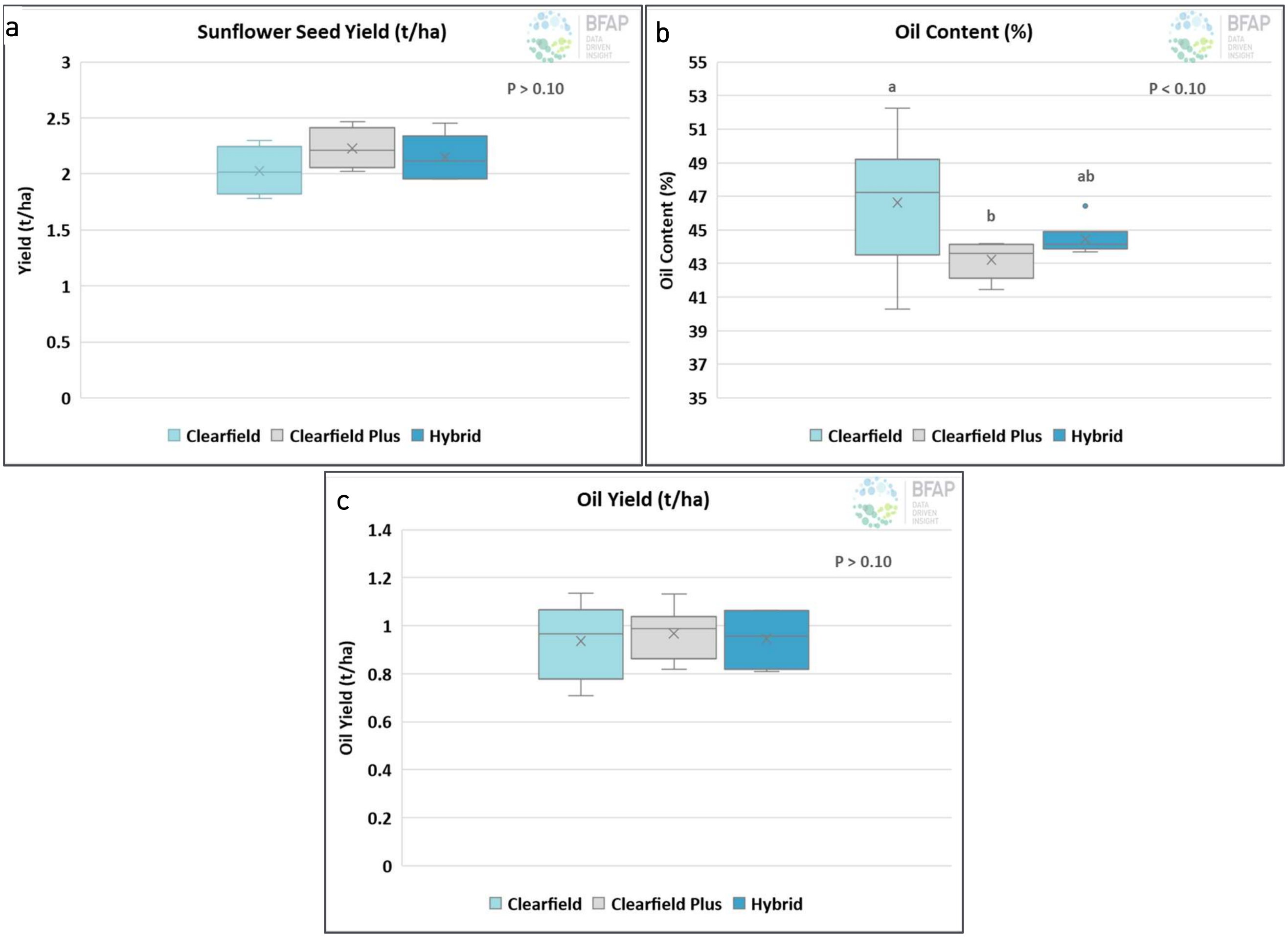


Figure 23 Boxplots of a) yield (t/ha), b) oil content (%) and c) oil yield for the different sunflower seed trait types: average for the period 2005 to 2019 for Potchefstroom, where x denotes the mean and the notation refers to Fisher's least significant difference calculated at the 10% level

There is a significant difference in the means between the sunflower seed trait types using the means from all locations for the time period 2005 to 2019 (Figure 22a i). However, this was not found in the data for the period 2014 to 2019 (P > 0.10) (Figure 22a ii). It should be noted that, in the latter period, the inclusion of the high oleic sunflower seed types included in the cultivar trials was low, thus excluding them from the calculation. The means for yield between the Clearfield Plus types and the conventional hybrids were not significant when calculated over all seasons and locations. Nor was there a significant difference in the means of the Clearfield type and the conventional hybrids. The high oleic type had the lowest mean, but this was not significant compared to that of the Clearfield types. Analysing the means of the four sunflower seed type traits for oil content, the means calculated across all years and locations were significantly lower for the Clearfield Plus type than for the other three trait types (Figure 22b i). The lower mean oil content of the Clearfield Plus type is also evident in the calculations based on the shorter time period (Figure 22b ii). For oil yield (t/ha) (Figure 22 c i), there was no significant difference between the two Clearfield types and the conventional hybrids (reiterated by the insignificant difference in oil yield over the shorter time period analysis (Figure 22 cii), but the high oleic type had a significantly lower oil yield per hectare. However, this lower mean was not so small and there was no significant difference between the high oleic type and the Clearfield and conventional hybrid based on oil content means. An analysis based on one location, Potchefstroom (Figure 23a-c), reiterates the findings that there is very little significant difference between the two Clearfield types and the conventional hybrids based on yield (Figure 23a) and oil yield (Figure 23c), but that the oil content of the Clearfield Plus type seems to have a lower oil content (%) (Figure 23b).

Thus, there seems to be some evidence that the Clearfield Plus sunflower seed types have a remarkably high yield and oil yield per hectare, but the oil content of the seed delivered is lower than that of the conventional hybrids.

It has also been stated that the oil content of sunflower seed delivered from the western Free State is lower than that received from other parts of the country. Figure 24 depicts the averages of sunflower seed oil (%) and protein content (%) as delivered in different silo regions based on data from SAGL for the period 2013 to 2019. From these time-series maps, it is evident that, especially from 2016 onwards, the oil content (%) delivered at silos in these regions was below 38%, whilst the rest remained at levels > 38%. Another, and equally negative, trend that becomes evident from the time-series maps is that the oil content even in these higher yielding regions is declining. This is depicted by the lighter green shades in the maps from 2016 onwards, compared to the maps from 2013 to 2015.

It can be speculated, but not proven by any evidence due to the lack of data, that the sunflower cultivar types planted in these western low oil-yielding regions are more likely of the Clearfield Plus types. The Clearfield Plus types became available to producers in 2014. Maize is the predominant cash crop in these regions and sunflower is often planted as a "catch crop", with preference not being given to the timing of production, such as optimal planting date, fertiliser applications, soil analysis or much of the required pest weed or disease programmes required for optimal production. Thus, the option of using Clearfield Plus types, which have a high yield and easy weed control, might have been attractive to farmers, despite their possible link to a slightly higher seed price. This is one plausible reason for the lower oil content of seed delivered to crushers in the past few seasons.

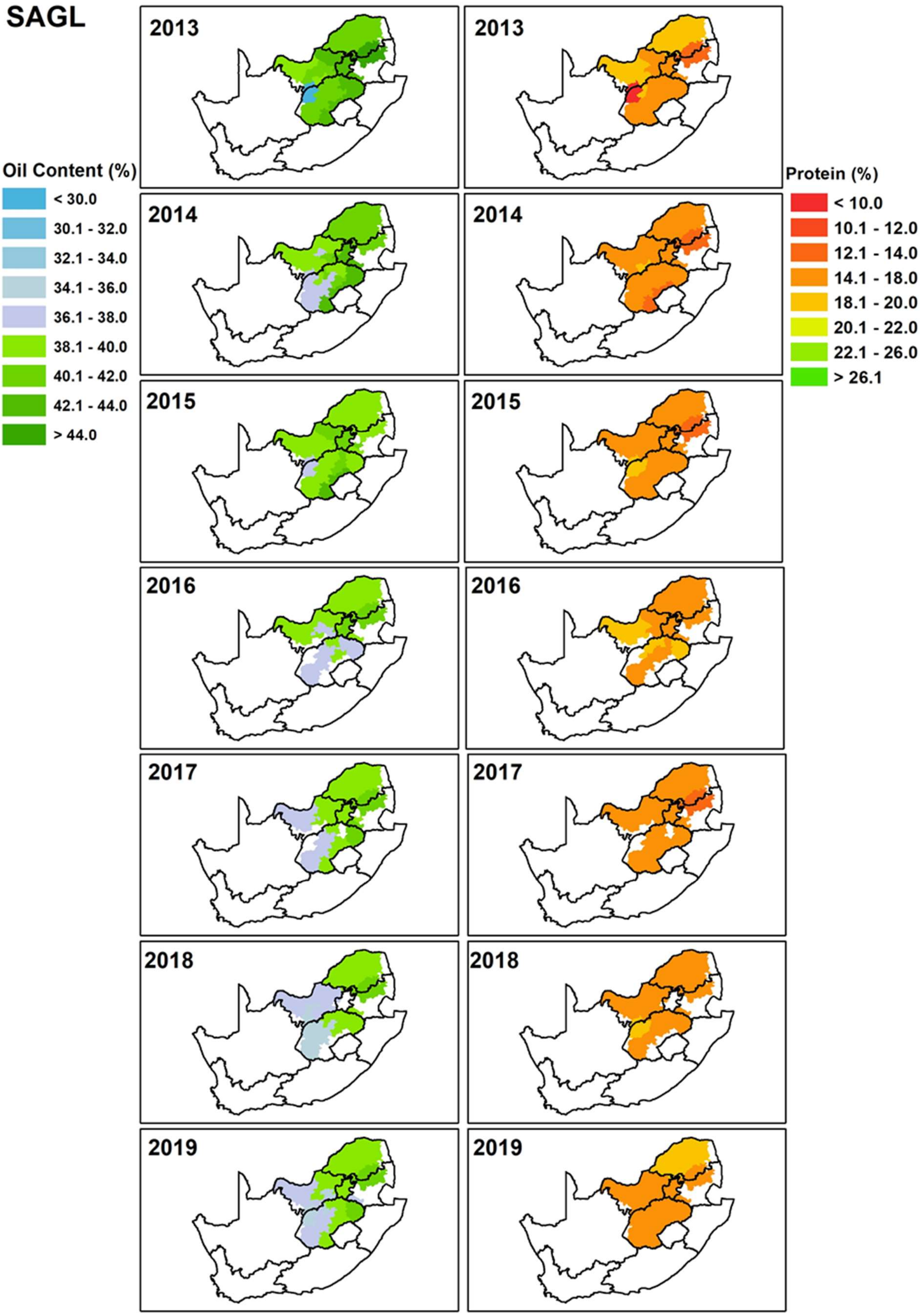


Figure 24 Averages of sunflower seed oil (%) and protein content (%) as delivered in different silo regions (Source: SAGL)

3.4. Environmental and Management Influences on Sunflower Seed Quality

Over the years, sunflowers in South Africa have received the status of an ideal crop to grow under conditions of low-input farming and marginal cropping conditions. The ability of sunflowers to produce relatively consistent yields under adverse weather conditions and their overall characteristic of drought tolerance makes them an attractive crop for farmers in dryland production regions. Sunflowers can also produce a crop on marginal soils with little or no additional fertiliser. As already mentioned in section 3.2.1, the area planted to sunflower seed has followed a declining trend in South Africa since its peak in 1999, with greater reductions in Mpumalanga compared with the other production regions. The reasons for these reductions differ from one region to the next and include:

- the adoption of new bio-tech maize cultivars with better yields,
- practical producer constraints, e.g. negative sentiments about the crop based on historic incidents, such as poor emergence, sclerotinia, lodging and bird damage ,
- the possible exclusion of marginal land under crop cultivation, and
- the switch to soybeans.

However, one underlying factor why farmers are reluctant to expand the area under sunflower production stood out in all production regions, namely that, under ideal growing conditions or irrigation, sunflowers do not provide the same upward potential in terms of both yield and profit as crops such as maize and soya beans. As the planting window for these higher-income crops is smaller, preference is given to these crops over sunflower, which has a much longer planting window. Consequently, many producers see the sunflower seed crop as a "catch crop". Sunflower seed is thus often not planted in its optimal planting window for the region, and also often on more marginal areas in terms of soil on the farm.

Areas in which sunflower is cultivated vary considerably in terms of climate, weather patterns (including rainfall and temperature), altitude, latitude and soil type, and these, together with cultural practices including planting date and water regime, have a marked influence on the growth and development of the crop. Significant genotype environment interactions (GEI) have been observed in many studies, confirming the fact that sunflower genotypes respond differently to different environments (South Africa: Schoeman (2003), Leeuwner (2007) and Ma'ali *et al*. (2019); International: Foucteau *et al*. (2001), Balalić *et al*. (2011), Hejazi and Khalkhali (2016) and Barrios *et al*. (2017)). The latter emphasises the need for testing sunflower hybrids in multiple environments. The performance of sunflower hybrids is highly influenced by the environment, followed by the GEI effects and then by the genotype.

Seed oil and protein content is affected by genetic as well as environmental/management factors, like:

- planting date,
- plant population,
- temperature,
- water stress,
- fertiliser and
- sclerotinia.

A short literature review underpinned by data from the national cultivar trials and the SAGL of all these factors is presented in Appendix C. Of all these factors, planting date is probably the most important and most applicable to the production of sunflower seed in South Africa.

Early plantings, before 15 November, and late plantings, after 15 January, in most cases deliver lower yields and seed with a lower oil content (Figure 25). Plantings early in the season are planted in "cool" conditions and mature (seed fill) when temperatures are high. Late plantings, on the other hand, are often planted when soil conditions are warm, which may lead to a decrease in germination and seeding vigour but mature under "cooler" conditions. Given that the summer solstice is 22/23 December, sunflower seed planted late will mature when daylight starts to decrease. This timing is linked to a higher likelihood of more cloudy days, so radiation-use efficiency and thus photosynthesis may be impaired, leading to a lower accumulation rate of seed components, which will have a negative influence on yield. Over the past few seasons, since 2016, the western production regions experienced very late starts to the summer rainfall season (see Figure 26). Plantings were delayed by more than a month; in the 2017/2018 production season, plantings sometimes took place as late as early February. The 2018 crop was extremely difficult. There were some good rains at the end of November 2017, but then almost nothing for six weeks. In some areas, the rains only came in middle of January 2018, when plantings could commence. Figure 25 underlines the negative impact of late plantings on oil content and, while farmers might intend to plant sunflowers as early as possible, late rains and low soil moisture often are the constraining factors.

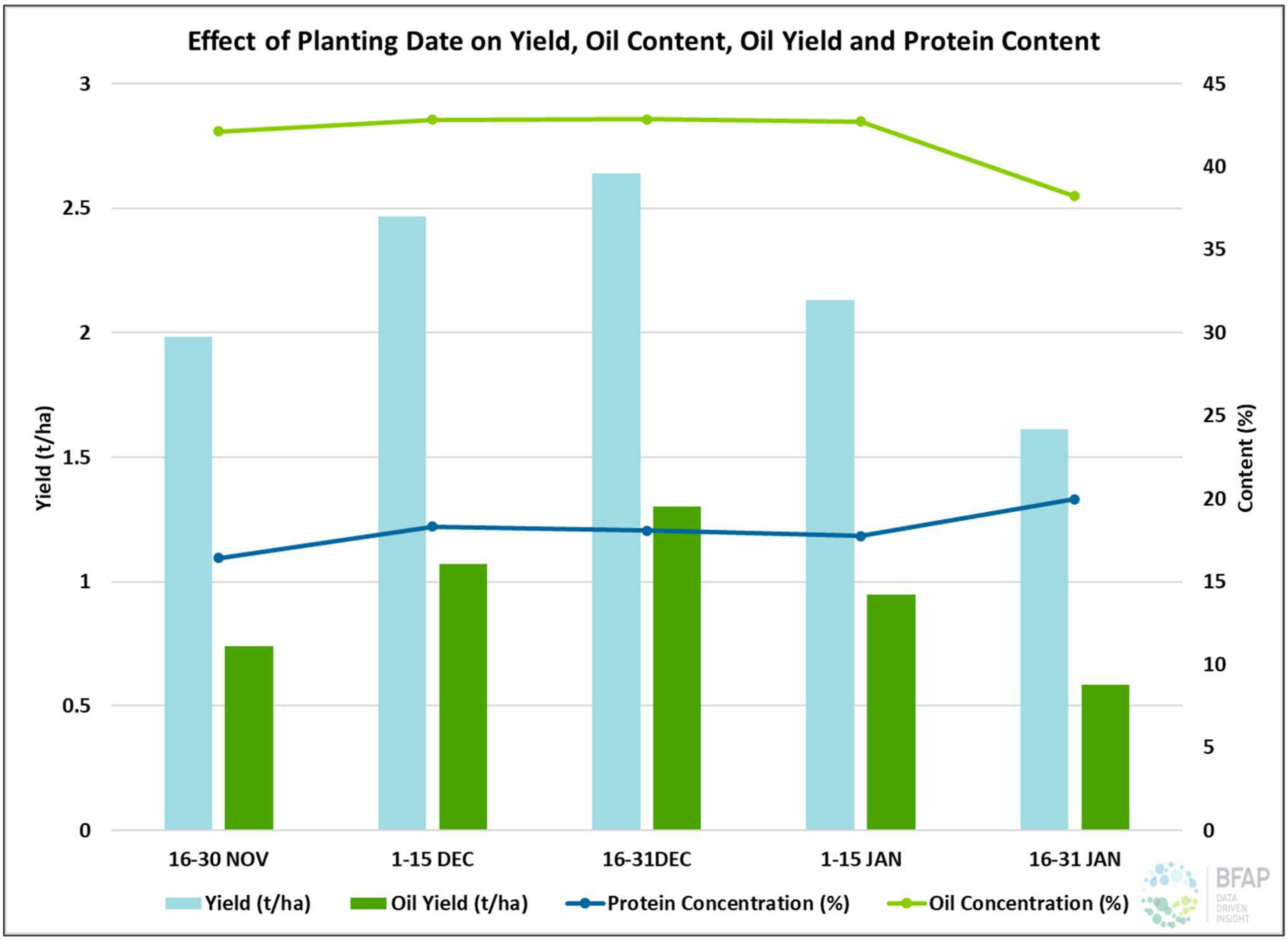


Figure 25 Effect of planting date on yield (t/ha), oil content (%), oil yield (t/ha) and protein content (%) over all locations and seed types, calculated from the averages of cultivar trails from 2010 to 2019

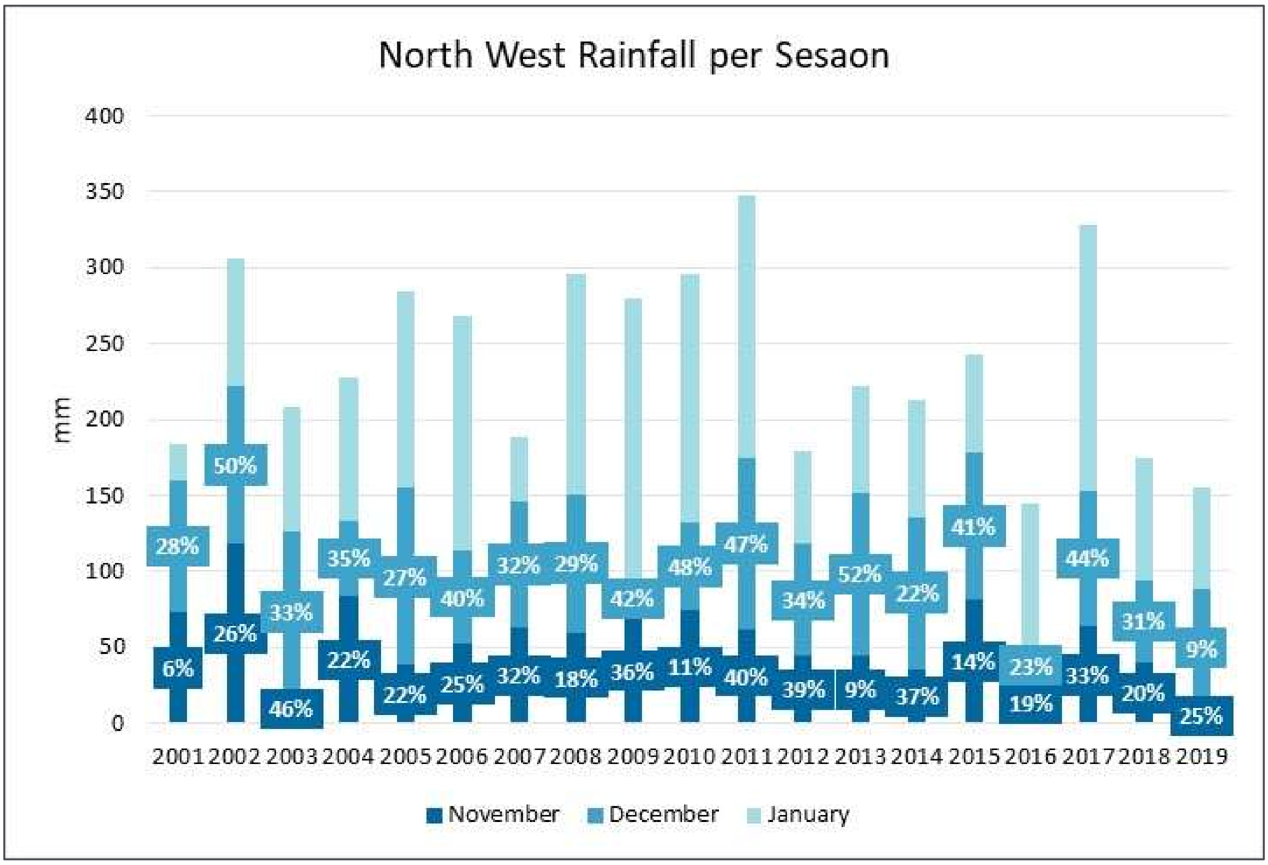


Figure 26 Rainfall in the western production regions (Source: WeatherSA)

Oil content (%) seems to decrease somewhat linearly the later the plantings, whilst the protein content (%) of the seed is not affected much by planting date. Similar trends in seed yield and quality have been observed by Unger (1980)in the USA.

The genotype–environment interaction has been the focus of work done by Schoeman (2003), Leeuwner (2007) and Ma'ali *et al.* (2019). In all three cases, the focus has been on yield stability across environments. None of the focus was on yield stability in conjunction with oil content or even oil yield per hectare. Cultivars in the national yield trials are replaced frequently, as testing of new varieties is the main focus of the research. However, using the same methodology but extending the number of seasons that some cultivars are kept in the trials, suitable data may be captured that can be analysed to find solutions to the multitude of interactions that are part of the sunflower complex. Capturing some additional data on soil, climate and crop management for each trial site could even enable crop and spatial models to be calibrated and run to simulate a multitude of scenarios for different management regimes, the possible influence of climate change on yield and oil content, and plausible adaptation and mitigation measures. Spatial modelling may give solutions to site specific cultivar recommendations based on mapping (also see Section 6.6 on page 85).

Table 15 Summary of management effects on sunflower seed yield, oil content, fatty acid composition and protein content

	Yield	Oil content	Fatty acid composition	Protein content
Planting date	Late planting: Yield ↓ Early panting: Yield ↓	Late planting: Yield ↓ Early panting: Yield ↓	Early planting: Oleic acid ↑, linoleic acid ↓ Late planting: Oleic acid ↓, linoleic acid ↑	
Plant population	Less than 20 000 plants/ha: Yield ↓ More than 45 000 plants/ha: Yield ↓	Plant population no effect → (Nel et al., 2000a)		Plant population no effect → (Nel, 2002)
Temperature	High temperature ↓ emergence seedling vigour	High temperatures during seed fill: Oil content ↓	High temperatures in linoleic types: Oleic acid ↑, linoleic acid ↓ High temperatures in oleic types: Oleic acid ↓↑, linoleic acid ↓↑	
Water stress	Water stress anthesis & seed fill: Yield ↓	Water stress vegetative & reproductive: Oil content ↓	Water stress on oleic and linoleic ratio ↓↑	

3.5. Farm-level Profitability

Traditionally, sunflower seed is the secondary or tertiary crop in on-farm crop mixes. However, due to its high tolerance to drier conditions, sunflower seed plays a crucial role in the crop mix,, especially in drier years or seasons when the rainfall is later. As was seen in the 2016 season, a lot of farmers in the western production regions did not manage to plant maize in optimal planting windows or not at all, and as a result relied more heavily on sunflower seed for cashflow for the next season. As a result, sunflower seed is often seen as a "catch-crop" and not as the primary cash crop for the farm, which has its own drawbacks in terms of the investments farmers are willing to make in their sunflower seed crop.

The status quo has largely been characterised by the alternative – farmers have focused more on producing higher farm yields, but at the expense of oil content. Over the past decade, farm margins have been relatively stable and positive, averaging R1 323/tonne between 2010 and 2020 (
Figure 27). The positive margins have been supported by relatively high sunflower seed prices, which allowed farmers to cover their production costs despite volatile yields. It is important to note, however, that producers have not experienced a profit at a yield below 1.2 tonne/ha on average over the past ten years.

Figure 27 Trends in farm-level gross margins (2010 to 2020)

At a yield above 1.5 tonne/ha and producer prices above R4 000/tonne, a typical South African sunflower farmer should be able to break even and make a profit. South Africa's historic five-year average yield is 1.57 tonnes/ha, against an average producer price of R5 048/tonne, both of which are well above the thresholds that would ensure positive gross margins. Table 16 provides a sensitivity analysis outlining a full spectrum of price and yield combinations and illustrates how changes in yield and producer price influence farmers' gross margin for sunflower seed production. Under the prevailing producer prices of R4 996/tonne, farmers in the Free State should be fairly comfortable. However, farmers in the North West might barely make positive returns, while the rest of the country will have yields that are much lower (between 1 tonne/ha and 1.3 tonnes/ha). Based on historic data, the chance that farmers nationally will produce a yield above 1.57 tonne/ha is 50%, while they have a 96% chance to produce above the breakeven yield of 1.2 tonne/ha.

Table 16 Sensitivity analysis of the impact of price and yields on changes in farm gross margin

Gross margin (R/ha)	**Yield (tonne/ha)**								
Producer price (R/tonne)	**0.5**	**0.75**	**1**	**1.25**	**1.5**	**1.75**	**2**	**2.25**	**2.5**
3 000	- 4.336	- 3.586	- 2.836	- 2.086	- 1.336	- 586	164	914	1.664
3 500	- 4.086	- 3.211	- 2.336	- 1.461	- 586	289	1.164	2.039	2.914
4 000	- 3.836	- 2.836	- 1.836	- 836	164	1.164	2.164	3.164	4.164
4 500	- 3.586	- 2.461	- 1.336	- 211	914	2.039	3.164	4.289	5.414
5 000	- 3.336	- 2.086	- 836	414	1.664	2.914	4.164	5.414	6.664
5 500	- 3.086	- 1.711	- 336	1.039	2.414	3.789	5.164	6.539	7.914
6 000	- 2.836	- 1.336	164	1.664	3.164	4.664	6.164	7.664	9.164
6 500	- 2.586	- 961	664	2.289	3.914	5.539	7.164	8.789	10.414
7 000	- 2.336	- 586	1.164	2.914	4.664	6.414	8.164	9.914	11.664

In the absence of a quality-based incentive for the farmer (status quo in South Africa), the farmer maximises profits related to sunflower plantings by maximising yield achieved. As discussed in previous sections, sunflower oil content is not affected only by cultivar selection, but also (often more importantly) by environmental variables and agronomic management practices.[6] From a plant science perspective, yield and oil content both require high energy and are theoretically expected to be negatively correlated. Therefore, if not incentivised, farmers will continue to drive higher yields to maximise profits rather than the quality (oil content) of sunflower seed produced. In addition, improving the profitability of sunflower seed on the farm level might also contribute to the prioritisation of sunflower seed as the primary cash crop. Therefore, incentivising the farmer to drive higher oil content can be a crucial building block for South Africa to achieve the sunflower seed oil content levels seen internationally. The incentive structure employed in Argentina and the Black Sea countries is a price premium for every 1% oil content delivered higher than a specified threshold (e.g. 38%) and is also the incentive structure unpacked in this section as an example.[7]

It would be important to consider an incentive structure that stimulates uptake to reasonably expect farmers to adopt high oil-content seed and to invest more from an input perspective in order to achieve higher oil content. At the farm level, the incentive will translate into a gross margin trade-off between producing "high yield–lower oil content seed" and "low yield–high oil content seed". Ideally, a price premium must sufficiently compensate a farmer for producing lower seed output with a relatively higher average oil content.

Section 3.3 on page 43 demonstrates that the theoretically expected negative correlation between yield and oil content is not always found in trial data and, depending on varieties, locations and time periods, a range of positive and negative correlations were calculated between yield and oil content (Table 14, Kaya *et al.*, 2007). Current data availability therefore

[6] South African-bred cultivars have achieved 4% to 6% higher oil content when grown in Argentina, for example.
[7] Alternative pricing/incentive structures are discussed in Section 6.5.

does not provide a conclusive and significant relationship between oil content and yield. It might well be that, in relation to the seed farmers select, yield is expected to be positively correlated with oil content, and therefore driving yields from the perspective of agronomic practices also benefits seed oil content.

A price premium based on oil content percentage above a given threshold (e.g. 38%) was tested in a pilot study described in Box 1 in Section 3.2.2. In this pilot study, the expected "low yield–high oil content seed" was not observed; in fact, 2 t/ha average yields were recorded with an oil content between 46% and 48% and farmers did not adjust farm management practices for this pilot. Furthermore, based on the results of the pilot study, in the case that a 1.5% premium was offered, a yield loss of 300 kg/ha would be required to "counter" the positive impact of the premium. Section 3.2.2 also concluded that adopting the new, high oil-yielding varieties available in South Africa could contribute to the achievement of higher oil content. Furthermore, stakeholders in the pilot study argue that on-farm returns and profits based on oil content can potentially outcompete the future profit increases linked to the 2% per annum increase in sunflower yields over the next 10 years.

Error! Reference source not found. shows a few scenarios, i.e. combinations of different price premiums (X% per 1% oil content achieved above 38%), average yield and oil contents achieved, and what the resulting effect would be on prices (green bars) based on the price premium model tested in the pilot study. Furthermore, it also shows the "yield flexibility" or "margin" (blue dots) that this price premium allows until farmers reach a net zero increase in the returns per hectare at the average SAFEX sunflower price. It is clear that both yield and oil content have significant effects on the farmers' returns and on the "yield flexibility/margin" that would be achieved by various premium levels. For an average yield of 1.5 t/ha and 42% oil content, the farmer would achieve a "yield flexibility/margin" of 0.025 to 0.15 t/ha, given various premium levels, while for an average yield of 2 t/ha and 47% average oil content, the farmer's "yield flexibility/ margin" would range from 0.09 to 0.37 t/ha, depending on premium levels.

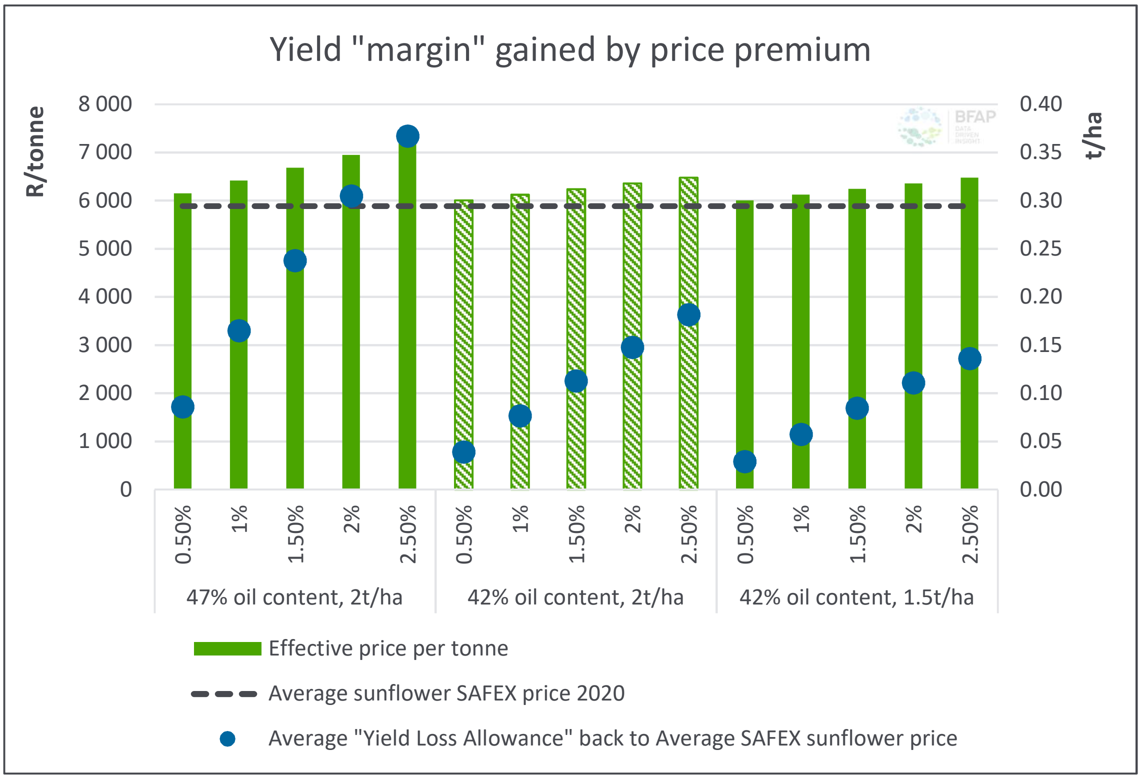


Figure 28 Yield "margin" gained by price premium

3.6. Summary

Seed yield is a complex and quantitative trait that is not only controlled by many genes, but also is influenced highly by environmental conditions, so both additive and non-additive genetic effects play an important role in the inheritance of seed yield.

According to the registrar of plant improvement there were 119 different sunflower seed varieties available to producers in December 2019 (DALRRD, 2019). Of these varieties, 113 were hybrids classed as high oil (capable of achieving higher than 40% oil content), two were high-oil open pollinated, three were low-oil hybrids and one was a low-oil open pollinated.

There was some correlation between the oil content (%) advertised on South African seed companies' websites and those obtained in the national cultivar trials (0.413). The index of agreement was 0.775 for oil content, which indicates that the selected cultivars in the cultivar trials deliver the advertised oil yield. Whilst the average advertised sunflower seed oil content (%) was between 38% and 46% for South African cultivars, an analysis of advertisements by seed companies supplying the Russian, Ukrainian, Hungarian and Argentinian markets indicate an advertised oil yield in the range of 45% to 54% – up to 10% higher than their South African counterparts.

On the other hand, some South African cultivars have been planted overseas (in Argentina) and the same cultivar yielded a higher oil content of 4% to 6% on average and up to 1 t/ha higher yield in Argentina than in South Africa. These findings reiterate that not only cultivars and technologies are drivers for oil content in sunflower seed, but that the environment and agronomic practices also are crucial.

Counter to what was thought, there was no negative correlation between yield and oil content over all cultivars, locations and the period from 2005 to 2019. This was also true for the hybrids. The correlation, however, was not strong (< 0.25). This means that a higher yield does not necessarily imply a lower oil content. However, for the Clearfield types and the high oleic types there was a negative correlation between yield and oil content, implying that the higher yields of these cultivars are associated with a lower seed oil content. Overall, the negative correlation between yield and oil content could not be proven conclusively from the cultivar trial data.

The means for yield between the Clearfield Plus types and the conventional hybrids were not significantly different over all seasons and locations. Nor was there a significant difference in the means of the Clearfield type and the conventional hybrids. The high oleic type had the lowest mean yield, but this was not significantly different from that of the Clearfield types. Thus, there seems to be some evidence that the Clearfield Plus sunflower seed types have a very high yield and oil yield per hectare, but the oil content of the seed delivered is lower than that of the conventional hybrids.

Some findings with respect to planting date can be summarised as follows:

- In most cases, early plantings before 15 November and late plantings after 15 January deliver low yields and seed with a low oil content.
- Oil content (%) seems to decrease somewhat linearly the later the plantings, whilst the protein content (%) of the seed is not affected much by planting date.

A price premium based on percentage oil content above a given threshold (e.g. 38%) was tested in a pilot study. The expected "low yield–high oil content seed" was not observed; in fact, 2 t/ha average yields were recorded with an oil content of between 46% and 48% and farmers did not adjust farm management practices for this pilot (this pilot featured one high oil-content cultivar). Furthermore, based on the pilot study results, if a 1.5% premium was offered, a yield loss of 300 kg/ha would be required to "counter" the positive effect of the premium.

A sensitivity study was performed to test various yield and oil content achievements by farmers, using the same premium model that was tested in the pilot study: For an average yield of 1.5t /ha and 42% oil content, the farmer would achieve a "yield flexibility/margin" of 0.025 to 0.15 t/ha, given various premium levels, while for an average yield of 2 t/ha and 47% average oil content, the farmer's "yield flexibility/margin" would range between 0.09 and 0.37t/ha, depending on premium levels.

4. Silo Level: Sampling, Grading, Seed Storage and Incentive Based on Oil Content

4.1. Introduction

Seed usually needs to be stored prior to crushing due to seasonality in harvesting. The quality of grains can be affected by entomological, microbiological and environmental factors during storage, resulting in physicochemical and organoleptic changes that lead to significant quantitative losses in the product (Iconomou *et al.*, 2006). Thus, operations before storage are important and may include:

- sampling
- grading
- pre-cleaning and
- drying.

4.2. Sampling

Sampling is required to produce a representative sample that can be analysed to determine the quality and therefore price of a consignment of sunflower seed. Furthermore, sampling functions as a verifier based on contractual essentialia and naturalia. For sunflower seed, using the appropriate tools and, depending on the method of transport, viz. bulk or bags, a 5 kg representative sample is drawn based on a fixed set of procedures. The bulk sample must be thoroughly mixed before a representative sample is obtained for grading. The reduction of the representative sample to a working sample is a direct instruction stipulated in the regulation. The working sample of 100 g for sunflower seed must be obtained by dividing a representative sample of the consignment according to the ICC 101 (approved 1960) method (Agbiz Grain).

Grading regulations promote fair business practices and a competitive marketing environment for grain and oilseeds. By the correct application of the grading regulations, fair and competitive trading practices are promoted, to the overall benefit of consumers and the agricultural industry. The Department of Agriculture, Land Reform and Rural Development (DALRRD) ensures the ongoing development and maintenance of uniform standards for South African inspection and weighing procedures for grain. The grading of sunflower is stipulated in Government Gazette No R45 of 22/01/2016. Grading factors for sunflower seed include damage, foreign matter, screenings and sclerotinia.

4.3. Grading of Sunflower Seed

There are three classes of sunflower, namely:

- Class FH, which consists mainly of sunflower seed with a high oil content,
- Class FS, which consists mainly of sunflower with a low oil content that is used as bird feed, and
- Class Other Sunflower Seed, which does not comply with the requirements for Class FH or Class FS.

There is only one grade for the classes FH and FS sunflower seed, namely Grade 1. No grades are determined for Class Other Sunflower seed. Ambiguity currently exists as to what is referred to as high oil content, as no reference measure is indicated.

The official grading system for South Africa is presented in Appendix B and covers the procedures and methodology of sampling.

Thus, in short, when delivering to a depot, the following actions must be taken:

1. A representative sample of no less than 5 kg must be taken from the consignment.
2. The sample is reduced by utilising a multiple slot divider to obtain two working samples.
3. One of these samples is used to determine the moisture content of the consignment.
4. The second sample is used to determine the quality of the seed.
5. The balance of the sample is screened to determine the presence of any stones, sand, soil or poisonous seeds in the sample.
6. During sampling, the consignment is checked for the presence of living grain insects, undesirable substances or odours in or on the consignment.
7. A grade is awarded to the consignment according to the Grading Regulations.
8. The mass of the consignment is determined and, if the moisture content is above 12.5%, a mass adjustment is made.
9. The producer is remunerated for the grain delivered taking into consideration the mass, moisture and grade awarded to the consignment.
10. When a consignment is accepted for storage, the grader, in conjunction with the silo operator, decides where the grain is tipped. A decision is made whether the consignment must be cleaned and/or dried.
11. Depending on the grade awarded to the consignment, a decision is made regarding into which silo bin the grain will be transferred.
12. The silo operator, under the auspices of the depot manager, must ensure that the grain in the silos is stored in such a way that the grain quality will not deteriorate during storage (Agbiz Grain)

4.4. Pre-cleaning and Drying of Sunflower Seed

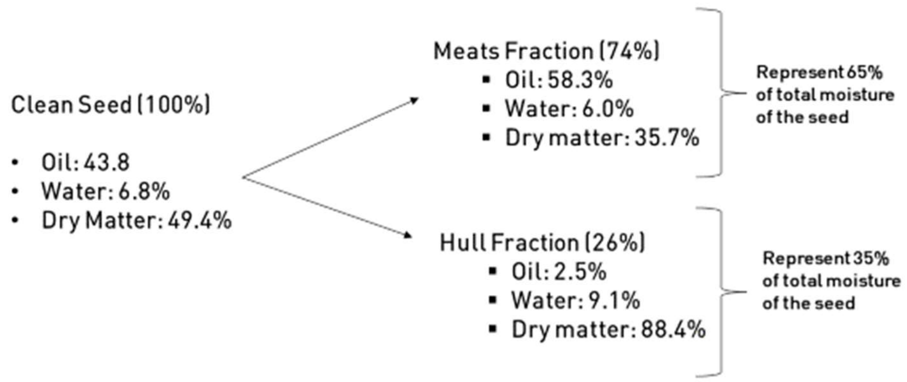
The marketing or acquisition of sunflower seeds is on a "zero foreign matter" basis. Nonetheless, sunflower seed contains foreign matter that needs to be removed in the process. Therefore, the mass of material received is greater than the traded quantity by the added amount of foreign matter. To obtain the equivalent mass on an "as received" basis requires a simple arithmetic operation.

Efficient pre-cleaning is highly recommended prior to drying to eliminate blockage or fires in the seed dryer. For pre-cleaning, sunflower processors generally use high-capacity perforated drums inside which special aspiration channels remove undesirable by-products from the harvest, such as stems, straw, stalks, chaff, stones, loose hulls or other cereals and seed. A magnet is then used to remove metal units. The aim is to prevent damage to equipment in the processing stage. The drying equipment must operate as such to avoid any splits.

In South Africa, sunflower seed is mostly left on the field to dry and harvested at low (< ±12.5%) moisture content). Some silos will only accept sunflower at 12,5% to 13.5% moisture when delivered directly from the field (GrainSA, 2020). Drying is important to preserve the quality of seed if the moisture content exceeds these levels. The moisture content of sunflower seed has to be at about 9.5% for storage up to six months. Sunflower seed has to be aerated continuously, or moved from silo to silo, to prevent any fungus build-up. Sunflower seed with a moisture content of over 12.5 % can have fungus build-up within 48 hours of being stored in a silo, and the heat generated by this process can start a fire spontaneously.

Although not normal practice in South Africa, if the moisture content is too high, sunflower seed should be dried. For this, direct combustion gases are mostly used. The fuel used for this process should contain minimum levels of sulphur, because its presence in the gases plus the moisture of the seed could lead to the formation of undesirable inorganic acids during the downstream meats-conditioning stage.

After the seed is cleaned and weighed, it will have a composition similar to the following analysis:



4.5. Storage of Sunflower Seed

The fluidity of the seed, together with a natural slope angle of 45° and an optimum density of -0.42 in silos makes sunflower seed easy to store. The most ideal storage containers are concrete or steel vertical silos. Storage conditions of oil seeds before industrial extraction might influence the quality of the crude oil.

The sunflower seed must have a maximum moisture content of 9% for maintaining quality during storage. During storage, there should also be facilities to provide ventilation and temperature control to maintain quality. The acidity of the oil inside the sunflower seed increases in an exponential manner when it exceeds the limits of stability caused by excess moisture or damage. Such a lack of stability is detected by the material temperature rising approximately 10°C above ambient temperature during storage (Le Clef and Kemper, 2015).

Martini and Añón (2005) investigated the effect of storage temperature, i.e. 10°C, 21°C and 37°C, on sunflower seeds. Extractions of the seeds were done with hexane to obtain the oil at different storage durations. The amount of oil extracted (25% to 40%) showed no significant differences related to storage conditions. The wax concentration increased with storage conditions (time and temperature). Waxes with a high carbon number cause more turbidity than waxes with a low carbon number due to their higher melting point, resulting in a low quality crude oil and therefore in variations in processing conditions during the oil is refined. They concluded that storage at low temperatures for short periods of time may be the more adequate conditions to obtain high quality oil.

The storage conditions of oil seeds before industrial extraction could influence the quality of the crude oil. Ghasemnezhad and Honermeier (2012) investigated the effect of different storage temperatures (4°C to 5°C, 21°C to 22°C, and 35°C) over a period of four months on two high-oleic and two low-oleic sunflower cultivars. The results indicate that the quality parameters of the seed, such as oil content, fatty acid composition and protein content, were significantly influenced by storage conditions, especially as time lengthened. The oleic acid content of the cultivar also decreased over time and the free fatty acids increased.

Internationally and nationally there is not much literature on the topic of sunflower seed storage. Locally, a study by De Villiers *et al*. (1986) was done on 98% decorticated sunflower seeds. Kernels were stored for six months under favourable (25°C, 50% relative humidity) and unfavourable (30°C, 75% relative humidity) conditions. Whole seeds were stored under the same conditions for comparison. Samples were collected at monthly intervals and the oil was extracted with hexane. The quality characteristics of the extracted oils were evaluated by a few physicochemical determinations. Free fatty acids (FFA) and induction period (IP) measurements were found to be the most sensitive parameters for indicating changes in the quality of the oils. Kernels stored under favourable conditions underwent no significant changes. Under unfavourable conditions, it was found that the deterioration of the oils started after one month of storage. The FFA values increased from 0.16% to 9.94% and the IP decreased from 600 to 74 minutes for samples exposed to air. Significantly higher mould growth occurred on kernels stored under unfavourable conditions.

The Argentine Sunflower Association (ASAGIR) is also working with producers to address the presence of pesticide residues on sunflower seeds and in oils, which has undermined Argentina's competitiveness in international markets. More recently, Argentine phytosanitary authorities banned the use of the pesticide Diclorvos, as the presence of its residue in sunflower products for export had led to shipment rejections in the EU.

Since large volumes of South African sunflower seeds are stored in silos before being delivered to crushers, it would be important to determine the oil content and, if required, the fatty acid composition of the sunflower seed when delivered to the silo and again before delivering to the crushers, as some deterioration in seed oil quality and quality may occur depending on the duration of seed storage.

4.6. Equipment and Methodology to Measure Sunflower Seed Oil Content

4.6.1. Methods of Determining Oil Content of Sunflower Seed

Knowledge of the oil content of sunflower seed is of key interest to the oil-milling business because in many cases the monetary assessment in the trade of oilseeds is based on this value. The raw material price depends on its oil content. The oil content, as hexane or petroleum extract, is defined as the whole of the substances extracted under the operational conditions specified and expressed as a percentage by mass of the product as received (ISO, 1988). In order to facilitate global trade in oilseeds, different standard methods, such as the methods of the German Fat Science Society (DGF) (DGF, 1988), the American Oil Chemists' Society (AOCS) (AOCS, 1993), the International Organization for Standardization (ISO) (ISO, 1988), and the Federation of Oils, Seeds and Fats Associations (FOSFA, 1998), are available.

Basically, there are four methods for determining the oil content of sunflower:

Direct solvent methods
Most of these methods are based on the first automatic solvent extraction apparatus, designed by Franz von Soxhlet in 1939, which involves the extraction of fat from the solid material by repeated washing with an organic solvent, usually hexane or petroleum benzine, followed by gravimetric determination. These methods for the determination of the oil content of oilseeds are considered to be the standard methods. The primary disadvantages of all of these methods based on the Soxhlet method are the slow and time-consuming process, the

large volumes of flammable organic solvents that are necessary for a complete extraction, and the destruction of the sample (Robertson and Windham, 1981). This method is used by the SAGL (see Section 4.6.2 on page 68) and is also known as "wet chemistry".

NMR (low-resolution nuclear magnetic resonance) (DGF, ISO, AOCS)
The NMR technique measures total hydrogen associated with the oil and water in seed (the only liquid constituents), independent of the hydrogen associated with the non-oil matrix (Conway and Earle, 1963; Collins *et al.*, 1967). If the measurement is made on dry seed, the response of the apparatus is directly proportional to the quantity of oil present in the seed. Accurate estimates of the oil content of oilseeds, however, can be made only when moisture contents are below 4%. Thus, this method requires pre-drying of the seed (Madsen, 1976). As the process is non-destructive and feasible even on single seeds, geneticists and plant breeders have used the NMR technique extensively (Alexander *et al.*, 1967; Grandlund and Zimmerman, 1975; Shchori and Navon, 1972). NMR provides a rapid, accurate means of measuring the oil content of oilseeds (Collins *et al.*, 1967; Robertson and Morrison, 1979) and has been found to be more reproducible and statistically more reliable than the direct-solvent and other extraction methods (Collins *et al.*, 1967, Madsen, 1976). Robertson and Morrison (1979) reported that the NMR technique gives relatively accurate estimates of the oil contents of sunflower seed, but they found the NMR response varied, depending on the linoleic acid content. Temperature is also an important factor that affects the reproducibility of quantitative results.

The NMR method is widely used in European countries, especially France and Germany, to measure oil in sunflower, rape and soybean. A related method is used in Spain to determine the oil in olives to assign commercial value. In North and South America, the official oil content in canola and sunflower is determined by the NMR method (Krygsman and Barrett, 2004).

NIR (near-infrared) (NIR) (AOCS)
Near-infrared reflectance (NIR) as a procedure for the estimation of protein in simple commodities was first reported in 1973 (Williams and Starkey, 1980). NIR utilises the absorption of near-infrared energy (1 100 nm to 2 500 nm). NIR has since become established as a simple, rapid and effective analytical tool for the simultaneous prediction of the oil, protein, fibre and moisture content of grains and oilseeds (Hymowitz *et al.*, 1974; Rinne *et al.*, 1975). The value of this technique to determine the chemical composition of sunflower seeds was reported by Robertson and Barton (1984), Pérez-Vich *et al.* (1998), Sato (2002), Fassio and Cozzolino (2004), Velasco *et al.* (2004) and Biskupek-Korell and Moschner (2006). NIR technology has been used successfully in the analysis of the fatty acid composition of sunflower seeds to assess the content of palmitic acid, stearic acid, oleic acid and linoleic acid (Velasco *et al.*, 2004), the content of oleic and linoleic acids (Biskupek-Korell and Moschner 2006), discriminant analysis of sunflower seeds for fatty acids (Grunvald *et al.*, 2012), the content of moisture, fat and oleic acid (Gonzalez-Martin *et al.*, 2013) and the content of palmitic, palmitoleic, stearic, oleic and linoleic acids (Pérez-Vich *et al.*, 1998).

The application of this method, however, requires that the equipment be calibrated to correlate with the NIR spectral information from a reference method. Standard samples representing all the expected variations in the contents must be used to construct a reference dataset (Velasco *et al.*, 1998). This is complex and time-consuming, as many samples are required, and therefore it is difficult to maintain accurate results on a large variety of product types. Nowadays, the complex and time-consuming calibration process is handled by the companies providing NIR machines, and calibrations can be purchased from the suppliers of the NIR machines and only an adjustment to South Africa-specific cultivars is needed. Calibrations are also transferable among equal types of machines. In addition to the plant species, the environmental conditions should also be considered because they can interfere with the spectral absorbance (Batten, 1998; Fassio and Cozzolino, 2004; Saaroni *et al.* 2010). Some techniques can also be destructive, as the samples have to be ground.

Van Loggerenberg and Pretorius (2005), using NIR to measure the oil and protein content of striped and black sunflower seed from the South African national cultivar trials, found that whole-seed calibrations revealed inaccurate prediction values for oil and protein. A combined striped and black sunflower seed calibration for ground samples, which was developed for oil and protein, also displayed low predictability, but the results were better than for whole seeds. However, NIR technology has improved rapidly over the past 15 years and the type of machine now determines whether samples need to be milled or whether whole sunflower seeds can be used.

Supercritical fluid extraction (SFE) (AOCS)
Supercritical fluid extraction (SFE) is an innovative and environmentally friendly extraction process that uses a supercritical fluid as an alternative to commonly used organic solvents (Chemat and Carvotto, 2011). A supercritical fluid (SF) has lower viscosity and higher solute diffusivity than a liquid solvent, which improves mass transfer, reduces the extraction time needed and simplifies the removal of solvent. Recoveries by SFE are influenced by three interrelated factors: solubility, diffusion and effects resulting from adsorption on the sample matrix. Carbon dioxide (CO_2) is the most commonly use supercritical fluid for extraction from oil seed, as its critical conditions are relatively easier to attain (critical temperature, 31.1°C and critical pressure, 7.39 MPa) compared to other supercritical fluids. The solubility of vegetable oils, however, varies considerably with temperature and pressure (Walker *et al.*, 1994; Salgın *et al.*, 2006).

Each of the four methods have pros and cons. A quick summary of the first three is presented in Table 17. However, to determine which is the better method would require a much more in-depth analysis, including factors such as the price of the equipment, ease of use, reliability under South African conditions, increased sample throughput, price of measurement per sample, etc.

Table 17 Pros and cons of three methods to determine oil content

	Soxhlet	NMR	NIR
Rapid determination	No	Yes	Yes
Chemicals	Yes	No	No
Sample destruction	Yes	No	Yes/No
Calibration complexity	No	Yes	Yes
Requires standards	No	Yes	Yes

While SAGL employs the Soxhlet method (primary testing method) in measuring quality variables including oil content, most cooperatives and grain-handling companies have invested in secondary testing equipment (e.g. NIR or NMR testing machines), since the time and equipment required for Soxhlet method testing is not practical. The accuracy of tests performed via secondary testing is highly dependent on the correct calibration[8] of the testing equipment. Agbiz, together with the SAGL, has been promoting the widespread adoption of a

[8] Note: calibrations can be purchased from the equipment providers; however, adjustments have to be made to account for South African cultivar/seed differences compared to international standards. Calibrations are transferable among equipment of equal type. In terms of best practices, minor accuracy adjustments can be made as described in the ring test to improve the comparability of results nationwide.

proficiency scheme whereby a grading ring test for sunflower (and other oilseeds and grains) can be performed on an annual basis.

A grading ring test will enable quality control as companies test and compare graders within their own company and with other grain graders in the rest of the industry. SAGL would then evaluate the results, and a combined report of the ring test can be distributed to all participating companies (all information will be kept confidential and censored, with unique codes known only to each participant). Ring tests or inter-laboratory comparisons are undertaken to monitor equipment, personnel and test methods. Service providers in the grain industry are tested to obtain an independent assessment of quality control measures. The primary aim is to have a quality-assurance tool for benchmarking against other laboratories, as good-quality results will lead to increased productivity and competitiveness.

Benefits of ring tests for the grain industry are:

- i) Regular independent checks of the quality of analytical measurements and grading.
- ii) To compare performance with an independent laboratory.
- iii) To demonstrate competence to customers (dispute resolution).
- iv) Monitoring of trends over time.
- iv) Evaluation of methods and instrumentation.
- v) Staff training and customer education.
- vi) Participants can meet customer requirements and optimise quality control systems.

The value for the entire grain and oilseeds industry is determined by:

- i) Regular participation.
- ii) Following the instructions.
- iii) Evaluation of results.
- iv) Corrective actions based on the results.

Ring tests are a valuable tool to maintain quality standards in the grain industry and should satisfy the needs of the National Regulator for Compulsory Specifications (NCRS) by proving that the grain industry is self-regulating.

4.6.2. Methods used by the South African Grain Laboratory (SAGL)

The following section is quoted directly from the SAGL report for sunflower seed (2019) (SAGL, 2019), pages 36 to 37.

4.6.2.1. Samples Collected from Silos

Sampling Procedure

A working group determined the procedure to ensure that the crop quality samples sent to the SAGL by the various grain silo owners are representative of the total crop. Each delivery is sampled as per the grading regulations for grading purposes. After grading, the grading samples are placed in separate containers according to class and grade, per silo bin at each silo. After 80% of the expected harvest has been received, the content of each container is divided with a multi-slot divider in order to obtain a 3 kg sample. If there were more than one container per class and grade per silo bin, the combined contents of the containers are mixed thoroughly before dividing them with a multi-slot divider to obtain the required 3 kg sample. The samples should be marked clearly with the name of the depot, the bin/bag/bunker number(s) represented by each individual sample, as well as the class and grade, and are then forwarded to the SAGL.

Grading
Full grading is done in accordance with the Regulations relating to the Grading, Packing and Marking of Sunflower Seed intended for sale in the Republic of South Africa (Government Notice No. 45 of 22 January 2016).

Test Weight
Test weight provides a measure of the bulk density of grain and oilseeds. Test weight does not form part of the grading regulations for sunflower seed in South Africa. An approximation of the test weight of South African sunflower seed is provided in this report for information purposes. The standard working procedure of the Kern 222 instrument, as described in ISO 7971-3:2009, was followed. The g/1 L filling mass of the sunflower seed samples was determined and divided by two. The test weight was then extrapolated by means of the following formulas obtained from the Test Weight Conversion Chart for Sunflower Seed, Oil of the Canadian Grain Commission: y = 0.1936x + 2.2775 (138 to 182 g/0.5 L) and y = 0.1943x + 2.1665 (183 to 227 g/0.5 L).

Nutritional Analysis
Milling - Prior to the chemical analyses, the sunflower seed samples are milled on a Retch ZM 200 mill fitted with a 1.0 mm screen.
Moisture - The moisture content of the samples is determined as a loss in weight when dried in an oven at 105°C for five hours according to AgriLASA method 2.1, latest edition.
Crude Protein - The Dumas combustion analysis technique is used to determine the crude protein content according to AACCI method 46-30.01, latest edition. This method prescribes a generic combustion method for the determination of crude protein. Combustion at high temperature in pure oxygen sets nitrogen free, which is measured by thermal conductivity detection. The total nitrogen content of the sample is determined and converted to equivalent protein by multiplication with a factor of 6.25 to obtain the crude protein content.
Crude Fat - In-house method 024 is used for the determination of the crude fat in the samples. After sample preparation, the fat is extracted by petroleum ether with the aid of the Soxhlet extraction apparatus, followed by the removal of the solvent by evaporation and weighing the dried residue thus obtained. The residue is expressed as % crude fat.
Crude Fibre - In-house method 020 is used for the determination of the crude fibre in the samples. Crude fibre is the loss on ignition of the dried residue remaining after digestion of the sample with 1.25% sulphuric acid (H_2SO_4) and 1.25% sodium hydroxide (NaOH) solutions under specific conditions.
Ash - Ash is defined as the quantity of mineral matter that remains as incombustible residue of the tested substance, after application of the described working method. In-house method No. 011, based on AACCI method 08-03.01, is used for the determination. The samples are incinerated in a muffle furnace at 600 ± 15°C for two hours.

4.6.2.2. Precision Oil Laboratories' Fatty Acid Profile Methods

Fat Extraction - In-house method POL 019 is used for the extraction of the crude fat from the samples. After sample preparation, the fat is extracted by petroleum ether under reflux, followed by the removal of the solvent by evaporation. The residue obtained from the fat extraction is used for the preparation of methyl esters for determination of the fatty acid profile.
Fatty Acid Profile - In-house method POL 015 is used for the determination of the fatty acid composition. Extracted fat is converted to methyl esters using an alkali catalysation method.

Methyl esters are injected into a gas chromatograph and an external fatty acid methyl ester standard is used to identify peaks based on retention times. The fatty acid composition is expressed as a total fatty acid content of 100%, with different fatty acids representing a percentage of the total fatty acids.

4.6.3. Methods used by South African Crushers

Crushing equipment operates best when supplied with uniform material because this eliminates constant adjustments to the machines to operate at optimum levels. However, sunflower seed is a biological product that varies in seed size, hull-to-kernel ratio, hullability, moisture content and oil content. These are all factors that have an influence on throughput, extraction rate and, as such, operational efficiency, which all may affect profit margins. Therefore, most crushing facilities have invested in equipment to measure the quality of seed on a continuous basis and have methodologies in place that meet their requirements.

The NIR testing methodology is the analysis of choice at crushing plants due to the speed of the test, the ease of testing and its relative accuracy. NIR machines are calibrated on a continuous basis against conventional laboratory tests commonly referred to as "wet chemistry". The nutrients that are calibrated would typically be protein, fibre, moisture and fat (also referred to as proximate analysis). There are numerous makes of NIR machines, and calibrations between these types of machines are unfortunately not normally transferable. The most common machines used in South Africa are FOS, Perten and Unity. The cost of an NIR testing machine is estimated at close to R1 million and therefore requires serious investment.

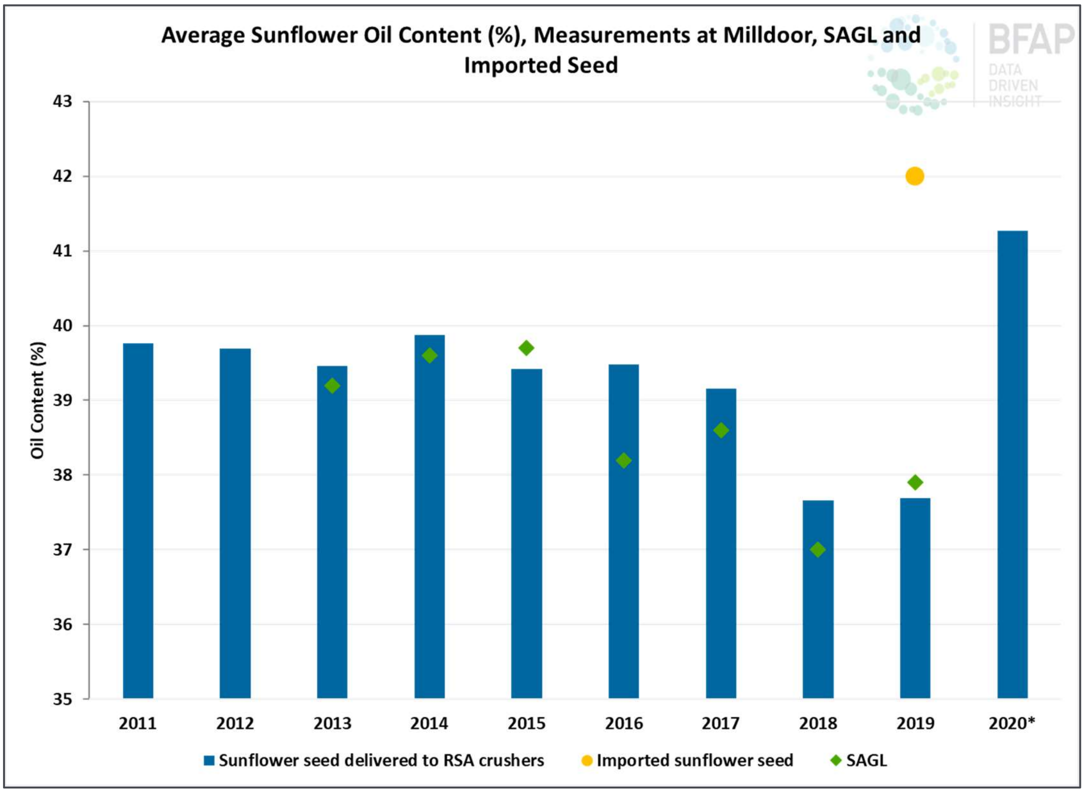


Figure 28 Example of the oil content (%) of sunflower seed delivered to crushers, imported seed and analysis by the South African Grain Laboratory (SAGL).

** all oil content measurements are on an as-is basis*

** figures for 2020 are preliminary numbers reported by crushers at the start of the harvesting season*

4.7. Hullability

Breeding for a higher oil content inadvertently leads to seed that is more difficult to dehull. Thus, investigations of the effect of poor hullability on the quality of oil cake started in the 1990s as a result of the increased world demand for oil cake (Evrard *et al.*, 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 that needs to be removed. With dehulled seed, wear of the expeller is reduced (Tranchino *et al.*, 1984; Ward, 1984; Shamanthaka Sastry, 1992; Dorrell and Vick, 1997). The hulls that are removed can be used as an energy source for steam production in a high-performance biomass boiler or as bedding in broiler houses.

Several seed characteristics, like oil, moisture and wax content, hull content, hull thickness, seed size and seed density, all affect the hullability of seed. Nel *et al.* (2000b) found that, in South Africa, environmental effects present the largest source of variation in grain yield and some physical seed characteristics, such as hectolitre mass, hull content and the production of fine material, whilst the cultivar contributes the most to the variation in thousand seed weight and hullability. Despite the large environmental effect, a stable response of the physical seed traits measured indicates that breeding for the stability of seed traits like hullability could be possible. However, 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 (Nel, 2001).

4.8. Plausibility of a Sunflower Seed-grading System Incentive Scheme Based on Oil Content

South Africa has no formal specification for a "norm" oil content to be delivered. The Agricultural Products Standards Act, 1990 (Act 119 of 1990) states that FH1-grade sunflower seed that is delivered should be seed of a "high oil yield", but does not specify what a high oil yield is (Appendix B). The industry's established norm is generally that all sunflower delivered on SAFEX should have an oil yield above 36% and preferably at a 38% norm. The 38% norm was also used by ITAC (2006) in their anti-dumping investigation of refined sunflower oil from Argentina and Brazil.

Comparing the results from the SAGL averages over all regions with those of the USA, it becomes apparent that the premium paid gives rise to sunflower seed delivered over all the seasons with an average oil content of > 40%, whilst the oil content of commercial production in South Africa, although in line with industry norms, was only around the 38% mark and with a declining trend (we could not get hold of similar oil data content for Argentina or East European countries and therefore only included the USA in the analysis) (Figure 29).

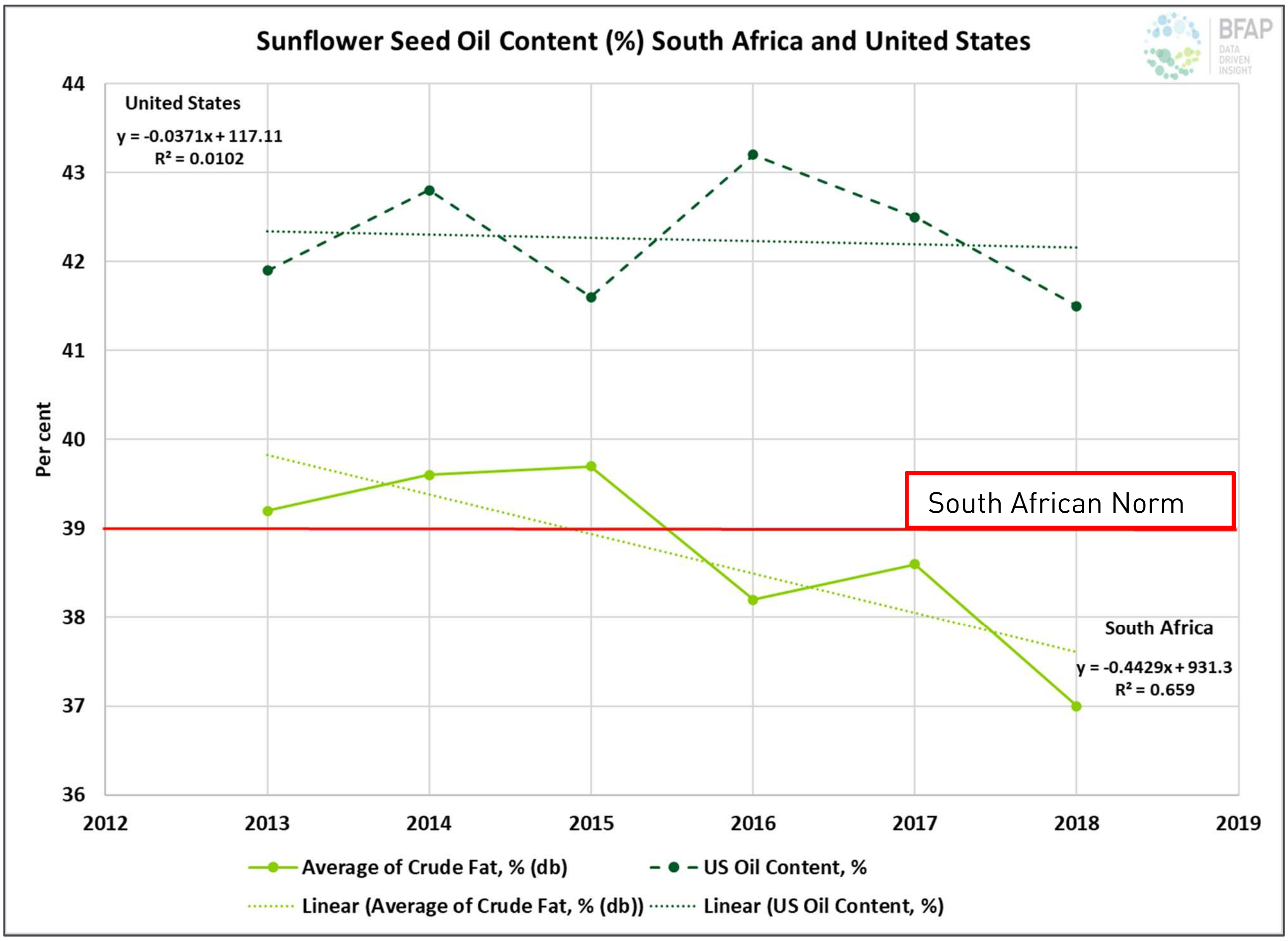


Figure 29 Comparison of sunflower seed oil content between South Africa (Source: South African Grain Laboratories) and the United States (Source: National Sunflower Association, U.S. Sunflower Crop Quality Reports) for the period 2013 to 2018

4.8.1. Practical Implementation at Silo Level

Currently in South Africa, the only measurements taken at silos are for weight, moisture content and those associated with grading. Implementing an amended grading and/or pricing structure for sunflower seed will have some practical implications at the silo level.

Firstly, in addition to the current grading, each consignment will have to be sampled for oil content. Practical considerations would be:

- How is this sample taken?
- How many samples will be taken?
- Will reference samples be kept?
- Are samples required before storing in the silo, or will they be taken later before sending to the crushers, or will they be taken in each instance?
- On what basis will the seed be stored? Different tubes for different oil-content seed?
- Testing will have to be done at an acceptable speed so as not to interrupt off-loading of consignments.
- Will seed consignments be blended to achieve a target oil content?
- What methodology will be used to sample?
- Who will pay for the sampling procedure?

- Measuring equipment is complex apparatus. Who will be responsible for the measurements?
- How often is the equipment calibrated?

The question thus arises whether it is practical to have oil content-testing facilities at each silo? Or else, where and when within the value chain can fair and equitable oil-content testing be done?

The availability of equipment to measure secondary quality characteristics (like NIR machines) varies from company to company. Some silo owners indicated that all their silos have NIR machines, whereas others only have NIR machines available at selected silos. Since cheaper equipment can be used for the abovementioned measurements for grading purposes (e.g. moisture content), the investment required to place NIR machines at all silo depots has not been made throughout the country. In principle, oil content is another measurement that could be added to the list that is monitored at silo level. However, since oil content is not a grading requirement and currently is a nice-to-have, it consequently is not measured and machines, where they are available, are not necessarily calibrated for this. Ring tests, as discussed in Section 4.6.1, can go a long way in ensuring that oil content is measured accurately at all value chain nodes (silos, crushers, etc.).

4.8.2. Review and Practical Implementations of Pricing Models Based on Oil Content

Sunflower hybrids that combine genetics for high oil content and hulling characteristics are generally preferred by processors. The general consensus is that crushing margins should increase with seed with a higher oil content, as this requires less volume (hectolitre mass) of seed to be crushed to deliver the same amount of oil.

In some countries, premiums are offered for certain types of sunflowers for oil content and other characteristics. Premiums depend on market conditions and the individual characteristics that buyers are looking for in sunflowers. Buyers and processors usually offer premiums to producers, providing them with an incentive for producing certain types of sunflowers.

In South Africa, premiums are not realised for a higher oil yield as is the case in countries such as the USA, where a 2% premium is paid for every 1% of oil content exceeding the US norm of 40% (Sunflower Association, 2016) (Figure 30). In France, a commercial standard of 44% oil, 9% water and 2% impurities has been fixed by the oil-crushing industry, and most of the results are expressed according to this standard. The grain cooperatives are subjected to premiums and penalties when selling their production to crushers. Only in a few cases are the farmers paid according to the oil concentration of the seeds they deliver to the cooperative. Most of the time, the premium in case of oil concentration exceeding 44% is shared among farmers, whatever their contribution to grain quality (Andrianasolo *et al.*, 2016).

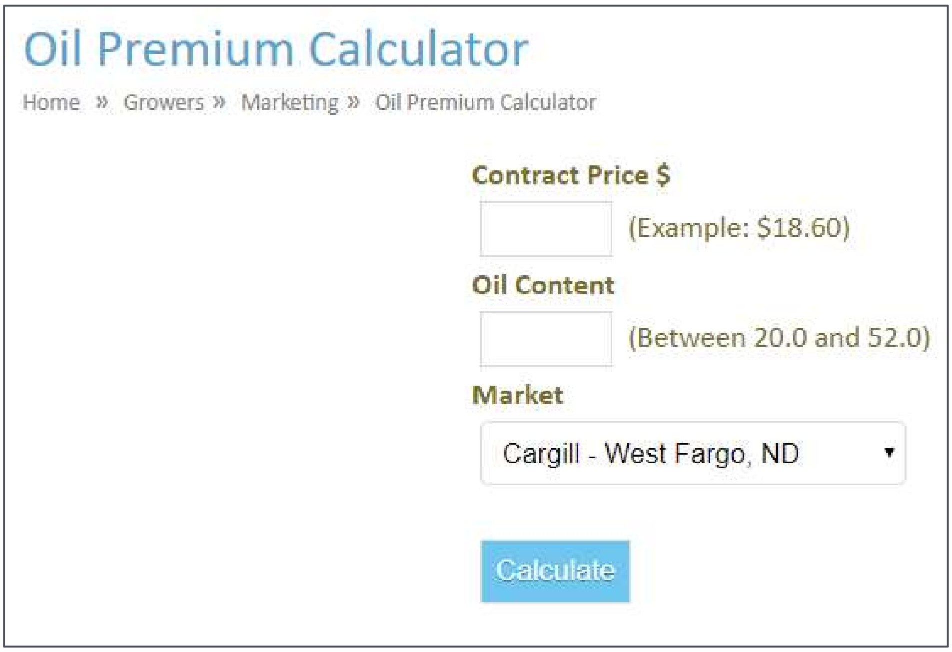


Figure 30 Example of the oil premium calculator on the website of the National Sunflower Association of the United States (https://www.sunflowernsa.com/)

4.8.3. Sunflower Pricing: International Examples

Various sunflower seed-exporting countries offer price premiums based on oil content (%). A summary of two export contracts (Black Sea and Argentina) is presented below. The typical base requirements for sunflower seed exported by Black Sea countries and Argentina are summarised in Table 18 below.

Table 18 Typical base requirements for sunflower seed exported by Argentina and Black Sea countries

	Argentina	Black Sea
Oil content	42.5%	44%
Foreign matter	2-4%	2-4%
Moisture	9-11%	9-10%
Free fatty acids		2-3%

For every 1% oil content delivered below the basis, the Argentinean and Black Sea contracts allow for a 1.5% decrease in the value/price of sunflower seed (from buyer to seller), while only the Black Sea contract allows a 1.5% increase in the value/price of sunflower seed for every 1% oil content delivered that exceeds the basis. This principle could incentivise farmers to select higher oil-yielding cultivars and/or take more care with respect to aspects linked to the environment, as highlighted in Section 3.4 on page 53, in order to cultivate seed with a higher oil content.

4.8.4. Domestic Canola Pricing Model

Canola is not traded on SAFEX and therefore the determination of the canola milldoor and producer price to get to a comparable price is a bit more complex. The canola milldoor price is derived from:

- A combination of crushing yields and costs and derived product prices:
    - Import parity prices of rapeseed oil and soybean oil and
    - Rapeseed oilcake price
- Sunflower seed SAFEX futures-based price
- Soybean SAFEX futures-based price

Furthermore, SOILL (Southern Oil) offers various contracting option to farmers: minimum price and final price contracts. The bulk of the canola harvest is contracted via the "minimum price" contract based on the announced milldoor price less storage and handling, transport and hedging costs. Farmers usually fix their anticipated harvest in August for the respective season. Based on actual costs and oil sales over a six-month period (September to April), a potential back payment is then calculated and paid out to qualifying farmers[9] at the beginning of April (difference between minimum price contracted based on estimated costs and the daily average milldoor price less actual costs). Similarly, a second potential back payment is calculated for the six-month period from April to September, which is then paid to farmers at the beginning of September. Back payments are only paid if the current prices (in April and September) are higher or actual costs are lower than estimated in the minimum contract, and it has happened before that no or only one back payment was paid. The minimum price contract also includes a force majeure clause that provides for cases when farmers cannot deliver the total volumes contracted due to drought, for example. In such cases, farmers are not required to buy back the balance at market value.

This contracting structure allows farmers to benefit from the upside of increasing product prices over time and provides the security of a fixed contracted minimum price. Furthermore, the pricing structure allows the processor/crusher to plan and minimise losses dynamically. For the sunflower market, perhaps such an optional incentive is a way to include farmers in the upside of good quality seed delivered and simultaneously allowing crushers the ability to plan and minimise losses in seasons when sunflower seed oil content is lower than expected.

4.9. Summary

There are two classes of sunflower, namely:

- Class FH, which consists mainly of sunflower seed with a high oil content, and
- Class FS, which consists mainly of sunflower with a low oil content that is used as bird feed.

These grades of sunflower seed, however, do not explicitly define what constitutes a high or low oil content.

[9] Only farmers who have opted for the minimum price contract qualify for back payments later in the season.

Knowing the oil content of sunflower seed is of key interest to the oil-milling business because in many cases the monetary assessment in the trade of oilseeds is based on this value. There are four methods available for determining the oil content of sunflower:

- Primary methods:
  - Direct solvent methods (Soxhlet)
- Secondary methods:
  - NMR (low-resolution nuclear magnetic resonance) (DGF, ISO, AOCS)
  - NIR (near-infrared) (AOCS)
  - Supercritical fluid extraction (SFE) (AOCS)

While SAGL employs the Soxhlet method (primary testing method) to measure quality variables, including oil content, most cooperatives and grain-handling companies have invested in secondary testing equipment (i.e. NIR or NMR testing machines) to some extent, since the time and equipment required for testing using the Soxhlet method is not practical. However, not all silos have such testing equipment available. The accuracy of tests performed via secondary testing is highly dependent on the correct calibration of the grading equipment.

Agbiz Grain, together with the SAGL, has been promoting the widespread adoption of a proficiency scheme whereby a grading ring test for sunflower (and other oilseeds and grains) can be performed on an annual basis. The primary aim is to have a quality assurance tool for benchmarking against other laboratories, and good-quality results will lead to increased productivity and competitiveness.

Selected silo depots have equipment to measure secondary quality characteristics and use it for the measurement of weight, moisture content and other measurements required for grading purposes. In principle, oil content is another measurement that could be added to the list that is monitored at silo level. However, since this is not a grading requirement and currently essentially is a nice to have, it is consequently not measured, and equipment, where it is available, is not necessarily calibrated for this. In addition, where equipment is not available, it will require a large investment by silo owners to acquire these testing machines for various solo depots.

A summary of various international and domestic quality-based pricing models highlighted two options for the sunflower industry:

1. Oil content-based price premium (or oil content-based grading)
2. Back-payment structure by which the farmer gets to share in high quality-driven (high oil content) advantages at the crushing level.

5. Crusher Level: Effect of Seed Quality and Other Factors on Crushing Margins

5.1. Crusher Level: Effect of Seed Quality and Other Factors on Gross Margin

South Africa's sunflower industry has been fairly competitive in the global market. Locally crushed crude oil from local seeds is the most cost-effective crude oil source in South Africa. A five-year average shows that it is R3 554 per tonne of crude oil cheaper to process local seeds in South Africa than imported seeds, and R1 797 more cost-effective than importing crude oil.

Figure 31 illustrates the historic cost to locally produce a tonne of crude oil with local seeds (at realised, as-is oil content), with the realised crushing margin, the cost to locally crush imported seed (with an oil content of 44%) and the imported crude oil cost.

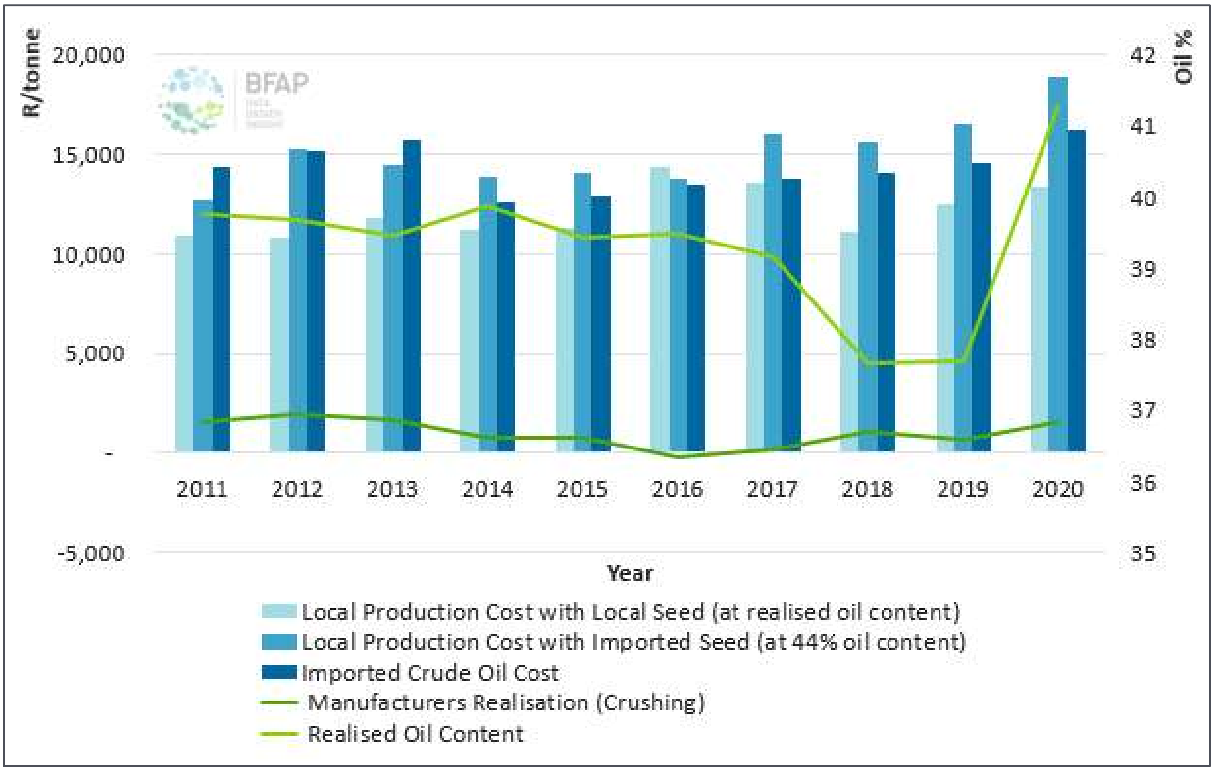


Figure 31 Trends in crushing margins (2011 to 2020)

On average, crushing margins have been under severe pressure due to a combination of low oil content, high seed prices and low oil selling prices. In 2016, a negative crushing margin was realised, as the sunflower seed price rocketed due to low supply in a severe drought season.

Local production cost to process local seed is comparatively lower than the cost to crush imported seed, because the local price for sunflower seed trades below import parity prices (

Figure 32). However, the challenge of using local seed has been the declining oil content of the seed, which has decreased from an average of above 39% between 2011 and 2014 to below 38% in 2018 and 2019. Overall, crushers note that the oil content of locally produced sunflower seed is substantially lower than the oil content of major global sunflower seed producers such as Argentina and Ukraine, which typically average 42% and 44% respectively. However, the cost to process this high-oil imported seed is still higher than the lower oil local seed.

The decreasing oil content affects the competitiveness of locally produced sunflower crude oil with imported crude oil. Taking a five-year average profit margin into account and excluding returns earned from cake, if the oil content drops below 34.3%, it will be more expensive to produce crude oil in South Africa than to import crude oil, and local crushers will make a loss on crude oil processing.

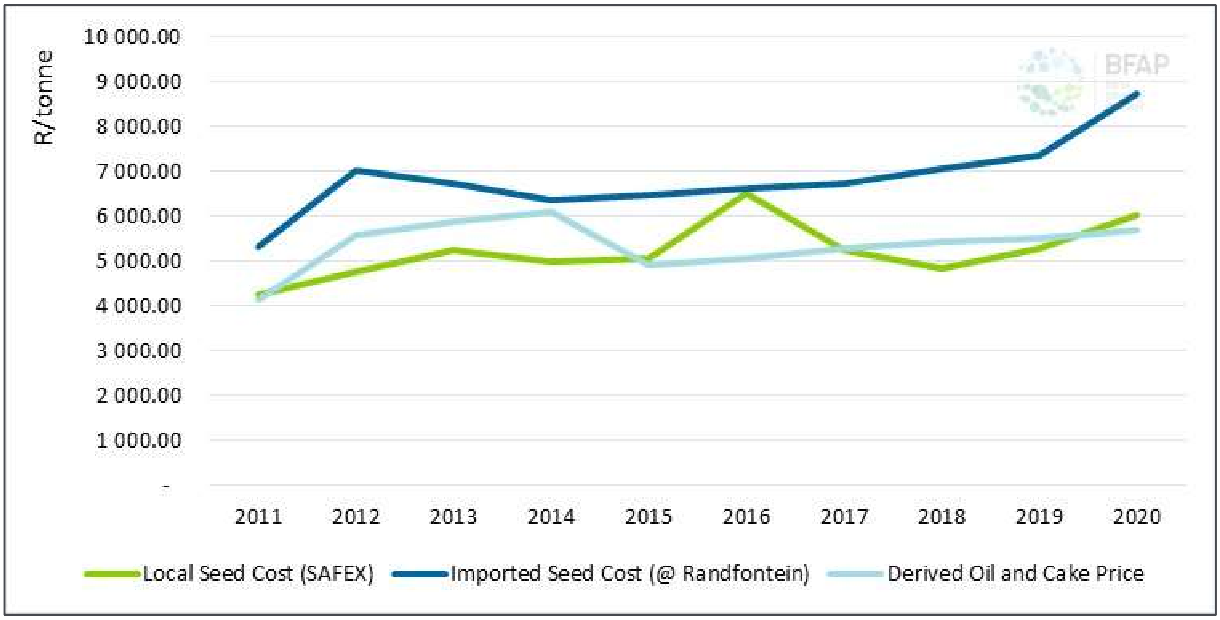


Figure 32 Trends in sunflower seed prices

Compared to import parity prices, local sunflower seed prices have been trading at a discount of more than 20% on average over the past decade. Furthermore, sunflower seed prices have also traded 3% below the derived price of oil and cake in the local market. In other words, the quality difference is to some extent already factored into the free market pricing of seed, cake and oil in the local market (Figure 32). Hence, depending on the price of seed, a low sunflower seed oil content has negative implications for crushers, who must buy more seed to produce the same amount of oil, thereby becoming less cost-efficient.

In an increasingly competitive global environment, South African sunflower seed producers may need an additional incentive, providing returns based on oil content in addition to yields, to consider high oil-content seed production in order to match global producers elsewhere in the world. Improving oil content in seed would entail a viable incentive system that would attract the widespread adoption of seed yielding higher oil (see Section 3.5 on page 57).
Figure 33 illustrates the effect of different price premiums on the crushers' gross margin. The presumptive base for the requisite oil content is 38%, which is the threshold that triggers a premium of X% per 1% oil content above 38%. As the percentage oil content increases, the gross margin of the crushers increases, as they can extract more oil from the local seed they purchase. As the incentive increases, the gross margin of the crushers decreases because they have to pay more per tonne of seed procured.

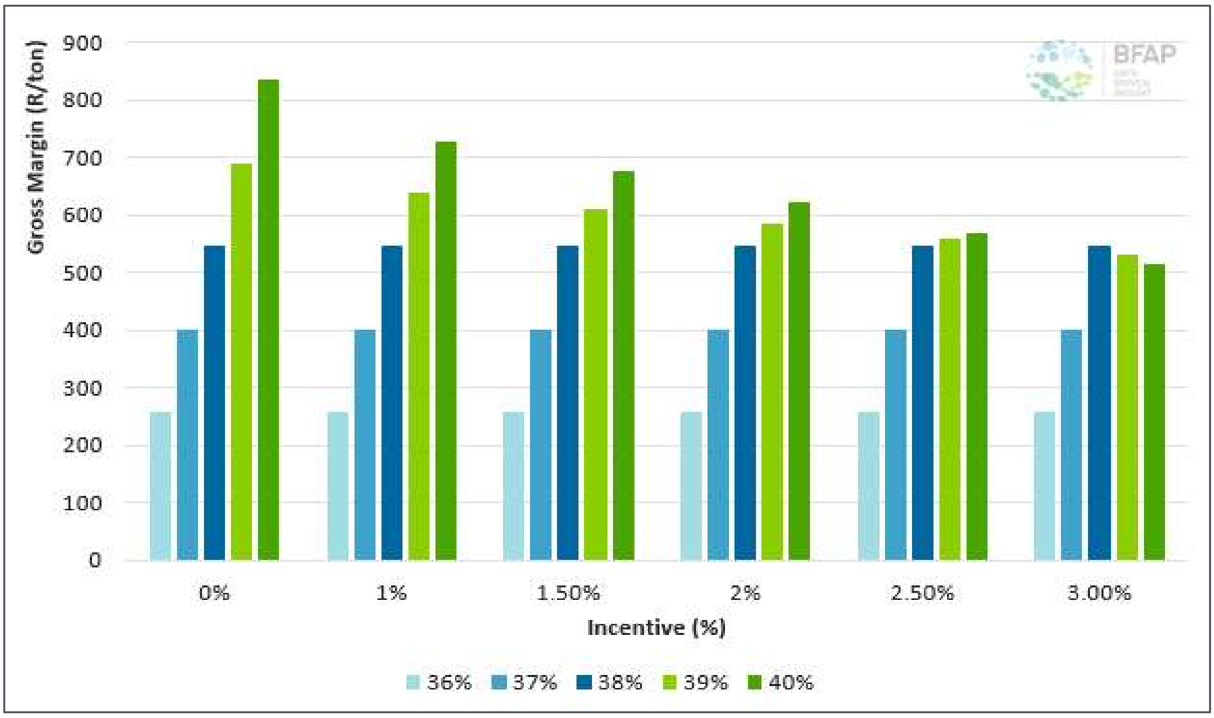


Figure 33 Five-year average crusher's margin with changing oil % and incentive

The margin effects of seed with a high oil content are significant – a 1% increase in sunflower seed oil content leads to a R145/tonne increase in the crushing margin (assuming average input and output prices between 2015 and 2020). At an incentive of 2.8%, the marginal change in gross margins per percentage of oil content is zero. Anything above 2.8% starts to counteract the positive effect of the increase in oil on crushing margins, as seen in
Figure 33 at a 3% incentive level. Furthermore,
Figure 33 illustrates the required oil content to ensure that crushers realise the same five-year average profit margin at different incentive levels. A 52% oil content is required to justify a 2.5% incentive, while an oil content of only 42% is needed at a 2% incentive, and 40.5% at a 1.5% incentive. Thus, an oil incentive above 2% drastically increases the required oil content, which is not yet generally achievable in South Africa. Based on historic data, it is unlikely that local producers will significantly change agricultural management practices in order to increase the national average oil content of seed to above 40% in the near future without significant changes in the incentive structure.

Error! Reference source not found. in Section 3.5 demonstrated that a price premium offering would comfortably offer farmers a yield "flexibility/margin" between 0.1 and 0.3 t/ha (depending on average yield and oil content achieved).

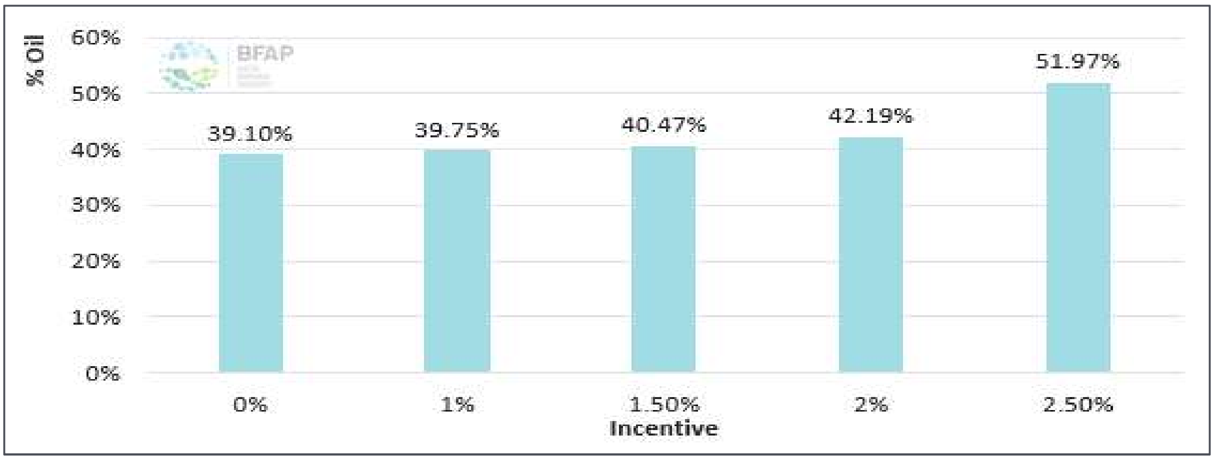


Figure 34 Percentage oil content required to get a five-year average gross margin for crushers

Note that this section illustrates an oil content-based percentage price premium, which is not the only way higher oil content seed uptake and higher oil content incentives can be achieved in South Africa. The widespread adoption of such a proposal by regulatory frameworks would take many years. A pilot-study approach is suggested, whereby crushers could test this model on a direct delivery basis. Such case studies can then contribute to illustrating the impact of such a change in pricing structure.

5.2. Summary

For sunflower crushers to compete in the global market, the seed price needs to stay below import parity and the local oil content may not drop below 34.3%, at which they will make a loss (excluding contribution from cake revenue and overhead costs).

The adoption of an incentive system that rewards farmers for producing seed with a high oil content would be one way of aligning the domestic market with international standard practice in pricing, and expectedly bring new hybrid technology. In principle, both of these innovations would benefit the industry as a whole. However, the analysis of farm-level and crushing margins reveals two critical viewpoints.

Firstly, the premium on high oil content seed would need to be high enough to compensate farmers for the sacrifice in farm yield gains.[10] Adoption of the high oil-yielding varieties would therefore be contingent on the extent and likelihood of farmers producing average oil content beyond the average baseline of 38%, which could be particularly difficult under the circumstances of shifting seasonal patterns.

Secondly, while the desire for crushers to procure higher oil content seed is well placed, the uptake of new high oil-yielding seed varieties will depend to a large degree on the processors' appetite for and willingness to add an oil content-based incentive to the sunflower seed pricing structure. Overall, it comes down to:

- Farmers' willingness to adopt new high oil content seed and their ability to consistently produce seed that exceeds the threshold 38% oil content, and

[10] As discussed in Section 3.4, this trade-off is expected theoretically (from a plant science perspective); however, it has not been conclusively proven on the basis of data.

- The wherewithal of processors to pay premiums that will sustainably stimulate high levels of production of high oil-yielding seed, while competing with crude oil imports.

The pilot study summarised in Box 1 in Section 3.2.2 found that a 1.5% premium for every percentage of oil content above 38% resulted in premiums between R793 and R883/tonne, and farmers harvested average yields of 2 t/ha. In this scenario, farmers could afford up to 0.3 t/ha yield losses, countering the 1.5% price premium, in order to achieve a net zero impact on the average SAFEX price. Additional case studies are required to improve the quantification of the negative correlation (which this study found to be inconclusive) and to verify the positive results found in the pilot study mentioned in Box 1, which was performed in a relatively good year in terms of production conditions.

Overall, one also needs to take cognisance of the fact that these relationships (pricing structures, profitability and farmer decisions) are by no means clearly defined cause-and-effect relationships when it comes to sunflower seed production in South Africa. As illustrated in Section 3, the causal relationships behind yield and oil content performance are not clear cut and the positioning of sunflower seed in the typical South African crop mix creates additional complexities.

6. Conclusions

6.1. Current State and Outlook

- In terms of the global production of an estimated 51.41 million tonnes of sunflower seed in 2018/2019, South Africa is the 13th largest producer, with 0.678 million tonnes.
- The market for sunflower seed is expanding due to rapidly growing global sunflower oil consumption that is mainly a result of rising health consciousness among consumers.
- In the last two decades, the average consumption of oils and fats in South Africa has increased, from nearly 15 kg/head/annum to around 25 kg/head/annum.
- The global market for sunflower oil is competitive, with many local and multinational manufacturers. The top five individual manufacturers account for less than a quarter of global market share in terms of production.
- The demand for sunflower seed has escaped the trade war that has adversely affected international soybean exports.
- South African sunflower production has been very variable, with ± 86% of the sunflower production originating from the Free State and North West provinces.
- Most of the sunflower plantings are under dryland conditions, with only a 1.2% of total national plantings irrigated.
- The median yield for the past 20 years was 1.28 t/ha, and that for the period 2015 to 2018, was1.25 t/ha. These 1.25t/ha are 28% lower than the world average over the same period.
- National cultivar trials indicate that a yield gap exists between the potential of the plant and the actual yields that are obtained in the field under commercial production.
- In line with historic norms, sunflower prices are projected to be marginally higher than those of soybeans but are expected to trade largely sideways over the medium term.
- For vegetable oil, a modest increase is projected to 2020, and prices are projected to stabilise in line with the underlying oilseed prices.
- The price in South Africa is driven mainly by the price of sunflower oil for human consumption and the price fetched for the oil cake to be included in animal rations. As South Africa is a net importer of these commodities, their prices are determined largely by the import parity prices.
- There is a fine balance between the price at which the South African farmer can sustainably produce a tonne of sunflower and the price that crushing plants can afford to pay for the seed and still be able to compete with imported oil and cake.

6.2. Opportunities Based on Trans-fat Policies and High Oleic Sunflower Seed

- By partially hydrogenating oils, they become moderately saturated and more stable; however, the process also creates artificial trans-fat, which may increase bad cholesterol.
- Around the world, governments' changes in policies have altered buyer preferences for edible oil. The final regulations relating to trans-fats in foodstuffs in South Africa – Regulation 249 – were signed into law in February 2011. According to South African legislation, the trans-fat content of any oils and fats cannot exceed two grams per 100 grams.
- Some European and most African countries, along with Australia, have no trans-fat policies. The absence of regulations could make it simpler to export sunflower oil from South Africa to these countries, as most of the sunflower oil produced in South Africa is of a high linolenic type associated with higher trans-fats.

- In the last decades, many new lines of sunflower with modified fatty acid composition have been developed through conventional breeding methods. One of the most successful was the production of mutants with very high levels of oleic acid (HO). The high-oleic sunflower seed oil market is well developed, and the potential for growth is still huge, as the demand for such oil is increasing steadily due to its health benefits and its potential for replacing palm oil.
- Planting high-oleic and mid-oleic sunflower seed types could be mechanisms implemented by South African farmers to find value over and above conventional sunflower seed production. There are, however, much logistics associated with such a move, such as separate storage, crushing and refining. Within the South African context, this may also only be a niche market, as premiums are paid mainly by the high-income sector. High-oleic sunflower oil could, however, be marketed as a premium, healthy and GMO-free oil and an alternative to olive and canola oil.
- Exports of high-oleic sunflower oil may be limited, as both Argentina and Ukraine are already supplying large volumes. Hence there already was an overproduction in this segment in 2016, which resulted in a reduction in price in this premium segment.

6.3. How Does South Africa Rate in Terms of Oil Content to the Rest of the World?

- Based on the year of release, there was an increase in the oil content of sunflower seed up until 2000, from 37% to over 40% found in the cultivar trials. However, since then the oil content has not increased and seems to even have decreased slightly. This is based on all cultivars included in the yield trials for the period 2010 to 2019.
- Over all cultivars that were in the national cultivar trails for two season or more for the period 2000 to 2010 compared to the period 2011 to 2019, the average yield increased by 14%, the oil content dropped by 3%, the protein content decreased by 0.6% and the oil yield per hectare increased by 17%.
- The yield gap between potential yield (cultivar trials) and obtained yield (SAGL) is about 4% for oil content on average over the period 2013 to 2019, indicating a potential to increase in commercial production.
- The index of agreement is 0.486 and 0.775 for day to flower and oil content respectively. This indicates that the selected cultivars in the cultivar trials deliver the advertised oil yield, whilst there is not such strong agreement on when 50% flower is reached. The cultivar trials mostly yield a higher oil content than advertised, indicating that the cultivars in the trial reach their genetic potential for the environment.
- The same cultivars planted in national seed company trials in Argentina yield up to 1 t/ha more than in South Africa, while achieving 6% to 10% higher oil content. This points to significant differences in environmental variables, general agronomic practices and crop prioritisation (and resultant agronomic practices).
- For South African cultivars, the average advertised sunflower seed oil content (%) was between 38% and 46%. An analysis of advertisements from seed companies supplying the Russian, Ukrainian, Hungarian and Argentinian markets indicate advertised oil yield in the range of 45% to 54%. This is significantly higher than the advertised cultivars available to South African producers. Given this, it may very well be possible to import sunflower seed with a higher oil content than what South African producers can achieve using the available genetic material. Thus, the South African sunflower seed market may benefit from new imported cultivars. This must first be tested, however, to establish their potential under South African climatic and management conditions.
- Comparing the results from the SAGL averages over all regions with those of the USA, it becomes apparent that the premium paid for high oil-content sunflower results in sunflower seed delivered over all the seasons with an average oil content of > 40%,

whilst the oil content from commercial production in South Africa, although in line with industry norms, was only around the 38% mark with a declining trend.

6.4. Climate-smart Cultivar Selection and Crop Management

- The amount of money being spent on sunflower research, both public and private, is dwarfed by the amount being spent on other field crops such as maize and soybeans.
- Seed yield is a complex and quantitative trait that is not only controlled by many genes, but also influenced to a great extent by environmental conditions, so both additive and non-additive genetic effects play an important role in the inheritance of seed yield.
- Genotype–environment interaction is also significant for percentage oil content. For example, oil content in the seed is affected by several factors, such as moisture availability at seed fill, duration of seed fill, and mean daily temperatures above 25°C.
- Thus, to achieve both high yields and a high oil content as inherent to the genetic potential of the sunflower seed, the crop should be planted in areas with suitable climatic conditions (temperature and water stress) with optimal crop management (planting date, planting density, fertilisation).
- In South Africa, yields and oil yield per hectare have increased over the years; however, the oil content has decreased. There is a negative correlation (-0.57) between the yield figures of the National Crop Estimates Committee and the oil content as reported by the South African Grain Laboratory. However, these correlations differed for various groupings of data from the national cultivar trials: over all cultivars, conventional hybrids and those with speciality traits. Correlations were inconclusive, i.e. either small or large or negative or positive.
- The lower oil content of sunflower seed delivered from the western regions of the Free State may be attributed to the a) late plantings in the window were oil content is expected to decrease and b) wider plantings of the Clearfield and Clearfield Plus types, in line with crop rotation within promoted conservation agriculture systems.

6.5. Feasibility of Introducing an Incentive-based Pricing Model Based on Yield and Oil Content – Advantages/Disadvantages for Farmers, Silo Owners and Crushers

- Maize is the predominant cash crop in the main sunflower seed-production regions and sunflower is often planted as "catch crop", with preference not being given to the timing of production, such as optimal planting date, fertiliser applications, soil analysis or much of the required pest, weed or disease programmes required for optimal production.
- Over the past decade, farm margins have been relatively stable and positive, averaging R1 323/tonne between 2010 and 2020 and supported by relatively high sunflower seed prices, which allowed farmers to cover their production costs despite volatile yields.
- Based on historic data, the chance that farmers nationally will produce a yield above 1.57 tonne/ha is 50%, while they have a 96% chance to produce above the breakeven yield of 1.2 tonne/ha.
- In the absence of a quality-based incentive for the farmer (status quo in South Africa), the farmer is maximising profits related to sunflower plantings by maximising yield achieved.
- The theoretically expected negative correlation between yield and oil content is not always found in trial data and, depending on varieties, locations and time periods, a range of positive and negative correlations were calculated between yield and oil content.
- Current data availability therefore does not provide a conclusive and significant relationship between oil content and yield.

- A pilot study in the 2020 season found that a 1.5% premium for every percentage of oil content above 38% resulted in premiums of between R793 and R883/tonne and farmers harvested average yields of 2 t/ha. In this scenario, farmers could afford up to 0.3 t/ha yield losses, countering the 1.5% price premium, to achieve a net zero impact on the average SAFEX price.
- A sensitivity analysis for farm-level returns found that i) for an *average yield of 1.5 t/ha and 42% oil content*, the farmer would achieve a 0.025 to 0.15 t/ha "yield flexibility/margin", given various premium levels, while ii) for an *average yield of 2 t/ha and 47% average oil content*, the farmer's "yield flexibility/margin" would range between 0.09 and 0.37 t/ha, depending on premium levels.
- Crushers note that the oil content of locally produced sunflower seed (between 37% and 40% between 2011 and 2020) is substantially lower than the oil content of major global sunflower seed producers, such as Argentina and Ukraine, who typically average 42% and 44% respectively.
- At a local oil content of 34.3% (five-year average), the cost to produce one tonne of crude oil from local seeds will be equivalent to the cost of imported crude oil.
- At a 0% "incentive added on the price", the five-year average crushing margin increases by R145 for each 1% increase in sunflower seed oil content.
- Most silo depots have equipment to measure secondary quality characteristics and use it for weight, moisture content and other measurements for grading. In principle, oil content is another measurement that could be added to the list that is monitored at silo level.
- It is also important to standardise the data representation of both yield and oil content to a set standard of moisture content for direct comparability, e.g. 9%., which is mostly taken as norm. This must be communicated to all parties collecting, reporting on and analysing data representing sunflower seed in South Africa.
- However, the measurement equipment (NMR/NIR) requires thorough calibration processes that currently would not include oil content as a metric to be considered.
- Agbiz Grain, together with the SAGL, has been promoting the widespread adoption of a proficiency scheme whereby a grading ring test for sunflower (and other oilseeds and grains) can be performed on an annual basis. The primary aim is to have a quality-assurance tool for benchmarking against other laboratories, and good-quality results will lead to increased productivity and competitiveness.

6.6. Opportunities for Further Research

- The industry will likely have to look to alternative interventions to provide the catalyst for the needed structural shifts. An increase in the sunflower oil import tariff by 1% or 2% for an interim period to induce shifts in optimal farming practices, investment in new hybrids, introduce more high-oleic varieties and aligning to health benefits and regulations might even assist as non-tariff trade barrier to keep out some of the bad palm oil and can be investigated in future work.
- Cultivar trials – The objective of cultivar trails is first and foremost to test different varieties under the same conditions in order to advise farmers on the best options suited to their specific environment. Although there are one or two varieties that are included as reference types (15 and 10 years in the trials since 2005, which is of particular importance for cross-seasonal analysis and trends), the other cultivars are replaced on a regular basis, based on what the seed companies observe the industry to demand. One recommendation would be to include not only a conventional type as a reference cultivar, but also one for each of the speciality traits. With some additional detailed data capturing of crop management actions, the cultivar trials can deliver a database for statistical analysis beyond that of cultivar recommendations. This can be

used in conjunction with spatial analysis and statistical modelling to identify the best regions for adaptation. Combining information on soil and climate and the coefficients for different genetic traits, mechanistic modelling could be used to identify plausible outcomes using the cultivars under a changing environment (climate change).

- Cultivar trials do not apply management regimes recommended by seed companies based on the genetic strains, but rather create an optimal environment for all cultivars by using hand weeding. Although not processing the same statistically strict layout, strip trials, usually undertaken on larger areas, offer an alternative to conventional trail layout. Strip trials, in which cultivars are treated more in line with conventional farming practices over a number of locations and years, could be used to determine better correlations between seed yield (t/ha), oil content (%), protein content (%) and oil yield (t/ha), as well as to quantify the impact of improved weed control for varieties like Clearfield and Clearfield Plus.
- Little is known of the influence of the different storage conditions on sunflower seed quality in South Africa. A small pilot study could prove useful.
- More in-depth study is needed on the cost of operations between the different methodologies and equipment available to determine oil content. See also the suggested ring test methodology to standardise the calibration of testing equipment.

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8. Appendix

8.1. Appendix A

Fats and oils
29. (1) In relation to fats and oils (single or in combination) which have been used in foods, and additional to the requirements of Regulations 18 and 26-
(a) in the case of vegetable oil blends sold as an end product for sale, the names of all the types of vegetable oils that might be present in the end product shall be listed in the list of ingredients, separated by the expression "and/or";
(b) the names of ingoing fats and oils shall specify from which type of "vegetable", "animal", "fish" or "marine" source the fat or oil originates from, in the list .of ingredients if a conclusion of what the source of the fat or oil is, is not self-evident from the name of the fat or oil;
(c) in the case of vegetable fats and oils, where the oil could be derived from more than one part of the plant, e.g. palm fruit and palm kernel, the particular part of the plant from which the fat or oil is derived, shall be included in the name of the fat or oil;
(d) fats and oils shall, when applicable, be further qualified by the term "hydrogenated";
(e) subject to the requirements of the Regulations Relating to Trans-fat in Foods, where a partially hydrogenated fat/oil is used as an ingredient, and it contains less than 2 g trans-fat per 100 g fat/oil, such fats and oils shall be further qualified by the term "partially hydrogenated".
(f) no pictorial representation of any specific oil such as olive oil in an oil blend, may be depicted on the label unless the type of oil depicted on the label constitutes at least 66% of the oils in the oil blend.

(2) No oil or oil blend from plant origin shall claim "cold extraction", "cold-pressed", "mechanically pressed" or any other words with a similar meaning unless it complies with the definition of "cold extraction" in these regulations.

STAATSKOERANT, 29 MEI 2014

8.2. Appendix B

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES

NO. 45 **22 JANUARY 2016**

AGRICULTURAL PRODUCT STANDARDS ACT, 1990
(ACT No.119 OF 1990)

REGULATIONS RELATING TO THE GRADING, PACKING AND MARKING OF SUNFLOWER SEED INTENDED FOR SALE IN THE REPUBLIC OF SOUTH AFRICA

The Minister of Agriculture, Forestry and Fisheries under section 15 of the Agricultural Product Standards Act 119 of 1990, has

(a) made the regulations in the Schedule;

(b) determined that the said regulations shall come into operation on the date of publication thereof; and

(c) read together with section 3(1) of the said Act, repealed the Regulations published by Government Notice No. R 477 of 20 June 2014.

SCHEDULE

Definitions

1. In these regulations any word or expression to which a meaning has been assigned in the Act, shall have that meaning and, unless the context otherwise indicates--

“animal filth” means dead rodents, dead birds and dung;

"bag" means a bag manufactured from--

(a) jute or phormium or a mixture of jute and phormium; or

(b) polypropylene that compiles with SANS specification CKS632 1246: 2012;

"bulk container" means any vehicle or container in which bulk sunflower seed is transported or stored;

"consignment" means--

(a) a quantity of sunflower seed of the same class, which belongs to the same owner, delivered at any one time under the same consignment note, delivery note or receipt note, or delivered by the same vehicle or bulk container, or loaded from the same bulk storage structure or from a ship's hold; or

(b) in the case where a quantity referred to in paragraph (a), is subdivided into a grade, each such quality of such grade.

"container" means a bag or a bulk container;

"damaged sunflower seed" means sunflower seed or portion thereof which is visibly discoloured as a result of external heat or heating due to internal fermentation;

"foreign matter" means--

(a) loose and empty shells above the sieve that occur in the consignment concerned; and

(b) all matter other than sunflower seed and the achene of sunflower seed above the standard sieve. Coal, dung, glass and metal shall not be present in the consignment at all.

"insect" means any live grain insect that is injurious to stored sunflower seed as well as other grain, irrespective of the stage of development of that insect;

"poisonous seeds" mean seeds or part of seeds of plant species that in terms of the Foodstuffs Cosmetics and Disinfectants Act 64 of 1972, may represent a hazard to human or animal health when consumed, including seeds of *Argemone mexicana L, Convolvulus spp., Crotalaria spp., Datura spp., Ipomoea spp., Lolium temulentum, Ricinus communis or Xanthium spp;*

"sclerotia" means hard masses of fungal tissue produced by fungus *Sclerotinia sclerotioru*m. The sclerotia vary in size and form and consist of a dark black exterior, a white interior and a rough surface texture;

"screenings" means all material that passes through a standard sieve;

"standard sieve" means a slotted sieve--

(a) with a flat bottom of metal sheet of 1,0 mm thickness with apertures 12.7 mm long and 1.8 mm wide with rounded ends (±0.03 mm). The spacing between the slots in the same row must be 2.43 mm wide and the spacing between the rows of slots must be 2.0 mm wide. The slots must be alternately oriented with a slot always opposite the solid inter segment of the next row of slots;

(b) of which the upper surface of the sieve is smooth;

(c) with a round frame of suitable material with an inner diameter of at least 300 mm and at least 50 mm high; and

(d) that fits onto a tray with a solid bottom and must be at least 20 mm above bottom of the tray.

"sunflower seed" means the seed of the plant species of *Helianthus annuus (L); and*

"the Act" means the Agricultural Product Standards Act 119 of 1990.

Restrictions on sale of sunflower seed

2. (1) No person shall sell sunflower seed in the Republic of South Africa--

(a) unless the sunflower seed are sold according to the classes set out in regulation
3
;

(b) unless the sunflower seed comply with the standards for the classes concerned set out in regulation 4;

(c) unless the sunflower seed, where applicable, comply with the grades of sunflower seed and the standards for grades set out in regulation 5 and 6 respectively;

(d) unless the sunflower seed are packed in accordance with the packing requirements set out in regulation 7;

(e) unless the container or sale documents, as the case may be, are marked in accordance with the marking requirements set out in regulation 8; and

(f) if such sunflower seed contains a substance that renders it unfit for human or animal consumption or for processing into or utilisation thereof as food or feed.

(2) The Executive Officer may grant written exemption, entirely or partially, to any person on such conditions as he or she may deem necessary, from the provisions of sub-regulation (1): Provided that such exemption is done in terms of section 3(1) (c) of the Act.

PART I

QUALITY STANDARDS

Classes of sunflower seed

3. Sunflower seed shall be classified as--

(a) Class FH;

(b) Class FS; and

(c) Class Other Sunflower Seed.

Standards for classes of sunflower seed

4. (1) A consignment of sunflower seed shall --

(a) be free from a musty, sour, khaki bush or other undesired odour;

(b) be free from any substance that renders it unsuitable for human or animal consumption or for processing into or utilisation as food or feed;

(c) not contain more poisonous seeds than permitted in terms of the Foodstuffs, Cosmetics and Disinfectants Act 54 of 1972;

(d) shall be free from stones, glass, metal, coal or dung;

(e) with the exception of Class Other Sunflower seed, be free from insects;

(f) with the exception of Class Other Sunflower seed, have a moisture content of not more than 10 percent; and

(g) be free from animal filth.

(2) A consignment of sunflower seed shall be classified as --

(a) Class FH if it--

(i) consist of at least 80 percent (m/m) sunflower seed of a cultivar with a high oil content; and

(ii) complies with the standard for Grade 1 set out in regulation 6.

(b) Class FS if it--

(i) consist of at least 80 percent (m/m) sunflower seed of a cultivar with a low oil content; and

(ii) complies with the standards for Grade 1 set out in regulation 6.

(c) Class Other Sunflower Seed if it does not comply with the requirements for Class FH or Class FS.

Grades for sunflower seed

5. (1) There is only one grade for the Classes FH and FS Sunflower Seed, namely Grade 1.

(2) No grades are determined for Class Other Sunflower seed.

Standards for grades of sunflower seed

6. A consignment of Grade 1 sunflower seed shall be graded as Grade 1 if the nature of deviation, specified in column 1 of Table 1 of the Annexure, in that consignment does not exceed the percentage specified in column 2 of the said table opposite the deviation concerned.

PART II

PACKING AND MARKING REQUIREMENTS

Packing requirements

7. Sunflower seed of different classes and grades shall be packed in different containers or stored separately.

Marking requirements

8. Every container or the accompanying sale documents of a sunflower seed shall be marked or endorsed with the class and, where applicable, the grade of the sunflower seed.

PART III

SAMPLING

Obtaining a sample

9. (1) A representative sample of a consignment of sunflower seed shall--

(a) in the case of sunflower seed delivered in bags and subject to regulation 10, be obtained by sampling at least 10 percent of the bags, chosen from that consignment at random, with a bag probe: Provided that at least 25 bags in a consignment shall be sampled and where a consignment consists of less than 25 bags, all the bags in that consignment shall be sampled; and

(b) in the case of sunflower seed delivered in bulk and subject to regulation 10, be obtained by sampling that consignment throughout the whole depth of the layer, in at least six different places, chosen at random in that bulk quantity, with a bulk sampling apparatus.

(2) The collective sample obtained in sub-regulation (1) (a) or (b) shall--

(a) have a total mass of at least 5 kg; and

(b) be thoroughly mixed by means of dividing before further examination.

(3) If it is suspected that the sample referred to in sub regulation (1)(a) is not representative of that consignment, an additional five percent of the remaining bags, chosen from that consignment at random, shall be emptied into a suitable bulk container and sampled in the manner contemplated in sub regulation(1)(b).

(4) If it is suspected that the sample referred to in sub-regulation (1) (b) is not representative of that consignment, an additional representative sample shall be obtained by using an alternative sampling pattern, apparatus or method.

(5) A sample taken in terms of these regulations shall be deemed to be representative of the consignment from which it was taken.

Sampling if contents differ

10. (1) If, after an examination of the sunflower seed taken from different bags in a consignment in terms of regulation 9(1), it appears that the contents of those bags differ substantially--

(a) the bags concerned shall be separated from each other;

(b) all the bags in the consignment concerned shall be sampled in order to do such separation; and

(c) each group of bags with similar contents in that consignment shall for the purpose of these regulations be deemed to be separate consignment.

(2) If, after the discharge of a consignment of sunflower seed in bulk has commenced, it is suspected that the consignment could be of a class or grade other than that determined by means of the initial sampling, the discharge shall immediately be stopped and that part of the consignment remaining in the bulk container, as well as the sunflower seed already in the collecting tray, shall be sampled anew with a bulk sampling apparatus or by catching at least 20 samples at regular intervals throughout the whole off loading period with a suitable container from the stream of sunflower seed that is flowing in bulk.

Working sample

11. (1) A working sample of sunflower seed shall be obtained by dividing the representative sample of the consignment according to the latest revision of the ICC (International Association for Science and Technology) 101/1 method.

PART IV

INSPECTION METHODS

Determination of undesired odour, harmful substances, poisonous seeds, stones, glass, metal, coal, dung, insect and animal filth

12. A consignment or sample of a consignment shall be assessed sensorially or chemically analysed in order to determine whether it--

(a) has a musty, sour, khaki bush or other undesired odour;

(b) contains a substance that renders it unsuitable for human or animal consumption or processing into or utilization thereof as food or feed;

(c) contains poisonous seeds;

(d) contains stones, glass, metal, coal or dung;

(e) contains any insects; and

(f) contains animal filth.

Determination of moisture content

13. The moisture content of a consignment of sunflower seed may be determined according to any suitable method: Provided that the result thus obtained is in accordance with the maximum permissible deviation for a class 1 moisture meter as detailed in ISO 7700/2, based upon result of the 3 hour, 103°C oven dried method [the latest revision of the AACCI ("American Association of Cereal Chemists International") Method 44-15].

Determination of percentage screenings

14. The percentage screenings in a consignment of sunflower seed is determined as follows:

(a) Obtain a working sample of at least 50g from a representative sample of the consignment.

(b) Place the sample on a standard sieve; screen the sample by moving the sieve 50 strokes to and fro, alternately away from and towards the operator of the sieve, in the same direction as the long axes of the slots of the sieve. Move the sieve, which rests on a table or other suitable smooth surface, 250 mm to 460 mm away from and towards the operator with each stroke. The prescribed 50 strokes must be completed within 50 to 60 seconds: Provided that the screening process may also be performed in some or other container or an automatic sieving apparatus.

(c) Determine the mass of the material that has passed through the sieve and express it that as a percentage of the mass of the working sample.

(d) Such percentage represents the percentage screenings in the consignment.

Determination of percentage foreign matter

15. The percentage foreign matter in a consignment of sunflower seed shall be determined as follows:

(a) Obtain a working sample of at least 20g of a screened sample.

(b) Remove all foreign matter by hand and determine the mass thereof.

(c) Express the mass thus determined as a percentage of the mass of the working sample.

(d) Such a percentage represents the percentage foreign matter in the consignment.

Determination of percentage sclerotia

16. The percentage sclerotia in a consignment of sunflower seed is determined as follows:

(a) Remove all sclerotia in the working sample in 15(a) obtained by hand and determine the mass thereof.

(b) Express the mass thus determined as a percentage of the working sample in regulation 15(a) obtained.

(c) Such a percentage represents the percentage sclerotia in the consignment.

Determination of percentage sunflower seed of another class

17. The percentage sunflower seed of another class in a consignment of sunflower seed shall be determined as follows:

(a) Obtain a working sample of at least 20g from a screened sample free of foreign matter and sclerotia.

(b) Remove all sunflower seeds of another class from the working sample by hand and determine the mass thereof.

(c) Express the mass thus determined as a percentage of the working sample.

(d) Such a percentage represents the percentage sunflower seed of another class in the consignment.

Determination of the percentage damaged sunflower seed

18. The percentage damaged sunflower seed in a consignment of sunflower seed, shall be determined as follows:

(a) Obtain a working sample of at least 20 g from a screened sample free of foreign matter and sclerotia.

(b) Shell the seed in the working sample by hand or with a machine so that nucleus portions thereof are retained.

(c) Remove all damaged sunflower seed from the quantity thus shelled and determine the mass thereof.

(d) Express the mass thus determined as a percentage of the working sample.

(e) Such a percentage represents the percentage damaged sunflower seed in the consignment.

PART V

MASS DETERMINATION

19. The mass of sunflower seed shall be determined by deducting the actual percentage sclerotia, screenings and foreign matter found during the inspection process from the total mass of the consignment: Provided that the weighing instruments used for the determination of mass shall comply with the requirements of SANS 1649:2001 published in terms of the Trade Metrology Act 77 of 1973 for the specific class of instrument.

PART VI

OFFENCE AND PENALTIES

20. Any person who contravenes or fails to comply with any provision of these regulations shall be guilty of an offence and upon conviction be liable to a fine or imprisonment in terms of section 11 of the Act.

ANNEXURE

TABLE 1

STANDARDS FOR GRADES OF SUNFLOWER SEED

<table>
<tr><th rowspan="3" colspan="2">DEVIATIONS</th><th colspan="2">Maximum permissible deviations</th></tr>
<tr><th>Class FH</th><th>Class FS</th></tr>
<tr><th colspan="2">Grade1</th></tr>
<tr><td>1.</td><td>Damaged sunflower seed</td><td colspan="2">10%</td></tr>
<tr><td>2.</td><td>Screenings</td><td colspan="2">4%</td></tr>
<tr><td>3.</td><td>Sclerotia</td><td colspan="2">4%</td></tr>
<tr><td>4.</td><td>Foreign Matter</td><td colspan="2">4%</td></tr>
<tr><td>5.</td><td>Deviation in 2,3 and 4 collectively: Provided that such deviations are individually within the limits of said items.</td><td colspan="2">6%</td></tr>
</table>

8.3. Appendix C

1. Review of Environmental and Management Factors Influencing Sunflower Seed Quality

1.1. Setting the Scene

One of the chevets eluded to throughout the document is the large impact environmental factors have on sunflower seed production. In order to put this into a South African context a literature search was conducted, which is summarised in Table 19 and with the full list presented in Appendix D.

The two pieces that stood out that had the biggest relevance to the current study on seed quality for processing were the thesis of Nel (2002), *Determinants of sunflower seed quality for processing*, and the associated articles and the one by van der Merwe 2011 on *Genotype by environment interaction for oil quality in high oleic acid sunflower lines*.

Table 19 Analysis of literature available referring to sunflower seed in South Africa

Topic	Number of Articles	First year published	Last year published
Agronomy	36	1978	2019
Breeding	15	1985	2019
Economic	7	2001	2015
Oil Yield	6	1998	2020
Other	6	1981	2014
Plant Protection	38	1980	2020
Seed Quality for Processing	9	1999	2002
Grand Total	117	1978	2020

It, however, stays important the highlight the agronomic factors that influence sunflower seed quantity and quality as these all interact with each other.

1.2. Planting Date

To better understand the effect of planting date on yield and oil content (%) and yield t/ha and protein content (%), each of the growth stages must be carefully considered:

- planting to floral initiation (GS1),
- floral initiation to bloom (GS2); and
- bloom to physiological maturity (GS3) (Figure 35).

The yield components of sunflower namely, heads per hectare, number of seeds per head, weight per seed and seed oil content are determined during these phases.

GS1: planting to floral initiation
This begins when the seed is planted and ends when the floral parts of the sunflower are initiated. Floral initiation cannot be observed directly; it occurs between the 10-leaf and 14-leaf stages. In GS1, sunflower is at its most delicate and is highly sensitive to stress. Fortunately, stress occurring during this period has little effect on yield. The plant must remain alive only to maintain the yield component of heads/ha.

GS2: floral initiation to bloom
Although the start of this growth stage is not readily recognisable, it determines the final yield. The floral parts, which later become the harvested seeds, are formed during this phase. After the seeds are initiated, they expand to form the visible bud and, eventually, the sunflower head, which blooms and thus completes GS2. The head size, or the number of seeds per head, is established during this stage. Any stress that limits growth rate during GS2 will result in a reduced number of seeds per head. Drought stress during this stage reduces yield more than at any other phase of sunflower development.

GS3: bloom to physiological maturity
The final stage of development begins when flowering is completed, and the plant reaches physiological maturity. During GS3, seed size and weight are determined. As physiological maturity approaches, the sunflower can utilise progressively lower temperatures for seed growth, while also becoming increasingly drought-tolerant. Stress during GS3 can reduce yield, but not usually to the same extent as the reduction during GS2, as seed weight is a relatively smaller contributor to yield than seed number under most conditions.

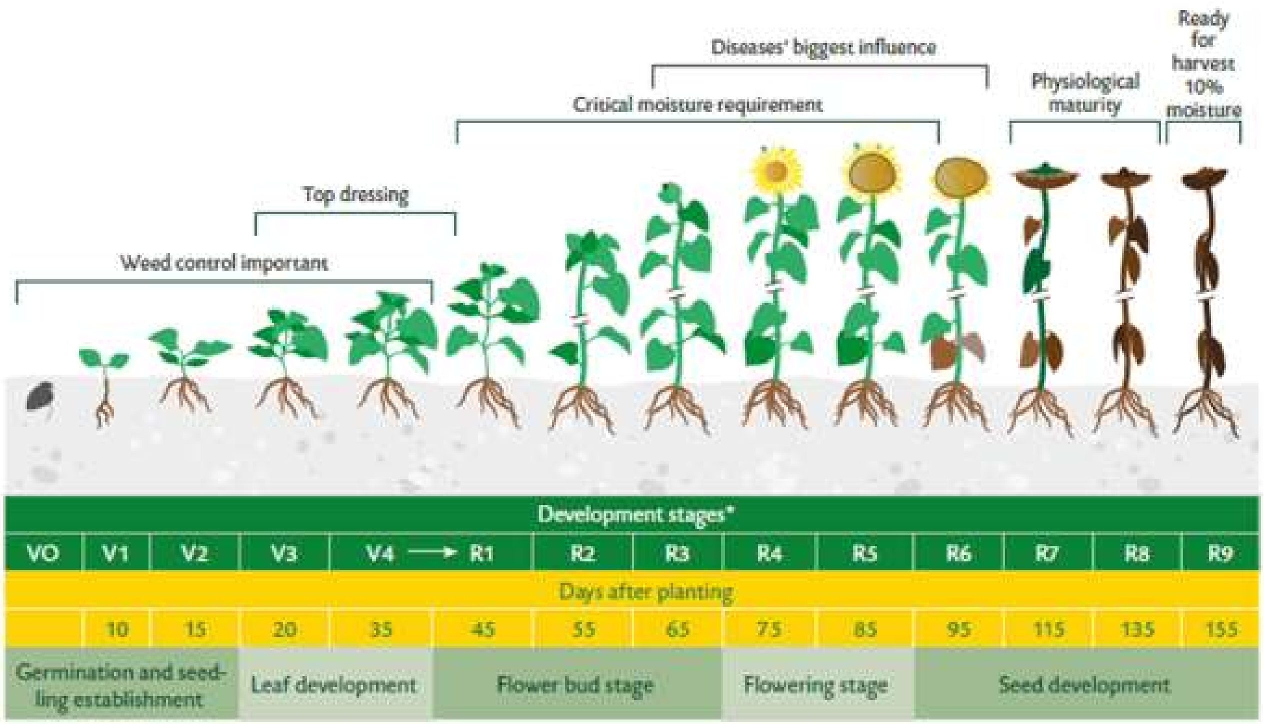


Figure 35 Growth stages of sunflower seed, source: Pannar,2020

Normally, sunflower seed is planted from the beginning of November to the end December in the eastern areas, and until mid-January in the western areas. When choosing the most favourable planting date several factors must be considered. These include the first date of frost, soil temperature, the moisture requirements of the crop, rainfall distribution, previous crop cultivated, and the danger of bird damage. The most important factor is however the outlook for the season in terms of rainfall.

High soil temperatures during planting time may cause poor germination. This is often a problem in the warmer western production regions with sandy soils, that lead to a poor plant density which ultimately leads to a reduced production. Planting in these regions should preferably be before mid-November when the soil temperature is not so high yet, or when a period of cooler weather is expected.

For quick and uniform germination sunflower should only be panted after enough rain was received. Because sunflowers are relatively sensitive to drought stress just before or during flowering, plating dates should be adjusted so that the flowering time coincides with a period with a good chance of rain. Another critical stage is at harvest time, when the soil should be relatively dry and no rain should fall, so that the seed can day quickly and harvesting progress with minimum seed loss. To minimize the effect of bird damage, farmers in a region should try and plant at the same time so that birds at pre harvest do not have the option to feed on only one field (du Toit *et al.*, n.d).

It is also important to adjust planting dates according the cultivars growth season length. Spreading planting dates on a farm may also insure that, if there are adverse weather conditions, the whole crop on the farm is not affected.

In South Africa, the adverse effects of the wrong planting dates have been trailed and propagated to producers and those who have adapted to guidelines of optimal cropping practices have achieved improvement in yields. It seems that sunflower hybrids currently available in the local market do have the genetic potential to produce higher yields that are more in line with the international trends. This fact is underlined by the average yields obtained in the cultivar trails trials across various provinces (Meyer and Van der Burgh, 2015).

1.2.1. Effect of Planting Date on Yield

To evaluate the effect of planting dates on seed production, data from 38 national sunflower cultivar trials planted by ARC-GCI in Potchefstroom for the past 10 cropping seasons was analyzed (considering three separate planting date ranges, viz. 1 to 30 November, 1 to 30 December and 1 to 30 January) (Ma'ali, 2017). The results indicated that seed yield was reduced by approximately 0,21t/ ha for each 30-day delay in planting after November (Figure 36). Similar results were found by de Vos *et al.* (1985)

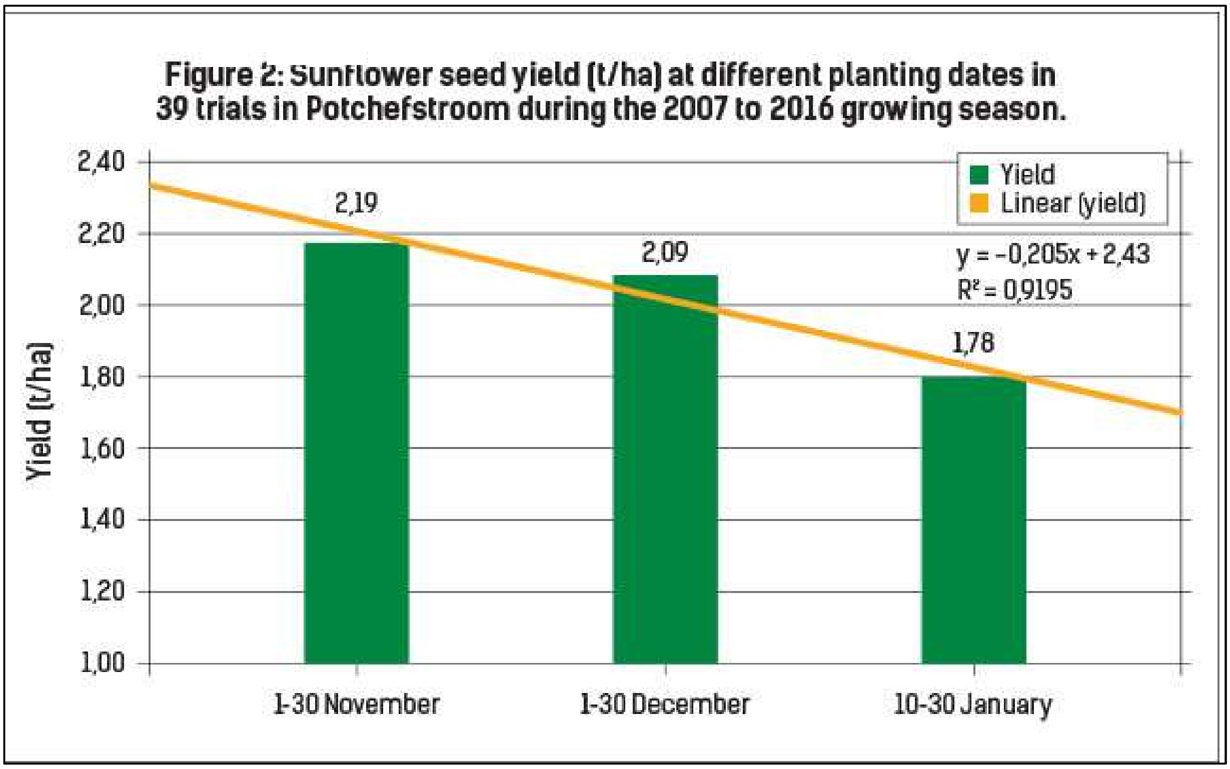


Figure 36 Sunflower seed yield (t/ha) at different planting dates in 39 trials in Potchefstroom (2007-2016)

Using data from cultivar trials for the period 2012 to 2019, averaged over all cultivars and locations, indications are that optimum yields could be achieved with planting dates from 15 November to 15 December (Figure 37). The spread of the data however indicates that in some season late plantings did not affect yield negatively. However, plantings before 1 November and especially after 15 January should be avoided as these tend to have consistently lower yields.

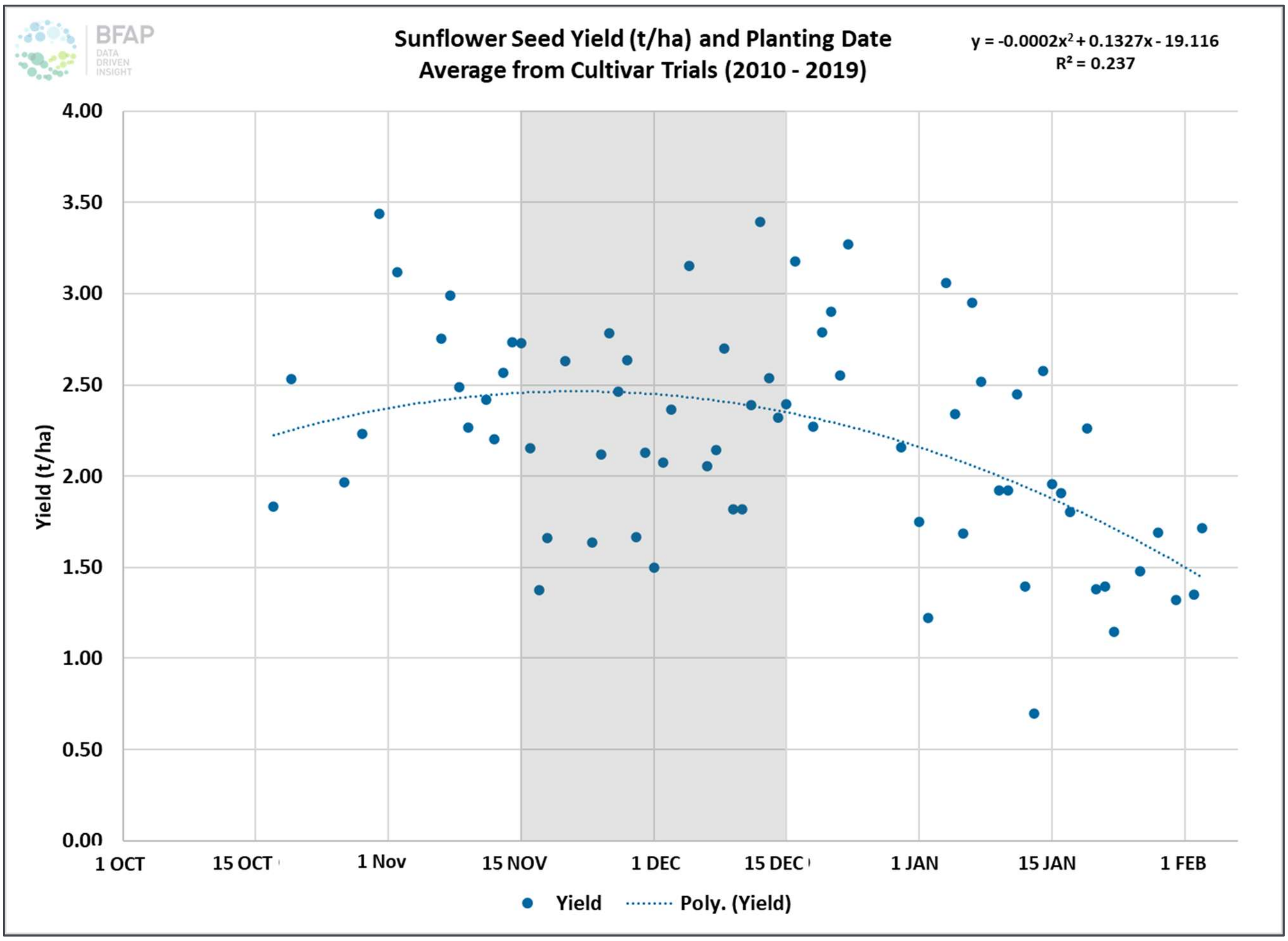


Figure 37 The effect of planting date on sunflower seed yield (t/ha) based on data from the national cultivar trials for the period 2010 -2019 with the grey area indication optimum planting dates for sunflower seed in South Africa

1.2.2. Effect of Planting Date on Oil Content and Fatty Acid Composition

Different planting dates and water regimes cause different environmental conditions during seed-filling and oil synthesis of sunflower seed and therefore a possible alteration in oil content and fatty acid composition of the seed (Flagella *et al.*, 2002). Different planting dates may cause flowering and seed development to occur during periods of widely different temperatures, radiation, day length and soil water availability. According to Seiler (1983) both oleic and linoleic acid concentrations of the oil of cultivated sunflower were significantly related to total solar radiation and day length.

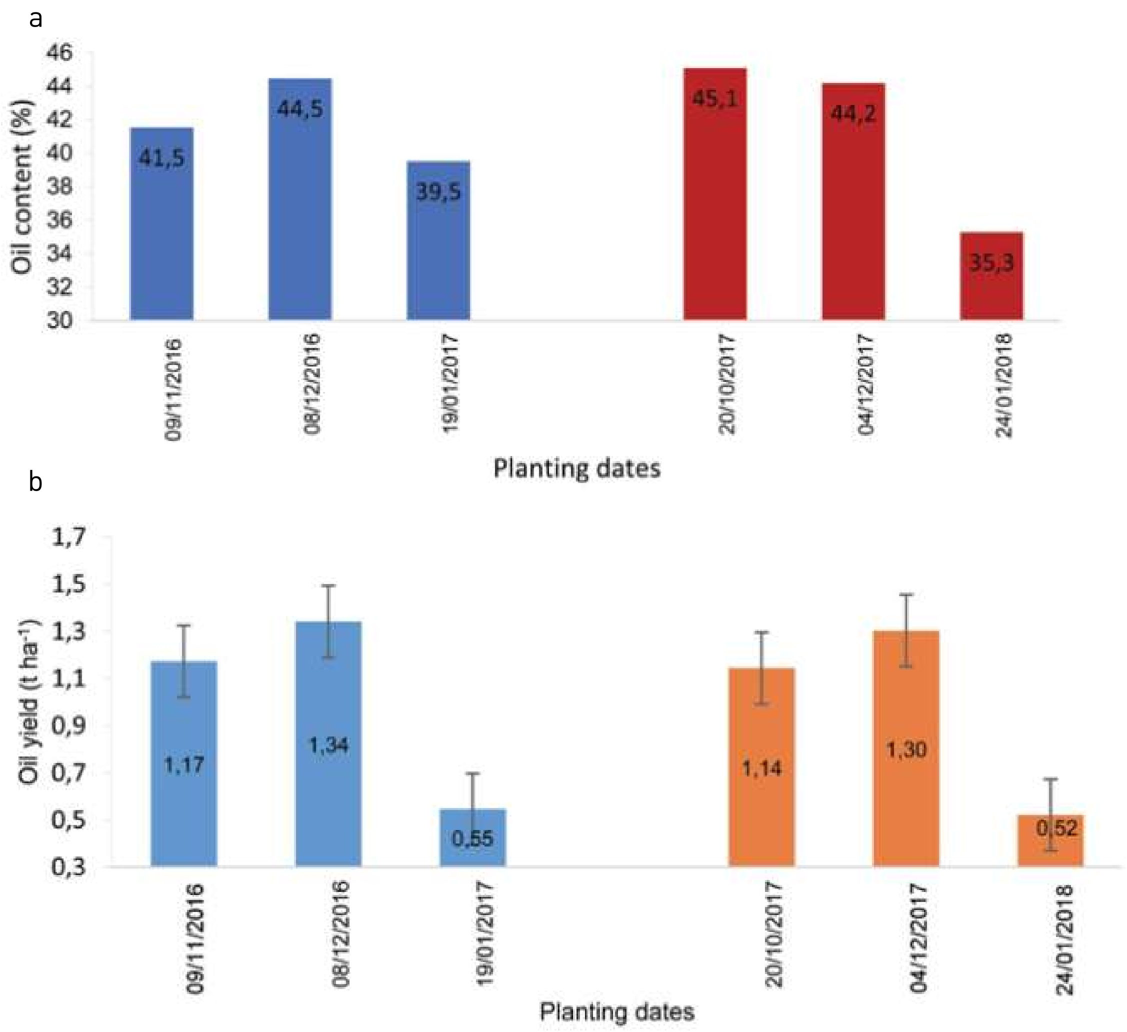
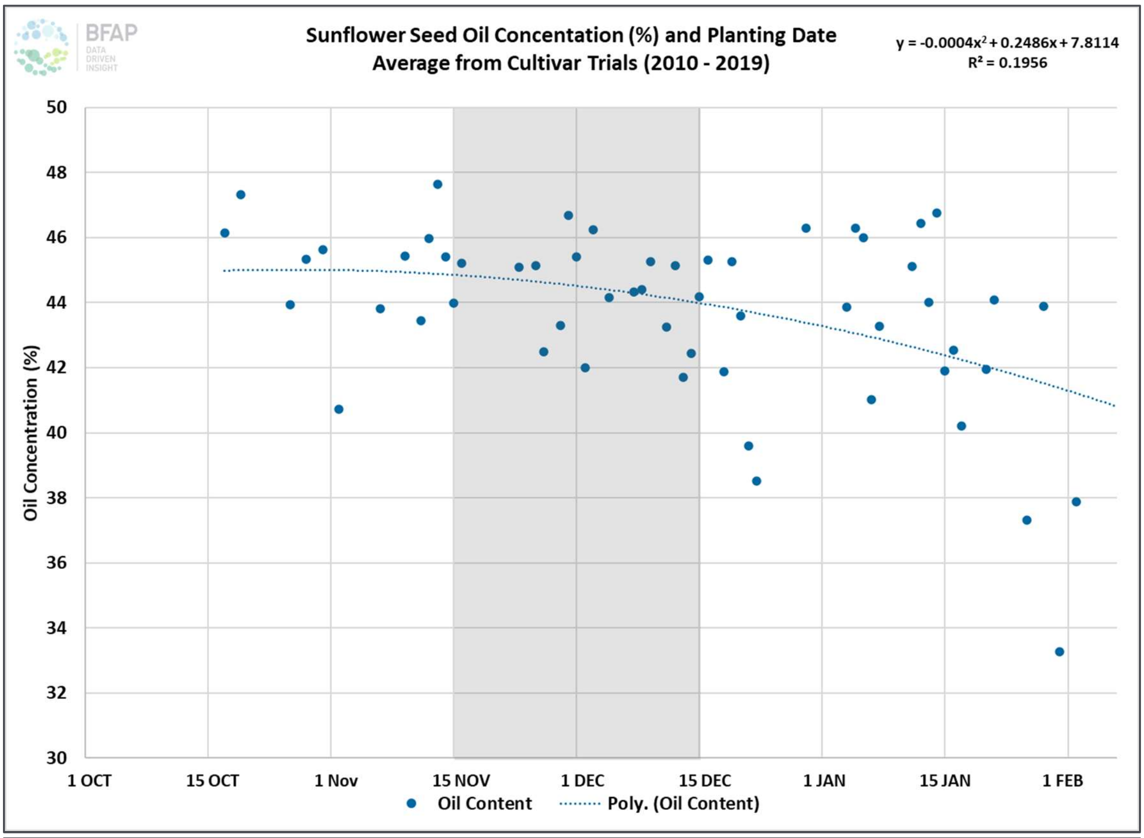


Figure 38 Oil content (%) (a) and oil yield (t/ha) (b) at Potchefstroom with different planting dates for the 2016 to 2018 growing seasons (Source: Ma'ali, 2019a)

Figure 38 indicates that for Potchefstroom late plantings have an adverse effect on oil content (%) and oil yield (t/ha) (Ma'ali, 2019a). Late planting (last week of January) reduced the oil content by 5% in 2016/2017 and by 10% during in 2017/2018 growing season. For oil yield (t/ha) (Figure 38 b), the late planting date (end of January) resulted in a 62% reduction in oil yield during both growing seasons.

Analysing the impact of different planting dates on sunflower seed oil content (%) and oil yield (t/ha) based on the cultivar trails from 2010 to 2019 reveals the same polynomial trend (Figure 39 a and b). Early and late planting dates have an adverse effect on the sunflower seed oil concentration (%) and oil yield (t/ha).

a



b

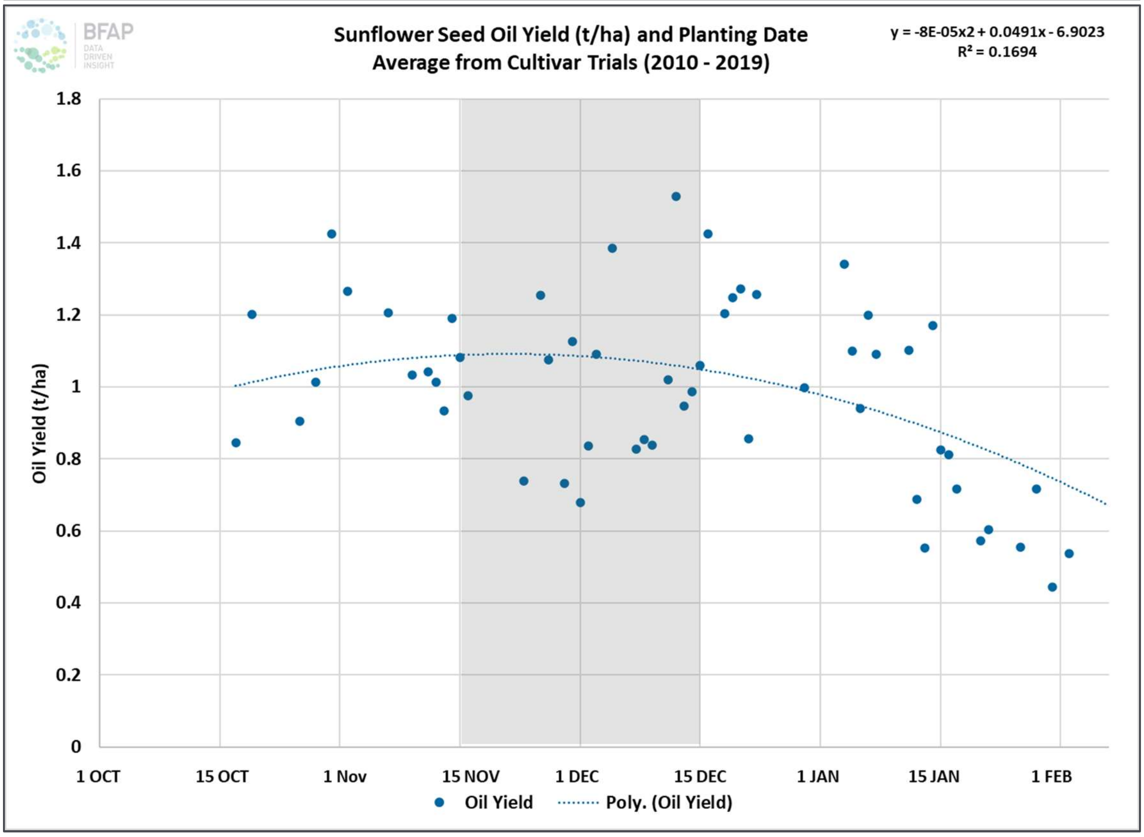


Figure 39 The effect of planting date on (a) oil concentration (%) and (b) oil yield (t/ha) based on data from the national cultivar trials for the period 2010 -2019 with the grey area indication optimum planting dates for sunflower seed in South Africa

Thus, in seasons with late rainfall and where the higher value crops such as maize and soybeans are planted first, sunflower plantings are deferred to the later dates which are often in January. Subsequently both yields and the oil content of the seed is low.

As from the 1970s, breeders have been developing high oleic type sunflower seed cultivars (Soldatov, 1976; Hardin, 1998; Kleingartner, 2002; Vick *et al.*, 2003; Burton *et al.*, 2004; Vick *et al.*, 2007; Skoric *et al.*, 2008. However, it has been found that some of these hybrids had reduced oil content relative to the traditional sunflower seed varieties. It is known that the fatty acid composition varies by genotype and by environmental conditions (Connor and Sadras, 1992). Because of this, knowing how, and in which situation, oil crops differ in fatty acid composition is very significant for oil quality (Zheljazkov, 2009). Thus, the cultivars suitable for the desired oil types must be cultivated in appropriate regions. For example, in a study by Popa *et al.*, 2013, a delay in planting decreased the concentration of oleic acid and increased linoleic acid concentration in all sunflower hybrids, except one hybrid, which was more stable in this regard.

Van der Merwe (2010) studied the genotype by environment effect for oil quality in high oleic acid sunflower lines. High and mid oleic acid sunflower hybrids, together with two traditional sunflower hybrids, were planted in field trials and these were analysed for variance across locations and years. Significant differences were observed between measured traits for the high and mid oleic, and traditional sunflower genotypes. Additionally, genotypes responded differently between locations and years and environmental conditions had a large influence on the performance of genotypes.

An almost linear association between sunflower seed yield and rainfall was observed. Generally, sunflower seed and oil yield decreased in locations and years with lower rainfall. However, too much rain was found to also lower yield and oil content and could be ascribed to low radiation (because of the cloudy weather) and/or waterlogging conditions. Waterlogging has a direct effect on a range of physiological processes such as respiration and photosynthesis. Under waterlogging the plant shuts down its stomata in order to reduce transpiration as a survival mechanism. Consequently, plant growth and seed development are restricted that may result in lower seed set Van der Merwe (2010).

With regards to linoleic and oleic acid content the standard linoleic genotypes yielded as expected. However, the high oleic genotypes showed differences in their response to oleic and linoleic acid contents among different trials. Van der Merwe (2010) found that from the eight high oleic genotypes tested, only one genotype was stable across region, whilst the other has variable linoleic to oleic fatty acid ratios. Van der Merwe (2010) found that the most important environmental effects that had an influence on the performance of the genotypes for oil content and fatty acid composition were rainfall, temperature and planting date. Higher oil yields were observed in environments that received more rain during the growing season. Rainfall also had a significant influence on the fatty acid profiles and especially the oleic and linoleic acid contents. Genotypes grown in drier and warmer environments showed higher oleic and lower linoleic acid contents than those grown in environments that higher rainfall had lower temperatures during the growing season. Different planting dates caused flowering and seed development to occur during periods of widely different temperatures, radiation and day length. The highest oleic acid content was observed for early plantings when seed maturation occurred during high mean daily temperatures. Later plantings caused seed maturation to occur when the mean daily temperatures were lower. As a result, genotypes showed higher linoleic acid contents in later plantings.

The results from van der Merwe's trials reiterated results by de Vos *et al.* (1985) who, for a single season (1983/84) found that large differences in seed yield occurred between planting dates and this was found to be related to moisture stress during flowering. Fatty acid composition of the seed oil was related to temperature during the seed filling stage and and moisture stress during flowering.

1.3. Plant Population (Planting Density)

Optimum density and row spacing depend on the environmental conditions during the crop cycle, management practices, and hybrid response. The optimum plant density in sunflower is influenced by several factors such as temperature, soil fertility, water availability, and genotype (Diepenbrock *et al.*, 2001; Villalobos *et al.*, 1994). However, in a given environment, the high plasticity of sunflower allows it to obtain the maximal yield in a wide range of plant populations. For example, it was found that for the 2019/20 season sunflower seed planted at a density of 23 000 plants/ha that is the recommended planting density of the area of the North West province only yield 0.3 tonnes less that sunflower panted at double the density of 46 000 plants/ha (Ferdi Meyer, personal communication). Sunflower seed's seed size and generally oil content decrease with an increase in plant density. (Esendal and Kandemir 1996). As seed size is also directly related to hullability and the production of fine material, hullability and oil cake quality may be indirectly affected by the plant population.

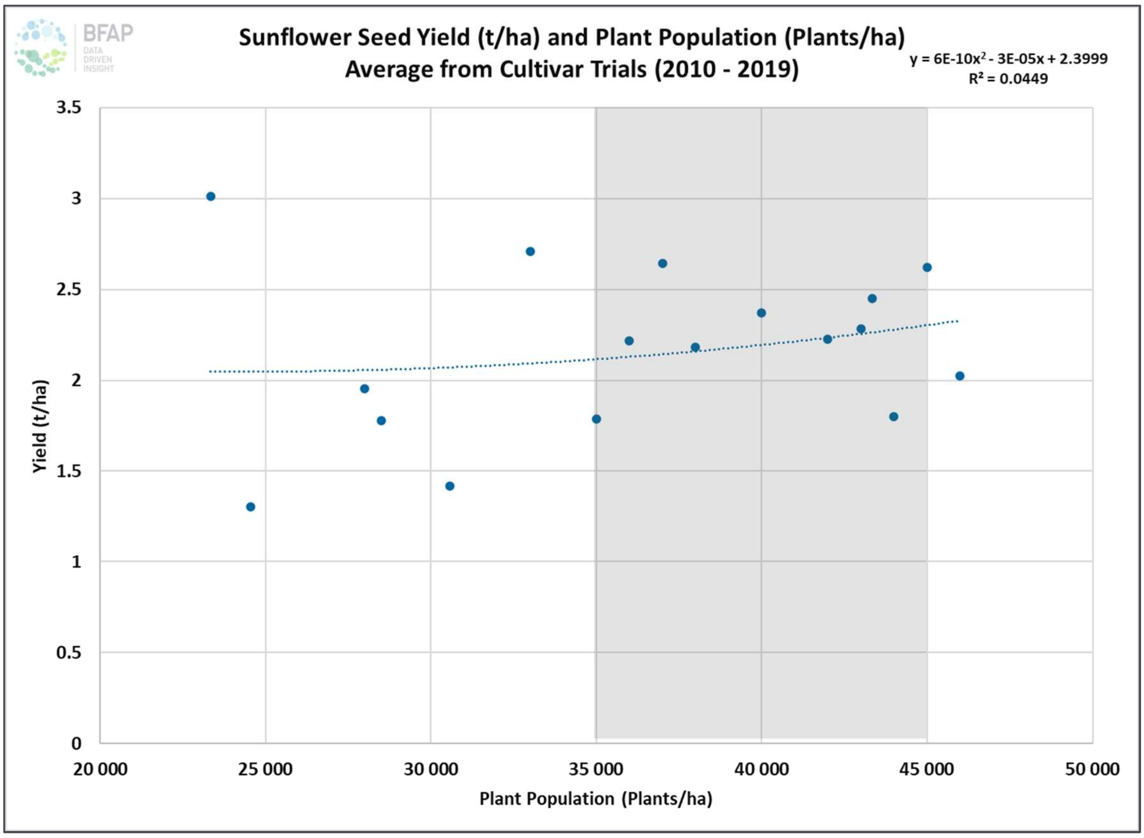
Nel et al (2000a) studied the effect of differences in plant population (20 000, 35 000 and 50 000 plants/ha) on the quality of sunflower seed for processing. They found that the highest grain yield was obtained at the 20 000 population. This was however in contrast with the results of Loubser *et al.* (1986) who found that 20 000 plants/ha yielded significantly less than 40 000 or 60 000 plant/ha under high potential conditions. In Nel's (2000) trials intense water stress occurring during the first 7 days of the grain filling stage, most likely affected these yields. Sadras and Hall (1988) found that plants in plant populations of 20 000 plants/ha have a smaller leaf area index than plants plated to a population of 35 000 or 50 000 plants/ha. Thus, the higher yields at a plant population of 20 000 plants/ha were due to a slower rate of depletion of the soil water due to a smaller transpiring area (Nel *et al*. 2000a). Water stress may therefore have been less severe in the 20 000 than in the higher plant populations.

According to Villalobos *et al.* (1996) growth of the hull is completed within two weeks after anthesis. Nel *et al.* (2000b) found that at a population of 20 000 plants/ha seed had a significantly higher hull content and hullability than the 35 000 and 50 000 plants/ha populations as the stage of hull development coincided with the stress period. Baldini and Vannozzi (1996) and Merrien *et al.* (1992) found that seed produced on plots which received irrigation frequently hulled easier than seed produced on plots less often irrigated. Nel *et al*. (2000b) thus concluded that that for dryland sunflower production in South Africa the plant population should rather be closer to 20 000 plants/ha than to 40 000 plants/ha. This would maximise hullability and minimise losses due to fine material, without affecting the oil and protein content of the seed.

In general, the recommendation for South Africa is a plant population of 35 000 to 55 000 plants/ha (Pannar, 2020). The lower plant population is recommended for areas with a low rainfall together with a wide row spacing, whilst under high potential conditions higher plant population at narrow row spacing is recommended. Sunflower plants can compensate for low plant population through head size and number of seed per head, but plant population lower than 20 000 plants/ha give no advantage. Uneven spacing's and low plant populations are undesirable as they result in excessively large heads which may cause the plants to lodge before harvesting and uneven ripening. On the other hand, it was found that populations of more than 45 000 plants/ha, even under irrigation, do not have any yield advantage. Excessively high plant populations may even result in small heads with a poor kernel development (Du Toit, *et al.*, u.d).

The plant population found in the cultivar trials ranged from 23 000 to 46 000 plants/ha. Both for yield (t/ha) and protein content (%) the cultivar trails did not show any clear indication of a positive or negative effect of plant population. However, for sunflower seed oil content (%) there was a clear significant curvilinear relationship between plant population and oil content, with an indication of the highest oil content to be achieved at plant populations between 30 000 and 37 000 plants/ha. A similar but not as distinct relationship was found for oil yield (t/ha) indicating high oil yields for plant populations between 35 000 and 45000 plants/ha. Thus, cultivar recommendations of 35 000 plants/ha seem to favour seed yield and oil yield (t/ha) and less the oil content (%), where maximum oil content may be attained with planting densities of between 30 000 to 35 000 plants/ha. Producers' focus is mainly to maximise yields and plant populations are recommended accordingly. However, if the focus were to shift to maximising both yield and oil content, farmers may benefit by planting at slightly lower plant populations which also may have a positive effect on hullability.

a



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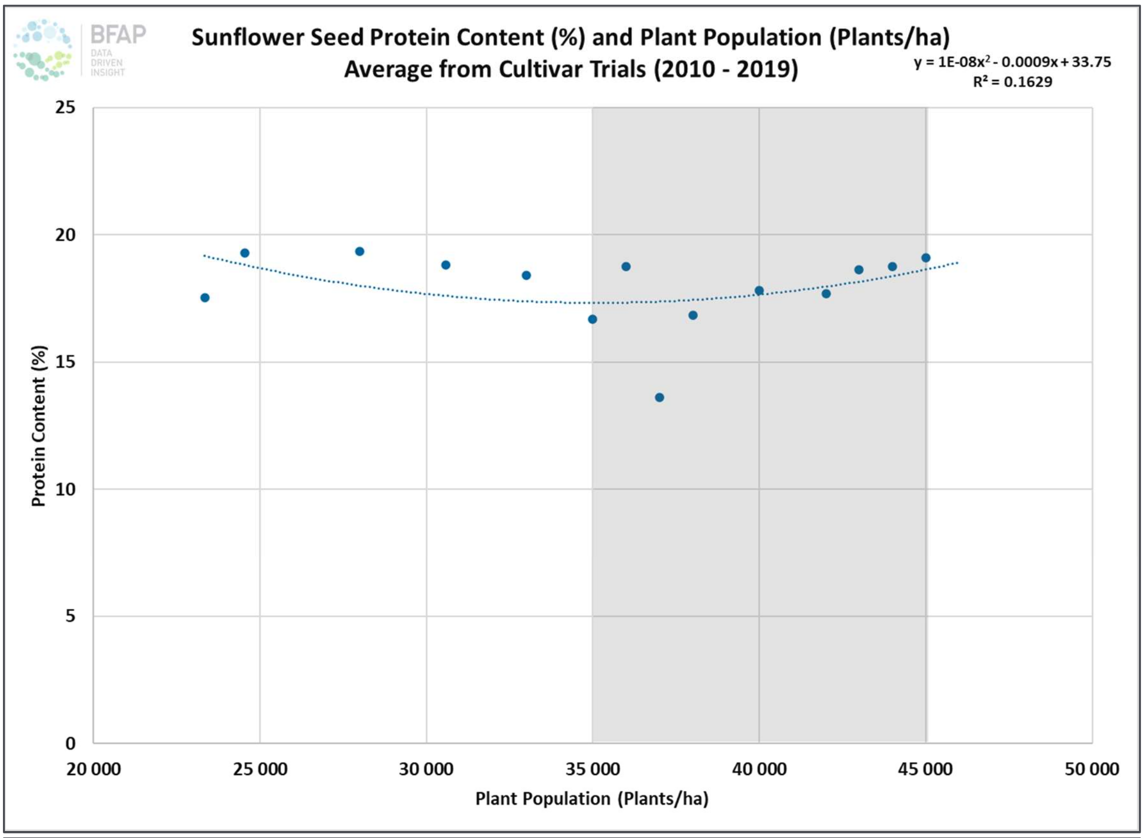

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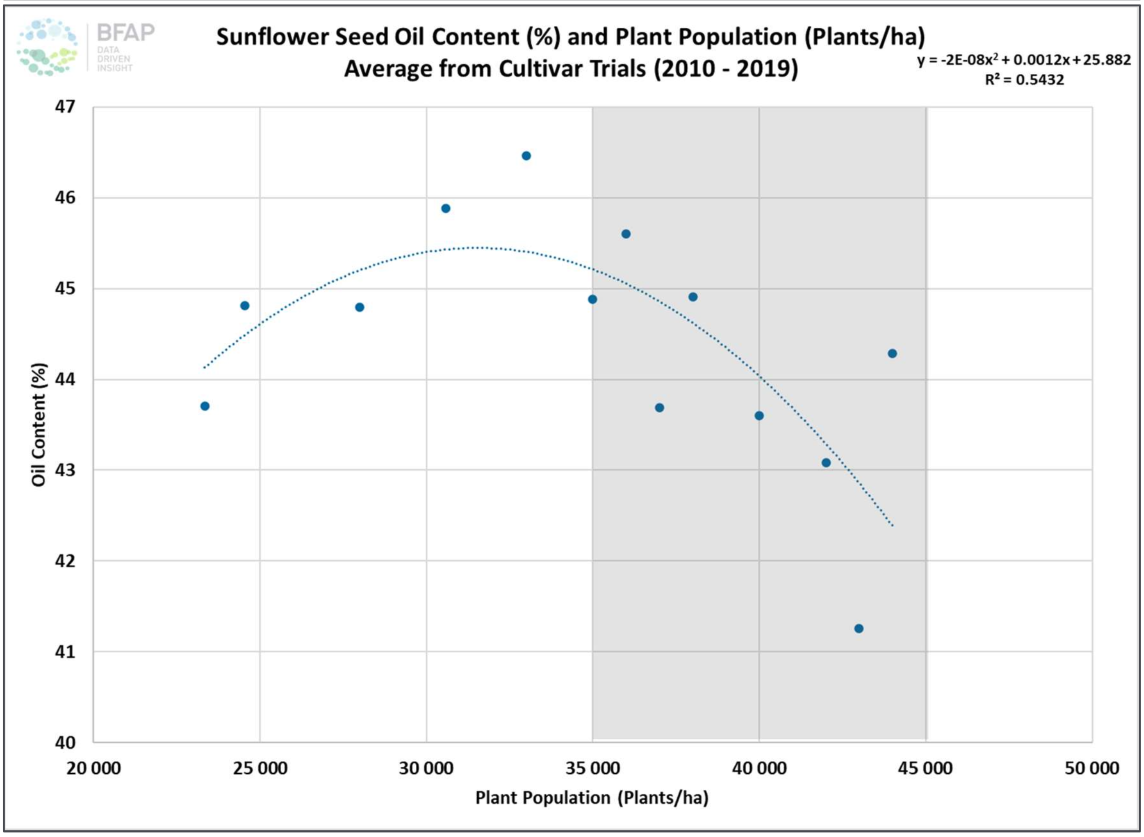

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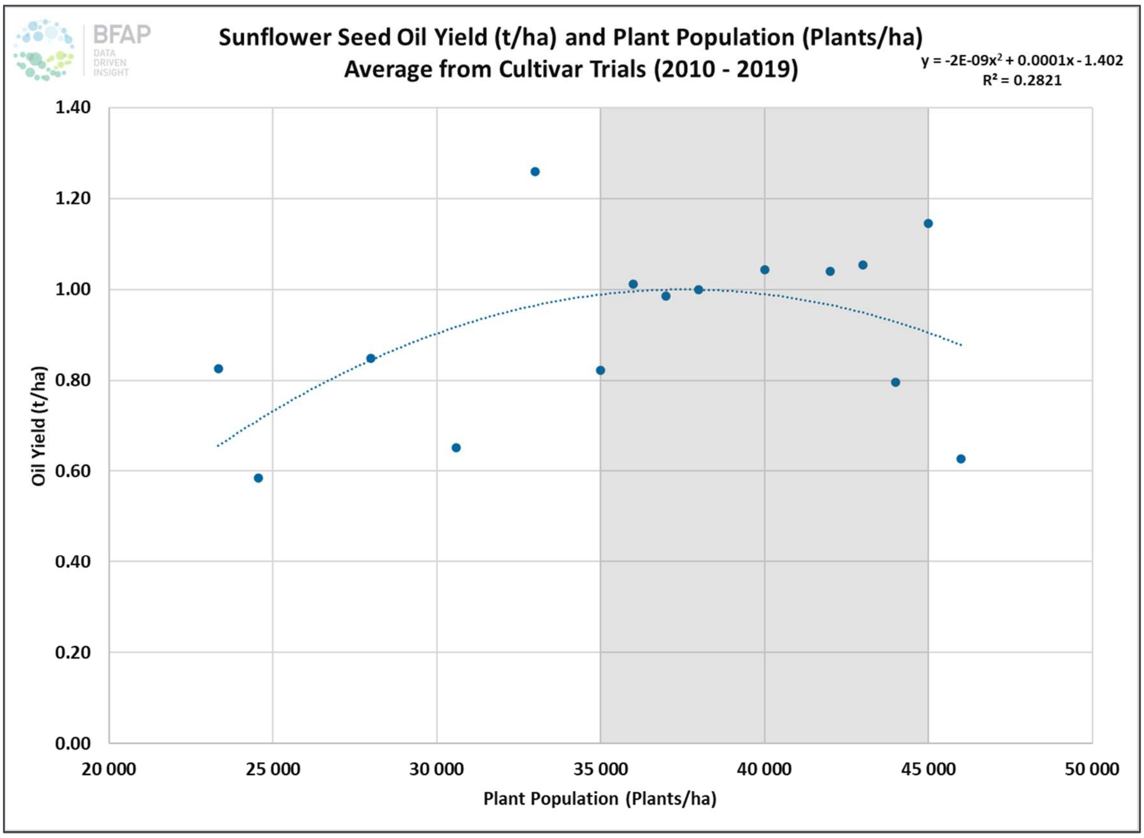


Figure 40 Effect of plant population on a) yield (t/ha) b) protein concentration (%), c) oil content (%) and d) oil yield (t/ha) of sunflower seed for the cultivar trials 2010 – 2019 averaged over all years, cultivars and locations

1.3.1. Temperature

The optimum growing temperatures for growing sunflower seed are 18 - 25°C; sub-optimally the range is 13 - 30°C. Mean January temperatures should exceed 19°C (Smith, 1998). To complete its growth cycle, sunflowers need 1 500 heat units with a base of 7°C and an upper limit of 30°C. They are frost and high humidity susceptible and thrive best at mean temperature around 22°C. As a rule of thumb each 1°C increase decreases oil content by 1.5% (Schulze,2007). Some of the main effects of temperature on the growth and development of sunflower seed have been eluded to in the previous two sections.

1.3.1.1. Temperature Effects on Germination and Seedling Vigour

Temperature, and especially soil temperature, influences sunflower seedling vigour. In the summer rainfall region of South Africa, the daily maximum temperature in the upper 20 mm of sandy soils is often higher than 45°C on cloudless days during November, December and January. At these supra-optimal temperatures, sunflower seedling vigour declines, resulting in a low plant population and lack of uniformity of plant density. Nel (1998) found that cultivars differed in their heat tolerance. This may be due to genotype or seed quality differences. The seedling vigour declined rapidly above a threshold temperature of ca. 44°C, however some seedlings survived and emerged at temperatures above 50°C.

The effect of soil temperature, on germination and seed vigour becomes important in the late planting in South Africa in that the loss of seeding might have a significant impact on plant density.

1.3.1.2. Temperature Effects on Oil Content

Baldini *et al.*, (2002) found that temperature and the amount of moisture in the soil are the major factors influencing sunflower seed oil composition and especially oleic acid content. High temperatures occurring during the seed-filling period have a big influence on the fatty acid composition of traditional sunflower oil (Rondanini *et al.*, 2003). It has been reported that high temperatures lead to an increase in oleic acid and decrease in linoleic acid content and vice versa (Harris *et al.*, 1978; Chunfang *et al.*, 1996). However, in high oleic acid sunflower cultivars, controversy exists regarding the effect of high temperature on oil composition. Differences in reports may be a consequence of different genetic backgrounds used (Salera and Baldini, 1998). Because sunflower fatty acid composition varies with different temperatures during seed development, there has been interest in developing both high linoleic and high oleic types that are temperature insensitive (Knowles, 1983; Miller and Vick, 2001). High oleic lines derived from Pervenets have been shown to be stable under different temperature regimes (Fernández-Martínez *et al.*, 1986).

Temperature was shown to affect both oil content and composition of sunflower seed during the period of seed development and maturation (Seiler, 1983; Seiler and Brothers, 1999; Rondanini *et al.*, 2003; 2006; Qadir *et al.*, 2006, Onemli, 2012). High temperatures (above 35°C) during seed development resulted in a reduction in total oil content (Rondanini *et al.*, 2003). However, the effect of temperature on oil content was variable. Canvin (1965) found that sunflower grown at a constant temperature of 21°C had a higher oil content than those grown at both higher and lower temperatures. According to Harris *et al.* (1978), oil content decreased as temperature increased. The cause of the reduction in oil content may lie in the greater proportion of the pericarp, due to the shortening of the seed filling period at high temperatures (Connor and Hall, 1997). This was explained by the fact that oil content decreased with an increase in the proportion of the pericarp (Anand and Chandra, 1979). Unger and Thompson (1982) reported that oil content of seed maturing late in the season (at lower temperatures) was lower compared to seed from sunflower planted earlier that matured during warmer weather. According to Connor and Hall (1997), this supposedly positive effect of temperature on oil content might possibly be associated with small or light seed that could be due to problems with pollination or subsequent seed growth.

The relative proportions of the major unsaturated fatty acids (oleic and linoleic acid) are strongly influenced by the environmental temperature during sunflower seed development (Harris *et al.*, 1978). There is an inverse relationship between temperature and the degree of unsaturation of the oil (Qadir *et al.*, 2006). Several studies have been conducted in order to clarify how temperature affects the fatty acid composition of plant lipids (Garcés *et al.*, 1992; Rondanini *et al.*, 2003; 2006; Qadir *et al.*, 2006). In controlled environment studies, high temperatures during seed development (especially night temperature) have been found to cause a decrease in the amount of linoleic acid and a corresponding increase in the amount of oleic acid in the oil (Izquierdo *et al.*, 2002). Seed maturation during periods of low temperature gave opposite results. The mechanism involved appeared to be the direct effect of temperature on the activity of the desaturase enzymes that are responsible for the conversion of oleic to linoleic acid (Canvin, 1965; Harris *et al.*, 1978; Silver *et al.*, 1984; Garcés and Mancha, 1991). Therefore, both temperature and genetic effects are mediated by changes in the activity of the microsomal Oleoyl-phosphatidylcholine desaturase (ODS). According to Izquierdo *et al.* (2002) variations in oil fatty acid composition were related to night temperature and maximum temperature during the light period. They suggested that the effect of temperature during the dark period on fatty acid composition was an indication that light or a metabolite associated with the day/night cycle could affect the activity of the ODS enzymes. Environmental factors (that may cause any type of stress) influence the proportions of fatty acids by altering the enzyme activity as well as transport between organelles (Steer and Seiler, 1990) and therefore a thorough understanding of the environmental factors influencing seed development and oil quality is necessary.

1.3.1.3. Temperature Effect on Oleoyl Phoshatidylcholine Desaturase (ODS) Activity

The ODS enzyme is highly regulated by temperature in sunflower seed and according to García-Díaz *et al.* (2002), different mechanisms might be involved in the control of the microsomal ODS activity. These mechanisms include:

- de novo enzyme synthesis or activation of ODS that is stimulated by low temperatures,
- the rapid and reversible partial inhibition of the pre-existing enzyme at high temperatures and
- the exchange of oleate and linoleate between TAGs and PC (Canvin, 1965; Garcés *et al.*, 1992; Sarmiento *et al.*, 1998).

In addition, Martínez-Rivas *et al.* (2001) proposed two separate and independent mechanisms that could be involved in the temperature regulation of ODS activity in developing sunflower seeds:

- The long-term direct effect of temperature, mostly related to the low thermal stability of the ODS enzyme and
- the short-term indirect effect of temperature on the availability of oxygen.

Higher solubility of oxygen in water at low temperatures may increase the total desaturase activity by increasing the availability of oxygen that acts as co-substrate for oleate desaturation. Both regulation mechanisms are of particular relevance as they act during field growth conditions of sunflower plants. However, temperature does not only regulate ODS activity, but also the amount of oleate (synthesised de novo and mobilised from preformed TAG) available as substrate for the enzyme (García-Díaz *et al.*, 2002).

1.3.1.4. Temperature Effect on High Oleic Sunflower

It is reported that in high oleic sunflower seed, fatty acid composition was not affected by climatic conditions (Salunkhe *et al.*, 1992). Several researchers reported that oleic acid content showed a great stability in different environments in high oleic genotypes, even if genetic differences were present (Salera and Baldini, 1998). Additionally, in high oleic mutants the oleic and linoleic acid contents were less influenced by temperature than standard genotypes (Flagella *et al.*, 2000). However, Champolivier and Merrien (1996) suggested that temperature had an effect on oleic acid content in high oleic sunflower hybrids. Tatini (1995) showed that an increase in temperature from 10-20ºC during seed filling produced an increment from 45-80% of oleic acid content in a high oleic genotype. In contrast, Lagravere *et al.* (2000) found that the high oleic hybrids they studied were insensitive to temperature conditions. The differences between these reports could be related to differences in hybrids studied as well as their genetic backgrounds. Oleic hybrids can be characterised as high or low oleic acid potential hybrids and the largest part of total variation in oleic acid percentage could be due to differences in potential acid percentages of the hybrids (Izquierdo *et al.*, 2002). Lagravere *et al.* (2000) suggested that hybrids with low oleic acid potentials could be more sensitive to environmental conditions such as temperature, while hybrids with a higher oleic acid content genetic potential were insensitive to temperature conditions.

1.3.1.5. Temperature and Climate Change

Current trends toward increased global temperature due to a changing climate (Easterling *et al.*, 1997) may increase the probability of occurrence of high temperatures in many regions of the world (Conroy *et al.*, 1994). These might also increase the frequency of episodes of high temperatures in warmer climates (Wheeler *et al.*, 2000). This change in weather may cause unusually high temperatures during the critical stage of seed maturation which will have an influence on sunflower oil quality.

1.3.1.6. Temperature Conclusions

The effect of temperature during the seed-filling period on oil content and composition in traditional, mid oleic and high oleic sunflower hybrids within South African genetic backgrounds is necessary to:

- facilitate breeding strategies focusing on developing stable and widely adapted traditional high linoleic, high oleic and mid oleic hybrids that are less sensitive to large temperature differences, and to
- enable to compile cultivar recommendations to producers that are optimized to their specific production region.

1.3.2. Water Stress

Water stress is the major limitation to sunflower yields worldwide. However, the crop presents several features to mitigate water stress and yield losses under water deficit. An example is the sequential development of flowers that gives the crop some plasticity in supporting short stress periods (Aguirrezábal and Tardieu., 1996). Also, there are reports of osmotic adjustment under drought stress and genetic variability among inbred lines of sunflower.

Sunflower can develop a deep root system. The deep root system also helps to avoid water deficit when water is available in deeper soil layer. Sunflower leaf wilting contributes in a genotype-dependent manner to the response of whole-plant transpiration rate to soil drying by changing the shape of the response function. A significant part of the genotypic difference in this response was explained by wilting. This mechanism allows sunflower plants to conserve more soil water and protects them from thermal stress and high radiation loads (Velázquez *et al.*, 2012).

Water use efficiency is used to describe the biomass–transpiration ratio and it relates yield with evapotranspiration (Fischer and Turner, 1978; Hall and Richards, 2013; Sinclair *et al.*, 1984; Steduto *et al.*, 2007). Water use efficiency of sunflower is low (720 g water per gram dry matter vs 400:1 for maize or 300:1 for sorghum) (Schulze, 2007).

1.3.2.1. Effect of Water Stress on Yield

Sunflower seed yields are profoundly affected by water stress (Muriel and Downes, 1974; Talha and Osman, 1975). Sunflower crops subjected to a stress period shortly before anthesis often generate a higher partitioning to the capitulum at the expense of vegetative organ and water stress during anthesis or grain filling results in a low harvest index mainly due to a by a decrease in grain number or weight per grain (Alahdadi and Oraki., 2011).

When sunflower seed plants, that were grown in glasshouse trials under controlled temperature regimes, were stressed during budding, anthesis and seed filling by withholding water until the leaf water potential reached -1600 and -2000 kPa, the leaf area of unstressed plants significantly exceeded those of plants under severe stress (Human *et al.*,1990). The CO_2 uptake rate per unit leaf area as well as the total uptake rate per plant, significantly diminished with increased water stress, and considerably increased during the reproductive phase of the plant. The effect of the water stress were significantly smaller heads and kernels, however the number of seeds borne in the inflorescence was not affected. Severe stress during anthesis and seed filling resulted in more empty kernels. Moderate and severe stress during budding significantly lowered both grain and oil yields while plants that experienced moderate stress during anthesis and seed filling significantly out yielded those under severe stress (Bezuidenhout, 1983; Human *et al.*, 1990).

In sunflower, Fereres *et al.* (1986) showed that drought resistance was not correlated with yield potential under stressed or non-stressed condition. Direct selection, for yield under water stressed conditions is complicated by the low heritability of yield. Alza and Fernandez-Martinez (1997) found that dryland yield was positively correlated with yield components and negatively correlated with canopy temperature and susceptibility index. They concluded that an efficient breeding strategy for sunflower under moderate drought-stressed conditions can be for simultaneous selection for seed yield in both rainfed and irrigated environments together with selection for canopy temperature and stem diameter.

1.3.2.2. Effect of Water Stress on Oil Content

Seed weight and seed oil concentration are determined during the seed-filling period, i.e., from the end of flowering to physiological maturity (Aguirrezabal *et al.*, 2003). Consequently, changes in the source of post-flowering assimilates could be reflected in final seed weight and in its oil concentration

Seed composition is also affected by water stress. Water stress during the vegetative and reproductive growth stages reduces the seed oil content (Muriel and 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 and Sadras, 1992). The effect of water availability on the major fatty acids such as oleic acid and linoleic acid has been examined in sunflower genotypes in response to water stress during different phases of crop cycles (Talha and Osman, 1975; Flagella *et al.*, 2000; Baldini *et al.*, 2002). Ceasing irrigation from flowering to physiological maturity enhances the percentage of oleic acid in sunflower seeds compared to those from well irrigated fields (Flagella *et al.*, 2000). An increase in oleic to linoleic acid ratio under water stress was also reported by Talha and Osman (1975). However, Santonoceto *et al.* (2003) have shown that sometimes oleic acid content per sunflower seed may increase with an increase in water availability which ultimately increases the oleic to linoleic acid ratio; while in contrast, Salera and Baldini (1998) observed no effect of water management on oleic acid content in sunflowers. Thus, there are many contrasting reports on the effect of water stress on sunflower seed oil content and composition and Ali (2009) found that cultivars differed in their response to water stress.

1.3.2.3. Effect of Water Stress on Hullability

The effect of water stress on seed hullability, a seed trait determining the efficiency of seed processing and the quality of the oil cake seem to be inconsistent. Denis *et al.*, (1994a & b) found the found the hullability of seed from a drier locality to be higher than that of seed from a wetter locality, whilst Merrien *et al.*, (1992) and Baldini and Vannozzi (1996), found the hullability of seed from a frequently irrigated treatment to be higher than that of a less frequently irrigated treatment. Nel *et al.(*2001), in South Africa, however, found that grain yield was reduced by 23% for production under a mild water stress for the first 25 days of the reproductive growth, but hullability was only reduced by 14% and the kernel oil content by only 2.3% while the seed composition was not affected.

1.3.2.4. Water Stress Conclusions and Breeding Opportunities for Climate Smart Sunflower

The negative effect of water stress on crop yield especially during the reproductive phases are not disputed. However, there seems to be conflicting evidence of the effect of water stress on oil content and especially the fatty acid composition of the seeds. During the past 15 years, the sunflower yield increase through genetic advance has been slower than before, suggesting that the current resources and breeding methods must be adapted (Vear, 2016). Breeding for drought resistance should not only include improvement in drought tolerance, but also the introduction of pest resistance, salt tolerance and changes in plant architecture for better adaptation (Dimitrijević and Horn 2018). This is referred to as climate smart selection. Climate smart sunflower traits should include:

- Flowering Time and Length of Vegetation
- Root Characters
- Heat Tolerance
- Cold Tolerance
- Drought Tolerance
- Flooding and Submergence Tolerance
- Salinity Tolerance
- Disease Resistance
- Nutrient-Use Efficiency
- Water-Use Efficiency
- Greenhouse Gas Emission and Carbon Sequestration
- Genome Plasticity (Miladinović *et al.*, 2019)

Miladinović *et al.*, 2019 suggest that the exploitation of the available plant genetic resources in combination with the use of modern molecular tools for genome-wide association studies (GWAS) and application of genomic selection (GS) could lead to considerable improvements in sunflower, especially with regard to different stresses and better adaptation to the increases in temperature and water stress associated with climate change.

Breeding for resistance to drought and high temperatures is an important objective in many sunflower breeding programs (Hladni 2016). Cultivated sunflower has narrow genetic base and is deficient in drought-survival mechanisms which were lost during the process of selecting plants for high yields. However, being a crop with medium water requirements (Ky < 1), sunflower has the ability to tolerate a short period of drought. However, in order to develop drought-tolerant lines and hybrids in sunflower breeding, breeders need to be aware of the relationship between drought resistance traits and yield and apply effective screening methods for these traits. Genotypes should have such advantages as enhanced leaf area, earliness, and earlier stomatal closure. Drought tolerance has been considered as a valid breeding target to partially compensate for the loss in yield. Traits connected with drought resistance include fast growth and flowering rate, lower plant height in the maturity, increased photosynthesis activity, and stoma conductivity Miladinović *et al.* (2019).

1.3.3. Fertiliser and Tillage Systems

Sunflower requires six macronutrients (N, K, P, Ca, Mg, and S) and seven micronutrients (Fe, Mn, Zn, Cu, B, Cl, and Mo). Uptake depends on root exploration, soil water content, and nutrient availability, rather than total nutrient content in the soil.

Nitrogen is involved in development and growth of leaves and florets. Nitrogen deficiency in early vegetative stages may reduce the leaf expansion (Trápani and Hall, 1996), significantly affecting the leaf area index (LAI), and therefore yield, by reducing intercepted solar radiation (IR). A high nitrogen deficit can also reduce radiation use efficiency (RUE) because most of foliar nitrogen is a constituent of the photosynthetic enzymes (mainly of Rubisco) and chloroplasts. Too high nitrogen fertilisation at the early stages of crop development can stimulate lush biomass development. The lush growth, i.e. big leaves (high LAI) may lead to proliferation of diseases and increased water consumption. The excessive water consumption may be restricted during grain filling in conditions of limited water supply which may have negative effect on seed and oil yield.

The nitrogen concentration in plants decreases with the increase of plant biomass by dilution (Debaeke *et al.*, 2012). Ensuring an adequate supply of nitrogen before floral initiation affects mostly the number of grains and root biomass. Late nitrogen applications only partially modify the weight per grain, affecting mainly the protein concentration and decreasing its oil concentration. Under nitrogen limiting conditions, nitrogen fertilisation tends to increase seed protein content at the expense of oil (Blarney and Chapman, 1981; Loubser and 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 *et al.*, 1997). In a greenhouse trial, Steer *et al.* (1986) found that timing of nitrogen fertilisation during the growing season influenced seed oil and protein contents. An excess of nitrogen availability can cause a reduction in grain oil concentration and oil quality without increasing seed yield (Merrien and Milán, 1992). Thus, a high nitrogen supply after anthesis results in lower seed oil and higher protein contents. Hullability is also affected by the availability of nitrogen and water. In this respect Baldini and Vannozzi (1996) have found that an increased supply of nitrogen improves hullability. Thus, the availability of nitrogen to the sunflower crop may have a determining effect on seed characteristics which influence the processing quality. Fertilizing rates should always be adjusted to avoid nitrogen availability for the crop that is higher than the optimum amount.

Sunflower nitrogen fertilization recommendations in South Africa are based on yield goals. In this approach, soil nitrogen supply is not considered with the result that nitrogen fertilization recommendations from different institutions disagree. However, the delta yield approach, the difference between a well fertilized crop and a zero-nitrogen fertilized control, is more reliable indicator of the economic optimum nitrogen rate. Nel and Bloem (2007) found that when comparing the two methods only 27% of the variation in the optimum nitrogen fertilization rate was explained by yield goal, compared with 87% by delta yield. The delta yield approach is thus a far more reliable indicator of the optimum nitrogen rate. The relationship between delta yield and the optimum nitrogen rate is best described by a power function: $Y=X^{0.669}$ with Y the optimum nitrogen rate and X the delta yield, both measured in kg per ha.

Nel *et al.*, (2000d), in a field trial, studied the response of sunflower seed yield and seed processing quality to the amount and timing of nitrogen application were studied. Nitrogen application rates were 20, 70 and 120 kg/ha with limestone ammonium nitrate as the nitrogen source. The timing of application treatments were, a) all nitrogen applied at planting and b) split in ratios of 1:1 and 1:3, applied at planting and at the beginning of flowering. Nel *et al.*, (2000d) found that the timing of nitrogen application had no effect on seed yield or any of the seed quality characteristics. Seed yield increased on average by 22% per 50 kg of nitrogen applied per hectare. Hullability was not affected, while seed oil content declined and the seed protein content increased moderately with increased amounts of nitrogen, leading to a decline in the amount of recoverable oil, an increase in the potential oil cake yield, an increase in the protein and decrease of the crude fibre content of the expected oil cake. The changes in seed quality characteristics were equal or less than 10% per 50 kg of nitrogen applied per ha.

The principles of conservation agriculture include minimal soil disturbance (reduced tillage or no-till), retaining crop residues on the soil surface to produce a layer of mulch, as well as multiple cropping (such as crop rotation). Studies of yield response of sunflower yields to conservation agriculture, particularly to no-till practices, in several countries are contradicting results. A trial over three seasons (2013/04 to 2015/16) examining the effect of different tillage systems and nitrogen rates at Potchefstroom concluded that the mean seed yield of the no-till system was significantly lower than that of the tilled treatment in the first growing season. This difference declined to an insignificant discrepancy in the second season, followed by the no-till system's significant advantage of 34% over the tilled system's yield. In all three seasons the seed protein content improved with increased nitrogen application rates. Tillage system and nitrogen fertilisation affected seed oil content but showed no interaction. The conclusion was made that the lack of interaction shows that the effect of tillage systems and nitrogen fertilization on the seed oil content is unpredictable .

1.3.4. Sclerotinia

Sclerotinia sclerotiorum is a fungal pathogen, which infects sunflowers, causing Sclerotinia head or stem rot diseases. This fungus attacks a wide range of field crops including sunflower, soybeans, beans, canola and lupins as well as various vegetable crops.

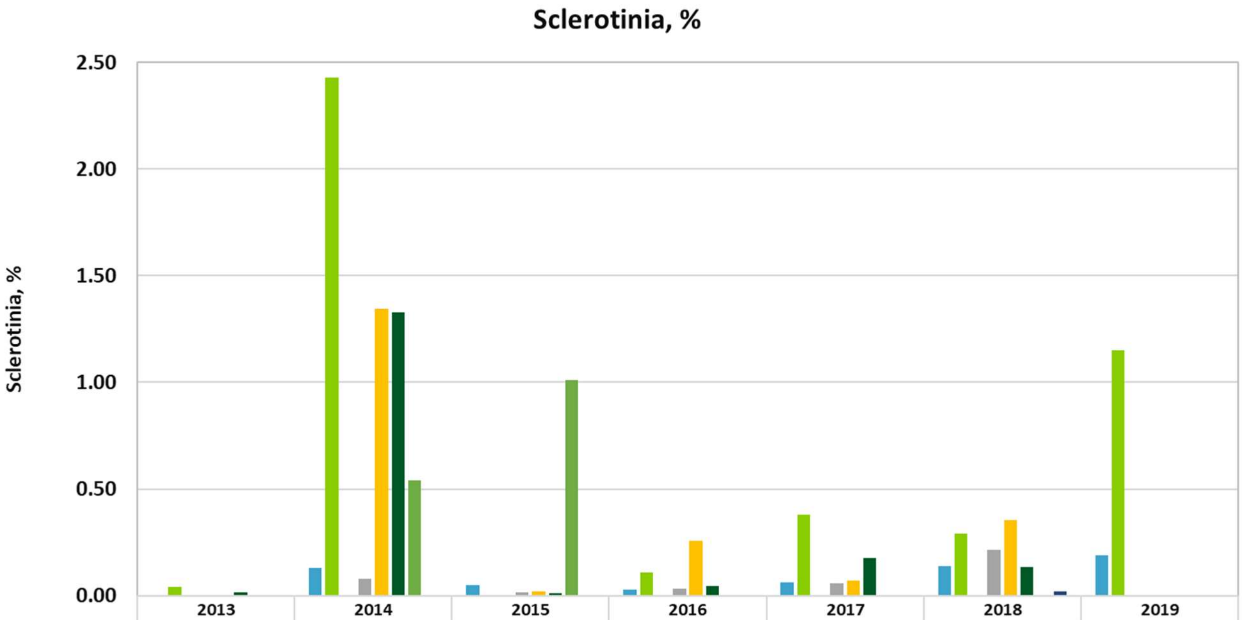
Sclerotinia stem rot of sunflowers is not a direct major threat to sunflower production with isolated plants in a field being infected. However, Sclerotinia head rot of sunflowers can cause major damage – particularly in late-planted crops that ripen in cool, wet conditions. The continued spread of this disease is a major threat for sunflower production in South Africa. Increased disease pressure will also impose an increased threat on production of other susceptible crops, particularly soybeans.

Sclerotinia Head Rot
This disease develops on the head in cool, humid weather, shortly after the onset of flowering. Infection occurs in the flowering stage and head rot is visible as soft, light brown patches on the back of the head. The symptoms quickly intensify. The inner layers of the sunflower are destroyed and when the soft lesions tear, the vascular tissue is exposed. The soft tissue in the head is destroyed and sclerotia are formed that cause the seeds and sclerotia to later fall off the head onto the ground. The fungus has a wide range of host plants, making crop rotation very difficult. Weeds can also act as hosts and together with the fungus's ability to survive for a long time, can contribute to the development of the disease and sunflower infection.

Sclerotinia Stem Rot
Wilting occurs when a sclerotium near the sunflower's stem or roots is stimulated to germinate and, with the help of mycelia, directly penetrate and infect the base of the stem. The distinguishing symptom is a single plant or plants that suddenly wilt overnight. A soft, rotten area with grey/brown lesions and fluffy white fungal growth is visible at the base of the stem. Because the lesions enlarge and later envelop the entire stem, the plant wilts. Dense white fungal growth develops on the infected area and forms white lumps that harden and eventually form the dark grey/black sclerotia. The soft white vascular tissue inside the stem disappears and sclerotia also form inside the stem. Wilting is the result of extensive root rot and is usually more prominent during early flowering.

The effective management of Sclerotinia through rotation with non-host crops is limited by the extensive host range and duration of survival of sclerotia in soil. Agronomic management decisions such as cultivar selection, proper irrigation management, planting dates and plant density can contribute to lowering disease severity. The use of tillage practices in fields previously infested with *S. sclerotiorum*, to manage diseases caused by *S. sclerotiorum*, is a point of contention. *Coniothyrium minitans* is commercially available in South Africa and can be used as a biological control agent for fields previously infested with *S. sclerotiorum.* The most effective prevention measure for Sclerotinia diseases are timely fungicide applications, at critical host growth stages. Currently, there are a limited number of preventative registered active ingredients in South Africa for fungicide use on sunflower; these include benomyl and procymidone.

The South African grain laboratory screens samples collected from different regions for Sclerotinia. Screening for sclerotia forms part of the sunflower seed grading process (Appendix B). Figure 41 presents the average percentage Sclerotinia per class and per province for the production seasons 2012/13 to 2018/19. As expected, the % Sclerotinia was higher for the Other class than the FH1 class. Furthermore, wet seasons like 2013/14 had high incidences of sclerotinia and the incidences of Sclerotinia were also higher in the provinces with a higher rainfall such as Mpumalanga, Gauteng and Limpopo. Figure 42 indicates that outbreaks of sclerotinia are mostly localised and that the foreign matter is within grading regulations.



	2013	2014	2015	2016	2017	2018	2019
FH1	0.00	0.13	0.05	0.03	0.06	0.14	0.19
COSF	0.04	2.43	0.00	0.11	0.38	0.29	1.15
Free State	0.00	0.08	0.02	0.03	0.06	0.21	
Mpumalanga	0.00	1.35	0.02	0.26	0.07	0.36	
North West	0.01	1.33	0.01	0.04	0.18	0.13	
Gauteng	0.00	0.54	1.01	0.00	0.00		
Limpopo	0.00	0.00	0.00	0.00	0.00	0.02	

FH1 COSF Free State Mpumalanga North West Gauteng Limpopo

Figure 41 Average percentage Sclerotinia per class and per province for the production seasons 2012/13 to 2018/19

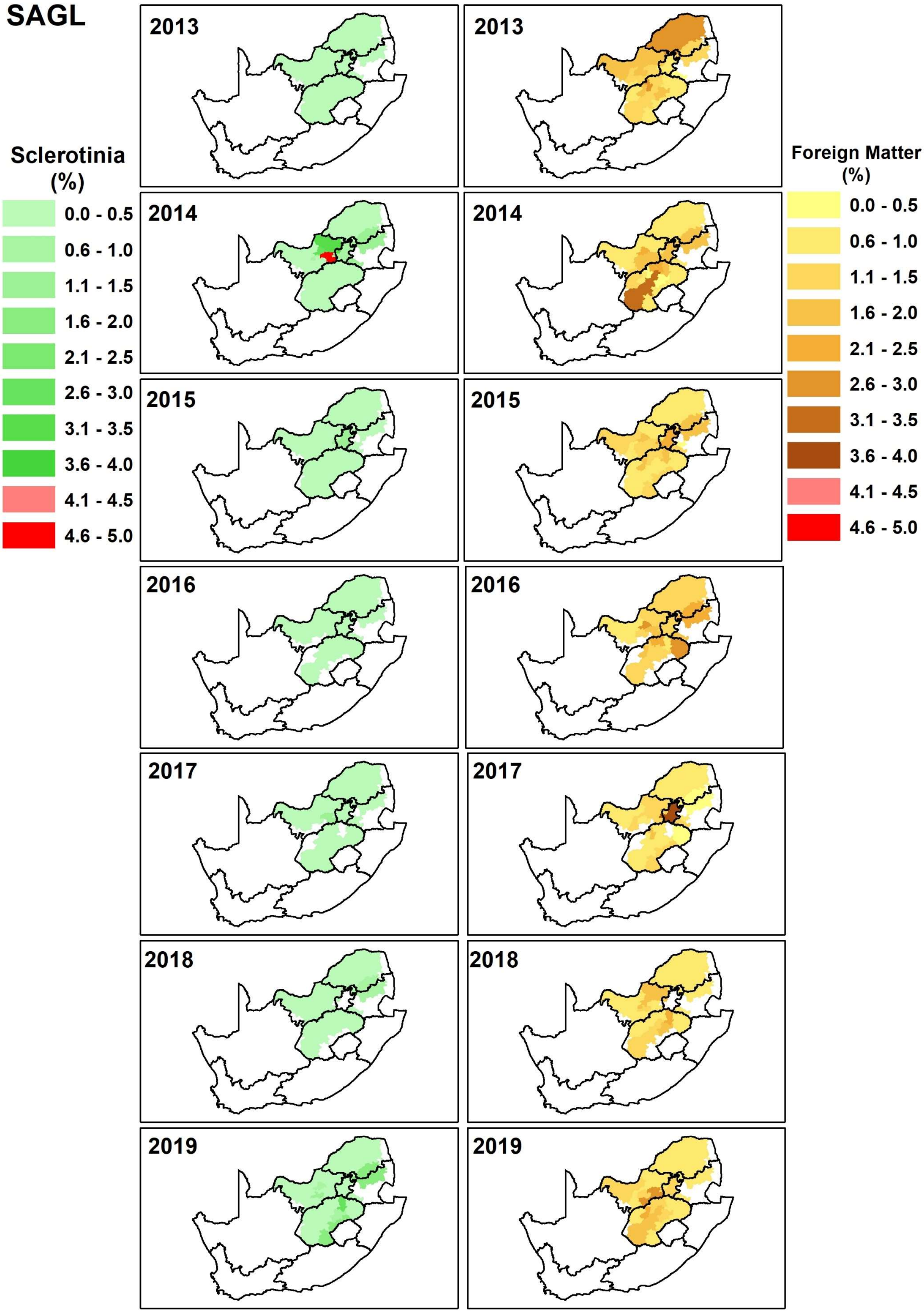


Figure 42 Spatial distribution of sclerotinia and foreign matter (Data Source: SAGL)

1.4. References

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8.4 Appendix D

Cultivar trials and genotype environment interactions	
Article	Year
Chigeza, G., 2007. Past, present and future sunflower breeding in South Africa: a public sector perspective based on yield trends. In *3rd Sunflower Symposium in Developing Countries*, 9th-13th December.	2007
Chigeza, G., Shanahan, P., Savage, M.J. and Mashingaidze, K., 2008. Heterosis for yield and oil content of sunflower lines developed from bi-parental populations. Breeding and Genetics. *Proc. 17th International Sunflower Conference*, Córdoba, Spain.	2008
Chigeza, G., Mashingaidze, K. and Shanahan, P., 2012. Seed yield and associated trait improvements in sunflower cultivars over four decades of breeding in South Africa. *Field Crops Research*, 130, pp.46-56.	2012
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Chigeza, G., Mashingaidze, K. and Shanahan, P., 2014. Advanced cycle pedigree breeding in sunflower. II: combining ability for oil yield and its components. *Euphytica*, 195(2), pp.183-195.	2014
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Article	Year
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