SUNFLOWER GENETIC GAIN IN ARGETINA

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ABSTRACT

Genetic gain studies help breeders to refine and/or change their breeding programs in desired directions and to make estimates of future progress. There are two methods to estimate genetic gains: comparing an historic set of cultivars with uniform management or from the trial data collected by breeding programs. Using the first approach, a set of historical hybrids released to the Argentinian market by a private breeding program between 1984 and 2015 were evaluated in a four location experiment during 2014/2015 season. We included hybrids of four segments: conventional (CONV), herbicide tolerant (HT), high oleic (HO) and herbicide tolerant high oleic (HTHO). Genetic gain for oil yield in CONV hybrids was 25.5 kgha^{-1}year^{-1}. For the HT hybrids, the genetic gain was 63.6 kgha^{-1}year^{-1}. In the case of the HO, genetic gain was 49.6 kgha^{-1}year^{-1}. For the HTHO hybrids genetic gain was 29.1 kgha^{-1}year^{-1}. When the HT hybrid was launched to the market in 2003, the oil yield compared with the best CONV hybrid was 25.6% lower. The HO hybrid was launched to the market in 2004; the oil yield compared with the best CONV hybrid was 19.5% lower. In the case of the HTHO, the oil yield compared with the best CONV hybrid was 26.3% lower. The gaps have been closed for HT and HO and reduced for HTHO. Once the gaps are closed the genetic gain will depend on the level of resources dedicated to each segment.

Key words: *Helianthus annuus* L., Genetic Gain, Breeding, Sunflower, Yield drag

INTRODUCTION

Maximize the genetic gain is one of the main objective of most of the commercial breeding programs. The genetic gain can be defined as the yield increase divided by the time consumed to develop the higher yielding cultivars.

There are two different ways to evaluate the genetic gain. One is to analyze a dataset of different hybrids during a given period of time using linear mixed models (de la Vega et al., 2007). The other approach is to produce an historic set of cultivars and evaluate them in a trial network (López Pereira et al., 1999; Sadras et al., 2000; Vear et al., 2003). However, this approach has a couple of sources of inaccuracies related with the weather, the diseases and the weather by management interactions (Bell et al., 1995).

Sunflower (*Helianthus annuus* L.) crop is one of the main edible oil crops in Argentina. Cultivation of Sunflower varieties began in the early 30s by immigrants who brought seeds from Europe. In the 60s, new varieties were obtained by official breeding programs coming from the combination wild species that improved disease tolerance (Bertero and Vazquez, 2003). In 1969, Leclercq discovered the cytoplasmic male sterility and several restorer genes were discovered after, allowing a rapid spread of hybrid production by public and private companies.

The germplasm evaluated in this study is coming from the same breeding program and will be restricted to hybrids developed by Dekalb from 1984 to 1999, by Monsanto from 2000 up to 2009 and from that year to the present by Syngenta. The breeding activities started in the mid-70s in Ines Indarht, then it continues in Bragado and now it is based in Camet, all in Buenos Aires province, Argentina.

The main objectives of this breeding program have been grain yield and oil content. Also some diseases like Verticillium wilt (*Verticillium dahliae* Klebahn) and Downy mildew (*Plasmopara halstedii (Farl.) Berl. & De Toni*) have been very important breeding traits for selection.

From the 90s, new type of hybrids appeared in the market and today the Argentinean market of oil type sunflower can be separated in four segments: conventional hybrids (CONV), herbicide tolerant hybrids (HT), high oleic hybrids (HO), and herbicide tolerant- high oleic hybrids (HTHO).

After the discovery of Imazethaphyr resistance in wild sunflower in 1998 by Al-Khatib et al.; seed companies incorporated this source of tolerance to create the IMISUN hybrids with resistance to different imidazolinone herbicides. This technology that allows better weed control was rapidly adopted by farmers in Argentina. It was reported that some linkage drag around IMISUN gene coming from wild sunflower produced a decrease in oil content in the seed (Sala et al., 2012).

As a request from the industry to get better quality of sunflower oil, the high oleic market was developed. Breeding programs incorporated the Pervenets mutation to increase the percentage of oleic acid content in the seed. The hybrids containing this mutation produce a different profile of fatty acids with high percentage of oleic acid and industry pays a premium price to the farmers for high oleic content above 80%. Depending of the donor of this mutation and the quality of the conversion, more or less yield drag has been observed in this type of hybrids compared with the CONV hybrids.

The newest market segment in Argentina is the HTHO that combine herbicide tolerance and high oleic acid content. Hybrids from this segment presented the largest yield drag.

The objectives of this work were: To quantify the genetic gain of this breeding program considering hybrids developed from 1984 up to 2015 and to calculate yield drags between market segments and the evolution they had.

MATERIAL AND METHODS

SITES AND CROP MANAGEMENT

Rainfed trials were conducted in five locations: Quemú Quemú, América, Olavarría, Camet and Necochea. All of them were located within the sunflower production area and the planting dates where the same as farmers (Table 1). Rainfalls during growing season were adequate for crop development. A final plant density of 50000 plants ha-1 was achieved planting higher densities and then doing manual thinning at the stage of V2 (Schneitter and Miller, 1981). Herbicides were applied after planting and remaining weeds were controlled manually. Insecticides were applied for insect control. Fungicides were applied in R1, no pressure of disease was observed.

Table 2. Location, planting dates and coordinates.

Location	planting date	GPS coordinates
America	10-Oct-2014	35°30'S 63°30'W
Quemú Quemú	14-Oct-2014	36°30'S 63°35'W
Olavarría	2-Oct-2014	36°41'S 60°22'W
Camet	16-Nov-2014	37°46'S 57°53'W
Necochea	22-Nov-2014	38°33'S 58°53'W

PLANT MATERIAL

Hybrids were produced during summer 2013-2014 in Syngenta sunflower breeding station in Camet. Most of the materials were chosen by the year of registration, performance and farmer adoption level. Table 2 summarizes hybrids, year of registration and market segment.

Table 3. Hybrids included in the trials, year of release to the market and market segment.

Hybrid name	year of release	market segment	Hybrid name	year of release	market segment
DK G100	1984	CONV	DK 3880CL	2003	HT
DK G105	1990	CONV	DK 4000CL	2003	HT
DK 3881	1993	CONV	DK 3910CL	2008	HT
DK 4100	1994	CONV	DK 3948CL	2008	HT
DK 3878	1997	CONV	SYN 3970CL	2012	HT
DK 4040	1997	CONV	SYN 4070CL	2012	HT
DK 3915	1997	CONV	DK_OILPLUS3845	2004	HO
DK 4050	1999	CONV	DK_OILPLUS3945	2004	HO
DK 3920	2002	CONV	SYN 3950HO	2011	HO
DK 3820	2003	CONV	SX132397HODM	2015	HO
SPS3150RDM	2004	CONV	DK 3955CLHO	2009	HTHO
DK 3810	2004	CONV	SYN 3965CLHO	2013	HTHO
DK 4045	2005	CONV			
DK 3940	2006	CONV			
DK 4065	2009	CONV			
SYN 3825	2013	CONV			

EXPERIMENTAL DESIGN AND MEASUREMENTS

A randomized complete block design with two repetitions was used for trials. Plot size was 7 meters by 4 rows. Interrow distance was 0.7 meters. Only the 2 central rows were harvested with a combined harvester machine. Samples were collected to measure oil content with nuclear magnetic resonance equipment. Days from planting to R 5.5 were measured in Quemú Quemú and Camet.

CALCULATIONS

Genetic gain was calculated as the slope of the regression between the trait and year of release. To make it comparable with other studies the genetic gain was also expressed as the % of the average yield for the considered period. Oil yield was calculated as the product of grain yield and percentage of oil content. Oil yield gap between market segments was calculated by the difference among best yielding CONV hybrid and traited hybrid expressed as the percentage of the CONV.

RESULTS AND DISCUSSION

YIELD PERFORMANCE OF CONV MARKET SEGMENT

When genetic gain of oil yield in each location was analyzed, a similar slope in Camet, America and Necochea and Olavarría was observed (Table 3). Yield data from Quemú Quemú was excluded from the analysis due to poor quality.

Table 4. Slope and determination coefficient for the linear regression analysis between oil yield and year of release for trial locations.

Location	Slope	r^2
América	21.14	0.391
Camet	25.58	0.398
Necochea	24.20	0.505
Olavarría	31.08	0.638

The genetic gain derived from the combined analysis of 4 locations was 25.51 kg year^{-1} for oil yield (Fig. 1). That rate represents 1.77 % of the average oil yield of the period considered. De la Vega et al. (2007) also found a positive trend in oil yield using a linear mixed model to calculate the best linear unbiased predictor. The reported genetic gain was up to 14.4 kg year^{-1} for oil yield in a dataset from central Argentina from 1983 to 2005.

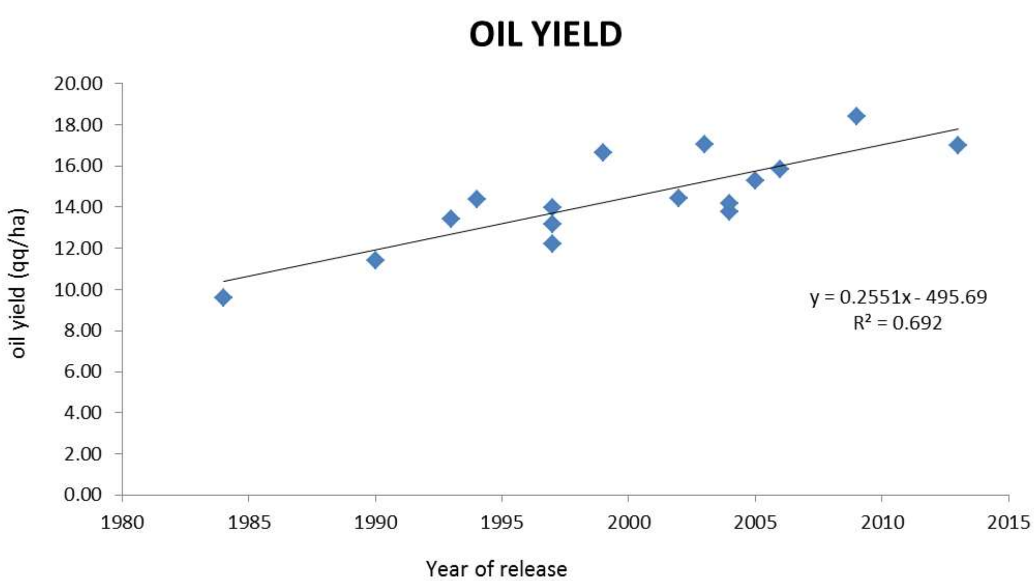

Figure 9. Linear regression between oil yield and year of release combining four locations.

Sadras et al. (2000) found a positive correlation between oil yield and year of release when cultivars from 1963 to 1998 were evaluated. However, no genetic gain was calculated. López Pereira et al. (1999) studied set of historical cultivars released between 1930 and 1995 and found positive association between grain and oil yield and year of release. This association has not been constant, a clear turning point was observed during the seventies with the introduction of hybrid cultivars. No significant improvement has been found after that point. These authors postulate that the lack of improvement might be related with "defiency" breeding (Richards et al., 1997). This means that breeding for disease tolerance, grain quality and a narrow genetic base might have restrained genetic gain for yield.

In France, a genetic gain study using a similar approach of this one but using cultivars released from 1960 up to 2000 found an improvement that represents 1.3% for grain yield per year (Vear et al., 2003). In a more recent study in the United States of America, Hulke and Kleingartner (2014) found a genetic gain of 0,698% for cultivars released from 1975 up to 2013. The main reasons for this level of genetic gain were related with the focus on defensive breeding. In this study, a clear progress in oil yield was found. The difference in the results of this study and the others found in literature might be explained by the fact that other assessment of the genetic gain for sunflower used different set of hybrids, different periods and different methodologies.

The genetic gain in oil yield for this particular study was only explained by grain yield and not by oil content. When components of oil yield were analyzed separately, the grain yield genetic gain was 46.92 kg year^{-1} but no clear tendency for oil content was observed (Fig. 2). The lack of association between oil content and year of release in this germplasm could be because the first released hybrids already have similar levels of oil content to the recently released hybrids. An example of this is the hybrid G100 registered in 1984 with an average oil content of 52.5%.

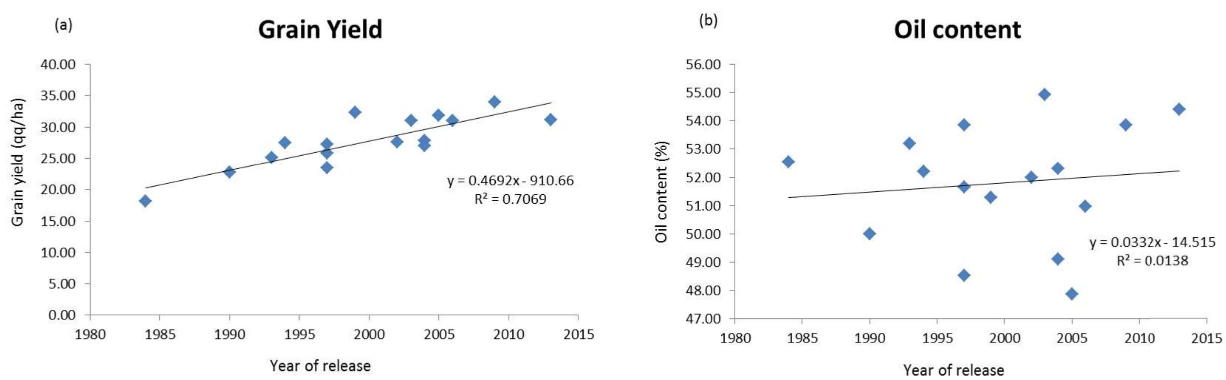

Figure 10. (a) Grain yield and (b) oil content linear regression with year of release.

De la Vega et al. (2007) found a bi linear function for the description of the relation of grain yield and year of release with a clear improvement from 1983 until 1995 and no improvements after that. Two reasons are postulated to explain this plateau. First, that in Argentina, during that period, a change in breeding process resulted in an increase of oil yield mainly due to the higher grain oil concentration rather than grain yield. Second, from 1991 to 2005 the explosive growth of soybean in central Argentina pushed the sunflower industry toward more marginal, lower rainfall western environment giving as result the declining of grain yield genetic gain.

COMPARISON BETWEEN MARKET SEGMENTS

Genetic gain for different market segments are presented in Fig. 3. Trendlines for each market segment are shown. Genetic gain for oil yield was 25.5 kg year^{-1}, 63.6 kg year^{-1}, 49.6 kg year^{-1} and 29.1 kg year^{-1} for CONV, HT, HO and HTHO respectively. It is important to point out that only few hybrids were used to calculate genetic gain for segments HT, HO and HTHO.

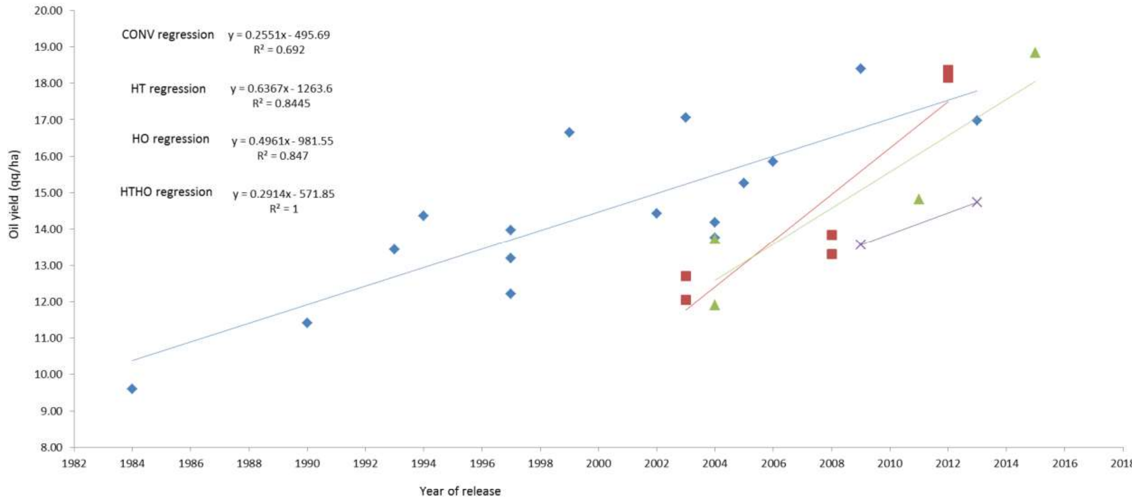

Figure 11. Linear regression between oil yield and year of release for four market segments. Symbols: diamond = CONV market, squares = HT market, triangles = HO market, cross = HTHO market.

As expected, HT, HO and HTHO have higher genetic gain than CONV segment mainly due to the fact that the first hybrids registered including the new traits presented a yield gap compared with the best yielding CONV hybrids. The reason of that gap might be related with the introduction of undesired alleles coming from the donor lines used as source of the new traits. The other reason for that gap could be related with the conversion process that had few backcrosses and the lack of tools like molecular markers for trait detection and background recovery.

First HT hybrids were released in 2003 with an oil yield gap of 25.52%. By 2012 this gap was closed reaching similar levels of performance with the CONV segment. A total of 10 years were needed to close this gap. The genetic gain in oil yield in HT market segment was explained by both, an increase in grain yield and oil content (Fig. 4). This situation differs from CONV segment where genetic gain in oil yield was explained only because of grain yield. This is an indicator of oil content linkage drag with of the introduction of IMISUN trait, as IMISUN gene comes from wild sunflower.

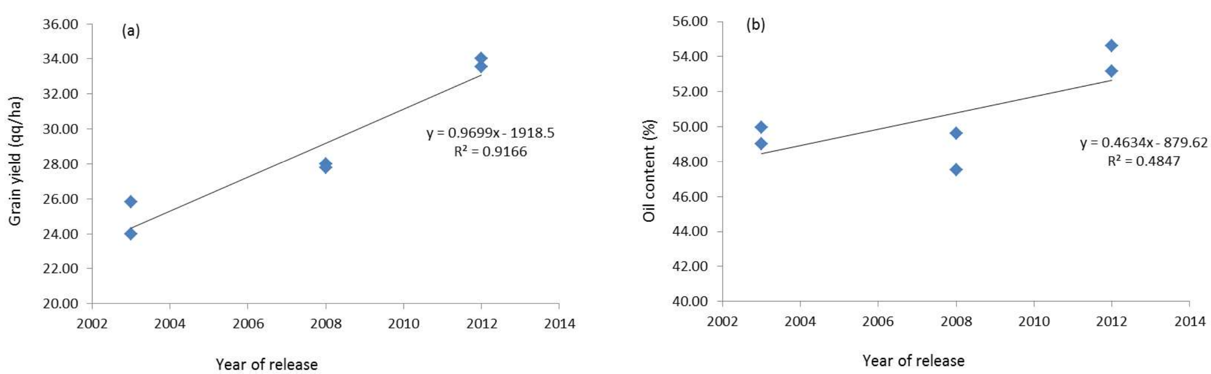

Figure 12. (a) Grain yield and (b) oil content linear regression with year of release for HT market segment.

First HO hybrids were released in 2004 with an oil yield gap of 19.5% and by 2015, after 12 years of breeding, this gap was closed and now HO hybrids have similar performance to CONV hybrids. The genetic gain in oil yield in HO segment was explained because of grain yield, as there is no tendency in oil content (Fig. 5).

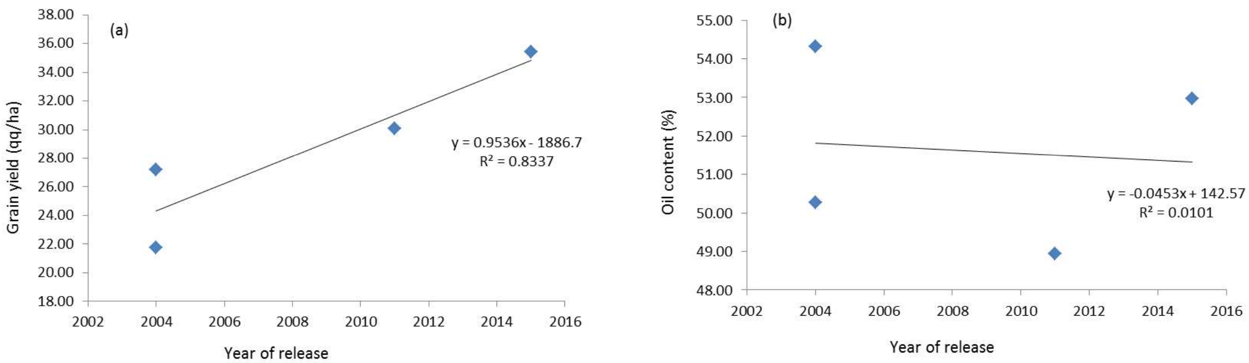

Figure 13. (a) Grain yield and (b) oil content linear regression with year of release for HO segment.

In the HTHO segment only two hybrids were included as this is the newest market segment. First HTHO hybrid was released in 2009 with an oil yield gap of 26.3% compared with the best CONV at that time. The second release in 2013 reduced the oil yield gap to 19.9%.

CYCLE LENGTH.

Cycle length defined as days from planting to R 5.5 showed a positive correlation with the year of release in all market segments (Fig. 6 a-b-c). Considering harvest moisture as indirect measurement of cycle length also presented positive correlation with year of release (Fig. 6 c-d-e). The same positive correlation was found comparing cycle length and oil yield (Fig. 7).

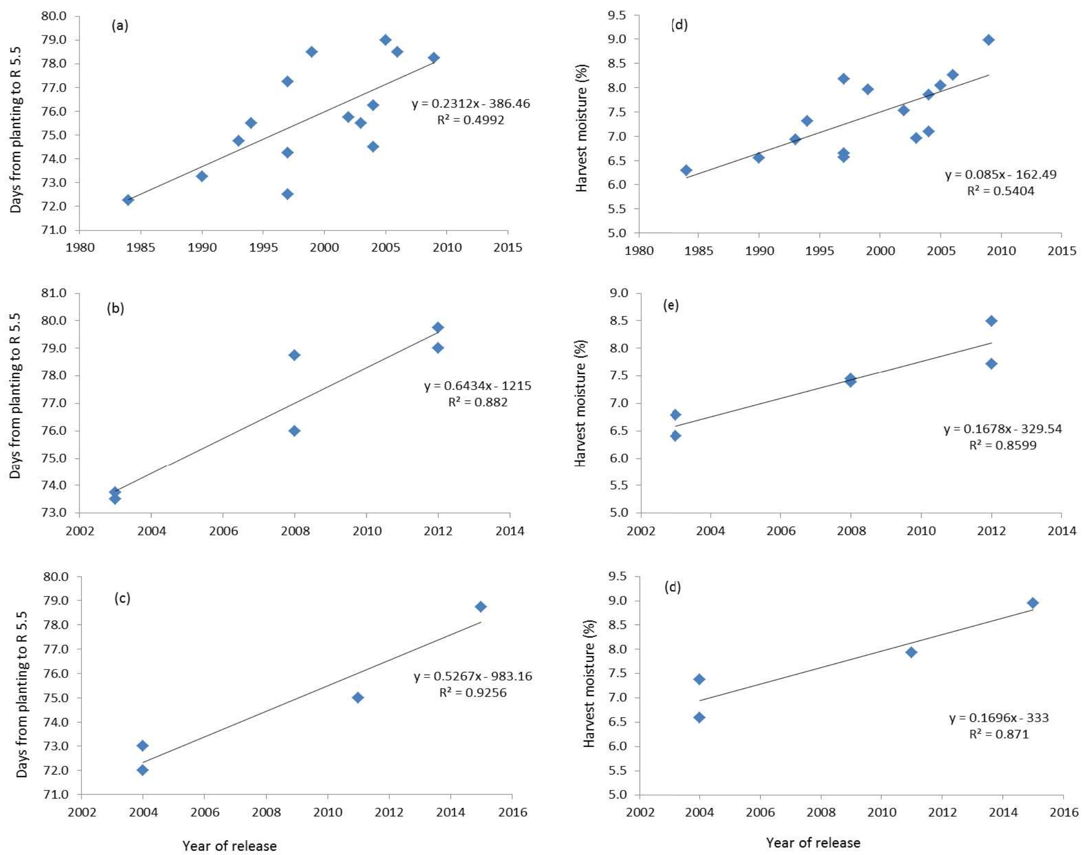

Figure 14. Relationship between cycle length and year of release. Cycle length as days from planting to R 5.5: (a) CONV market segment, (b) HT market and (c) HO market. Cycle length as harvest moisture: (d) CONV market segment, (e) HT market segment and (f) HO market.

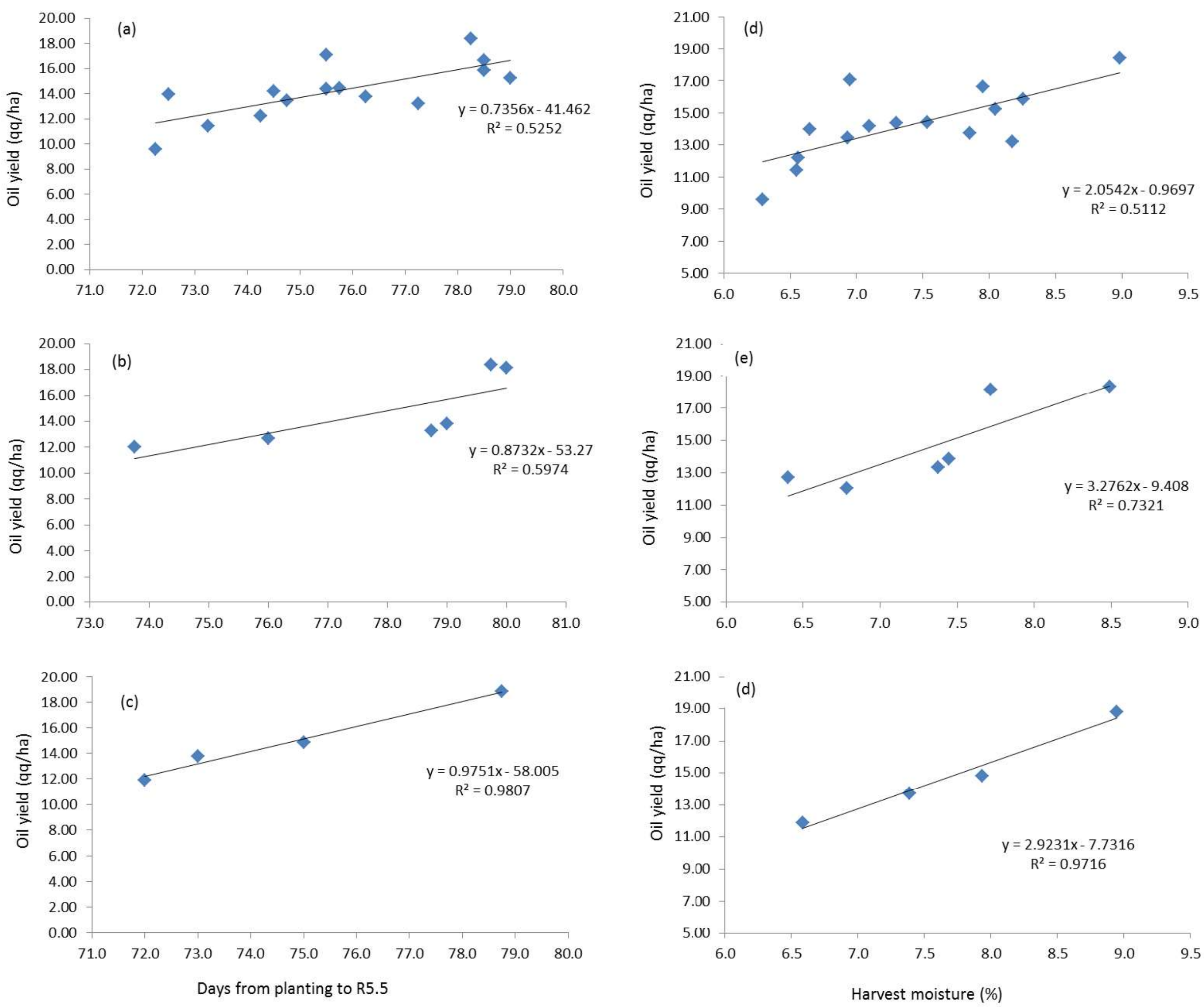

Figure 15. Relationship between oil yield and cycle length. Cycle length as days from planting to R 5.5: (a) CONV market segment, (b) HT market segment and (c) HO market segment. Cycle length as harvest moisture: (d) CONV market segment, (e) HT market segment and (d) HO market segment.

Earlier studies indicated no relation between days to anthesis and year of release (De la Vega et al., 2007; Sadras et al., 2000). Even more, Lopez Pereira et al., 1999 reported that breeding and selection shortened cycle length during the period 1930 and 1995 and that most of this reduction in cycle length was accounted for a reduction in time to anthesis.

CONCLUSIONS

Oil type sunflower breeding programs objective is to increase oil yield but strategies to achieve this could be different. In this study, and for the hybrids included, we reported different tendency in grain yield, oil content and time to anthesis compared with other studies that included a different set of Argentinean or foreign cultivars.

As breeding strategies could be different among breeding programs, studies that mix many pools of germplasm could be undercovering specific effects or tendency for different traits in each germplasm. Genetic gain studies done by specific germplasm might allow detecting these tendencies that each breeding program improved to get the final objective of increasing oil yield.

This particular germplasm is in active growth as no plateau was detected either for grain or oil yield. The increase in cycle length has reached the maximum value for suitable season growth in Argentina. The challenges for this germplasm will be to maintain the same rate of genetic gain in oil yield.

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