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REVIEW

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Topical Issue

The sunflower crop in Argentina: past, present and potential future

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Abstract – Sunflower was a crop of great importance in Argentina until 2002; it was ranked among the countries with the largest production, about 18% of the world total. Currently, it is in the fourth place, with only 7%. Several factors caused Argentina to lose its leadership, the most important being that farmers preferred the soybean crop because of its competitiveness pushing sunflower to areas where the former crop was not adapted. However, in 2016/2017 there was an increase in area and production of sunflower, probably associated with the reduction of state intervention in farmer's income because export duties were totally eliminated, while those for soybean remained high. International forecasts suggest that an increase in the demand for sunflower oil and by-products is expected. Argentinean farmers can make a significant contribution to meeting these needs. The whole sunflower chain of value, grouped in the association ASAGIR, makes continuous efforts to improve the sunflower product, by research programs and other activities which will render sunflower more attractive for farmer. It is likely that, in a short time, Argentina could regain its place on the podium of sunflower producing countries.

Keywords: history / agronomy / breeding / production / perspectives

Résumé – La culture du tournesol en Argentine : passé, présent et potentiel futur. En Argentine, le tournesol était une culture majeure jusqu'en 2002. À cette période, le pays assurait 18 % de la production mondiale. Quinze ans plus tard, cette contribution a chuté à 7 %. De multiples facteurs ont conduits l'Argentine à perdre cette position privilégiée. Parmi les plus importants, on peut mentionner le soja qui est devenue la culture préférée des agriculteurs argentins en raison de sa plus haute compétitivité, comparativement à toutes les cultures estivales. Par conséquent, la culture de tournesol a été repoussée dans les régions plus marginales où le soja n'était pas adapté. Durant la campagne agricole 2016/2017, la surface emblavée ainsi que la production de tournesol a cependant augmenté par rapport aux années précédentes. Un phénomène qui peut être associé à la réduction de l'intervention de l'État dans le revenu des agriculteurs. Ainsi, les droits à l'exportation ont été totalement supprimés pour le tournesol, alors que ceux du soja restent encore élevés. Selon des organismes mondiaux, une hausse de la demande globale d'huile de tournesol et de sous-produits pourrait être attendue à court terme. Pour les agriculteurs argentins, se dessine une très belle opportunité de répondre à ces besoins internationaux de manière significative. En Argentine, toute la chaîne de valeur est regroupée dans l'association nationale du tournesol, dite « ASAGIR ». Des efforts sont menés en vue d'améliorer le produit tournesol *via* différentes activités et programmes (mise en valeur, divulgation, recherche, etc.). L'objectif est clair : rendre cette culture oléagineuse beaucoup plus attractive pour les agriculteurs locaux. Ainsi, il est fort probable que, d'ici peu de temps, l'Argentine retrouve sa place dans le podium des nations les plus productrices du tournesol.

Mots clés : histoire / agronomie / amélioration génétique / production / perspectives

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1 The beginning

Sunflower (*Helianthus annuus*) came originally from the United States. After the colonization period, it was introduced to Europe, towards the middle of the 16th century, by Laguna, a physician and botanist who was interested in its healing and ornamental properties (Patiño, 1963). These ornamental qualities captivated Peter the Great, who introduced it to Russia at the beginning of the 18th century, but the rise of the sunflower crop in Russia was linked to religion: in about 1830, the Orthodox Church made a list of foods that were restricted during Lent and since sunflower was not included, its consumption was encouraged during this liturgical season (Putt, 1997).

Towards the end of the 19th century, the life of Jews in Russia was difficult and, in 1881, President Roca decreed the promotion of Jewish immigration from Russia to Argentina. The Jewish Colonization Association in Argentina, created by the Baron Maurice de Hirsch, promoted colonization and helped immigrants in their agricultural settlements in Argentina. The first colony was Moisés Ville in the NW of Santa Fe Province (MHC, 2017) and there were other settlements in the provinces of Entre Rios, Chaco and Buenos Aires. Near to the village Carlos Casares, the town Colonia Agrícola Mauricio was founded in 1891 in recognition of Baron de Hirsch. The immigrants had brought sunflower seeds with them and these were multiplied and distributed in different regions of Argentina. Carlos Casares was designated national capital of sunflower on July 13, 1962 (MCC, 2017).

2 Crop evolution

The interest and importance of the sunflower crop in Argentina has been divided into 6 periods (ASAGIR, 2017). The first is known as "*Pre-industrial*". Towards 1910, sunflowers were sown for ornamental purposes and also roasted, for human consumption, and for poultry feed (MCC, 2017). Most seed came from an old open pollinated variety (OPV) known as "Giant of Russia or Mammoth Russian", introduced and multiplied by immigrants. It is estimated that the area, sown in the Colonia Mauricio region, ranged between 400 and 800 ha (Fig. 1) (ASAGIR, 2017).

The second period, between 1930 and 1949, is known as "*The Great Expansion*". This period coincided with conflicts in the Northern Hemisphere, the closure of markets and reductions of Argentine exports to Europe, in particular to the UK. After the war, these markets reopened and exports of oilseeds and oils increased enormously. In June 1941, the Ministry of Agriculture recognized sunflower as an oilseed crop and commercial value was given to the oil obtained (MCC, 2017). The crop spread to the vast territory of the Province of Buenos Aires (BA), and its area increased from 4.5×10^3 ha to about 1.8×10^6 ha in 1949 (Fig. 1) (ASAGIR, 2017).

At that time, farmers used improved varieties adapted to local conditions, the first being "Selección Klein", obtained in the village "Estación Plá", Alberti, (BA) in the 1930s. It was more uniform than the base populations, shorter, earlier maturing and with higher seed-oil content (about 39%). It was followed by other varieties, such as "La Previsión 8 and 9", selected from "Giant Russian", in the experimental station "La Previsión", at Barrow, Tres Arroyos (BA). In Pergamino (BA), the National Institute of Agricultural Technology (INTA) began work at the end of the 1930s with the Russian OPV Saratovsky, from which the improved, shorter cycle OPV "Saratov Selección Pergamino" was obtained (Vázquez, 2002; Bertero de Romano and Vázquez, 2003).

The third period, "*Crisis*" covered 1950–1959. This situation was caused by economic and disease problems. Towards 1953, there were severe attacks of sunflower rust (*Puccinia helianthi*) (Antonelli, 1985), which led farmers to reduce their sunflower acreage, especially as prices were low. As a result, the area sown was reduced to 560×10^3 ha (1954/55), or even less, 480×10^3 ha (1957/58) (Fig. 1) (Bertero de Romano and Vázquez, 2003; ASAGIR, 2017). However, by 1958, a state agency that regulated the seed market was set up (Junta Nacional de Granos) (JNG, 1963). For sunflower, the price which farmers were paid was based on a kernel percentage in the seed of 61%.

The "*Recovery*" period was between 1960 and 1974 when seed companies created varieties with resistance to rust, which contributed substantially to recovery of the sunflower crop. In the 1960s, a series of OPVs were created by INTA: Manfredi INTA, Impira INTA and Cordobés INTA, created in Manfredi, Córdoba Province, and Guayacán INTA, Ñandubay INTA and Pehuén INTA, in Pergamino (BA) (Antonelli, 1985). Except for Pehuén and Guayacán, these varieties came from crosses of cultivated sunflower with wild *H. annuus, H. argophyllus, and H. debilis* ssp. c*ucumerifolius*, which offered resistance to *P. helianthi*. Selection was necessary for oil content and non-shattering properties (Vázquez, 2002; Bertero de Romano and Vázquez, 2003). The OPV "Negro Bellocq" was released by the Ministry of Agriculture Experimental Station of Bellocq in 1972. The private sector also contributed at this time, through the release of Norkinsol and Norkinsol 2 (from Northrup King Seed Company), in 1970 and 1972, respectively. The "Forrajeras Bonaerenses" and "Forestal" seed companies in BA contributed with "Riestra 70", in 1971, and "Forestal Cambá", in 1972, both varieties with higher oil content.

The crop was helped by two important developments. In 1970, geographically referenced crop statistics, including those for sunflower began to be gathered and stored (MAI, 2017). Then, in 1973, a law defining plant breeders' rights was promulgated and is still in force (INFOLEG, 2017). These provided tools to facilitate diagnosis and implementation of agricultural policies and the provision of a legal framework for the marketing of seed and sub-products. Farmers could now claim on the identity and quality of seed while seed companies retained their ownership of inventions. At the end of this phase, the crop covered about 1.3×10^6 ha sown, with an average yield of 0.8×10^3 ton/ha (Fig. 1) (MAI, 2017).

The fifth period, known as "*Dissemination of hybrids*", covered 1975–1999. There was a rise in the interest of farmers, mainly due to the emergence of hybrid cultivars, showing heterosis and improved uniformity. The discovery of genic male sterility, and then cytoplasmic male sterility and fertility restoration, made possible production and dissemination of hybrids on a commercial scale. In 1970, the F1 hybrid Dekalb G104 was the first released in Argentina, obtained using genic male-sterility (Semienchuck *et al.*, 1974). According to its authors, the hybrid produced 30% more oil/ha than the varieties used at that time (Guayacán, Impira and Cordobés). It

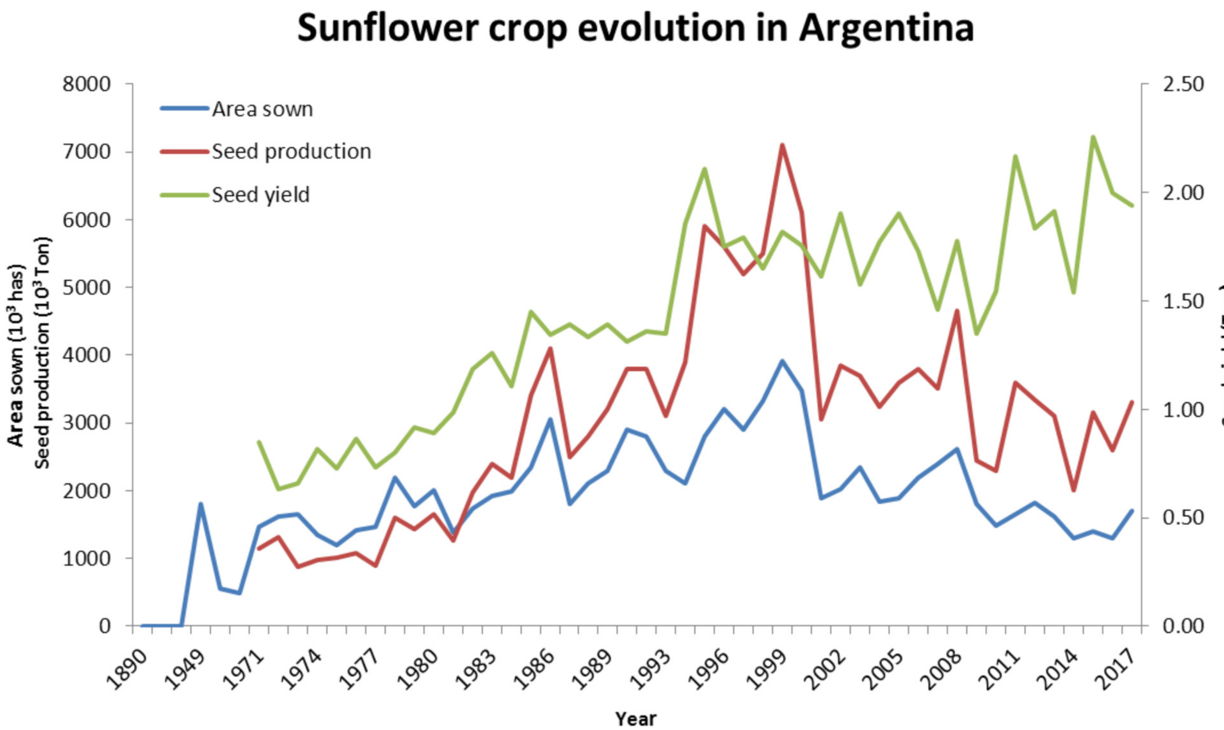

Fig. 1. Evolution of the sowed area, seed-production and seed-yield of the sunflower crop in Argentina from 1890 until 2017. (*Elaborated from ASAGIR, 2017; MAI, 2017; USDA, 2017*).

also showed more uniform flowering and maturity, which facilitated harvest, and greater resistance to lodging. The first cytoplasmic hybrid was Cargill S200 (Monge Navarro, 1977). It should be noted that from 1980/81, USDA Agricultural Statistics published annual quantitative data on area, seed-yield and seed-production of sunflower, within and outside the US.

During the period 1977–1999, there was an increase in the sunflower area in Argentina from 1.46×10^6 to 3.91×10^6 hectares, (MAI, 2017; USDA, 2017). Production increased from 9×10^5 to 7.1×10^6 ton. Yields increased from 0.73 to 1.82 ton/ha in the same period, passing over 1 ton/ha in 1981/82 (MAI, 2017; USDA, 2017) (Fig. 1). This improvement was based on a combination of availability and adoption of technologies and commercial germplasm improvement; at that time, the potential yield of the best hybrids was about 3 ton/ha (ASAGIR, 2017), although maximum national production was 2.1×10^3 ton/ha (Fig. 1). Widespread use and marketing of hybrids created the need to enforce plant breeders' rights and the "Registro Nacional de Cultivares" was started to register cultivars which could then be included in the "Catálogo Nacional de Variedades" where there is information on the variety and the owners of its rights. All varieties that comply with these two steps are legally approved for marketing in Argentina.

In 1979 the first F1 hybrids (Norkinsol 2001 and Norkinal 3005) were registered for marketing. By 1999, seed companies had registered 393 cultivars, of which 65% were F1 hybrids, 29% 3-way hybrids and 6% OPV. The 15 hybrids and the 11 OPV already marketed were allowed to continue and were automatically registered in 1980 (RNC, 2017). The last oil-crop OPV was registered in 1990 and the last confectionery OPV in 1997. There started to be a change in oil composition, with 15 High Oleic and one Mid-Oleic hybrids registered in this period. The peak in the sunflower crop was also reflected in the growth from 8 to 64 national or international seed companies, and also public institutions such as INTA and universities, legally enabled to register sunflower cultivars (RNCyFS, 2017; RNC, 2017). In December 1994, Argentina acceded to the UPOV Convention.

At the beginning of the 1980s, the "Asociación Argentina de Girasol"-(ASAGIR), whose objectives include the promotion and implementation of actions to improve the competitiveness of sunflower in the oil complex nationally and internationally, was created. It has played a key role in the survival of sunflower in Argentina, members representing all value chains. It should be noted that ASAGIR, together with the International Sunflower Association-(ISA), organized the 11th and 18th International Sunflower Conferences, in 1985 and 2012, both at Mar-Del-Plata. It is also responsible for the National Congresses where various current topics concerning sunflower are presented and discussed

Finally the sixth and final period, from 2000 to the present, is known as "*Relocation*". In this period there has been a reduction in sunflower area and production. In 2000, there were almost 3.5×10^6 ha, producing 6.1×10^6 ton, whereas, in 2001, only 1.9×10^6 ha were grown, producing 3.1×10^6 ton. These fluctuations continue today (MAI, 2017; USDA, 2017). Yields also vary, the maximum mean seed-yield of 2.26×10^3 ton/ha being obtained in 2015 (Fig. 1).

Several reasons may explain the farmers' loss of interest in the crop. One was demand for palm oil, produced at a lower cost because it is a perennial crop. Just before 2000, there was also a strong demand for plant proteins for animal feed to provide animal proteins, the world consumption of which had risen from 17.2 kg/inhab./year in 1950 to 36 kg/inhab./year in 1990. In the Mercosur region, this demand was partly supplied by the fishing industry but overfishing reduced fishing grounds and aquaculture gradually developed. The industry producing food for fish required flour and vegetable oils for their formulation and these were found most easily in soybean (Huergo, 2001).

The demand for soybean, for which highly productive cultivars were available, the low-priced field rentals, and the use of direct sowing, resulted in a lower cost of production for this crop and many Argentinean farmers turned to it almost exclusively. Consequently, the sunflower crop shifted to marginal areas where soybean was much less adapted (Añón, 2016). It may be noted that the soybean area in Argentina has increased each year since 1990. In 1993 there were 4.9×10^6 ha, whereas in 2017, soybean covered 19.2×10^6 ha. Maize covered 2.6 and 3.4×10^6 ha in 1993 and 2016, respectively, and 5.1×10^6 ha in 2017 (MAI, 2017). It can be concluded that the sunflower crop has lost to soybean, more than to maize.

Soybean monoculture thus transformed the Argentinean mixed crops + livestock model to almost permanent cropping, especially in the humid pampas. Unfortunately farmers were motivated to gain land for cultivation through deforestation, especially in Northern Argentina. The emergence of the "Round-Up Ready" (RR) soybean facilitated weed control. At present, average seed-yields obtained in soybean in Argentina (2.96 ton/ha.) are similar to those in other leading countries for the crop (USDA, 2017). Soybean became a highly competitive crop in Argentina and the sunflower crop was pushed towards less favorable regions and environments (ASAGIR, 2017), similar to what happened in Western Europe after 1992 (Vear, 2016). Sunflower was grown on soils of relatively low quality, compared to the other summer crops. Also, since it is considered as a good weed competitor, crops were not hoed, reducing yields. Sunflower became a replacement crop when the possibilities for other crops were not favorable (ASAGIR, 2017).

Reduced interest in sunflower by farmers did not discourage seed companies, who registered 487 new cultivars, providing a total of 880 cultivars on the national register. Compared to other periods, modern cultivars have a wider range of uses: 90% are oil-type, 9% confectionary and 1% ornamental. Fourteen High-Oleic hybrids, 2 Mid-Oleic, 17 Clearfield and 4 with HO-CL technology have been registered (RNC, 2017). There are 40 seed companies breeding sunflower (RNCyFS, 2017), 38% less than at the end of the 20th century.

The old OPV have been used as sources of resistance for several biotic stresses. For example, Gulya (1985) released the synthetics HAR (from 1 to 5) derived from "Selección Pergamino", "Impira", "Saenz Peña", "Guayacán" and "Charata". The importance of HAR-1, 3, 4 and 5 is related to their different alleles (*i.e.,* "a", "b", "c" and "d", respectively) for the R4 gene to *P. helianthi,* while HAR-2 has the R5 gene against the same pathogen (Miller *et al.*, 1988). These genotypes also contributed to downy mildew resistance: HAR-4 is the D7 differential line, with the *Pl16* resistant gene to *Plasmopara halstedii*. A cross between HAR-5 and the French line PRS7 generated QHP1, the D8 differential genotype, with *Pl13* (Tourvieille *et al.*, 2000). They also provided some tolerance to the Red winged blackbird (*Agelaius phoeniceus*) in the breeding pools BRS-1, 2 and 3 derived, from Impira (Fox, cited by Harris, 1983). In Canada, the BRS-2 was the origin of the line CM614 with bird tolerance as well as resistance to some races of *P. halstedii*, *P. helianthi* and *V. dahliae* (Dedio and Rashid, 1991).

3 The sunflower crop today

In 2016, cultivated land in Argentina covered 270×10^6 ha, of which 13% were annual crops, including 0.62% sunflower (BCR, 2017). This crop can be grown between 24° and 38° S, in many different environments. The Buenos Aires Grain Exchange has defined 13 zones, where the agency collects *in situ* production data (BCBA, 2017) while breeders have divided the sunflower area into three regions or mega-environments (North, Central and South), for which each seed company releases adapted cultivars (de la Vega and Chapman, 2010). In this paper, the two classifications have been combined as presented by ASAGIR (2017) (Fig. 2).

In Argentina, sunflowers are sown from north to south, as soil temperatures increase. Sowing starts towards the end of July in the Northern region, and extends to mid-December (or even later), in the Southern region. Harvesting is from mid-late October, for the North, and mid-end of April for the South. De la Vega and Chapman (2010) showed some meteorological variables estimated during the crop cycle in each of the three regions, with data obtained between 1991 and 2008 (Tab. 1). These conditions were also related to the phenological phases of the crop.

The Northern region, with a subtropical climate, has the highest average maximum temperature (28.4 °C) and the minimum average photoperiod (13.6 h) and 80% of rainfall during the vegetative (September and October) and the grain filling stages (December). In the Center region, only 64% of rainfall was during the growing season (October–December). The Southern region, which comprises the vast territory located below National Route No. 5 (Vázquez, 2002), has the highest average photoperiod (14.9 h), lowest minimum temperature (9.9 °C) and quite regular rainfall during the growing season (Tab. 1).

In 2016–2017, the 1.7×10^6 hectares sown with sunflower produced approximately 3.3×10^6 ton (Fig. 1) (BCBA, 2017), an increase in cropped area (31%) and production (27%), compared to 2015–2016. Mean yield was 1.94 ton/ha, slightly lower than that estimated (2 ton/ha.) for 2015/16 (Fig. 1) (BCBA, 2017; USDA, 2017). The South had the large part of total area (55%) and production (58%), the average seed-yield was of 2.02 ton/ha (Tab. 2). The North had 33.8% of area and 29% of production and a mean yield of 1.71 ton/ha, while the Center had 12% of total area and 14% of production, but a mean yield of 2.21 ton/ha (BCBA, 2017), higher than the national average.

The decrease in yield in 2016/17 compared with 2015/16 can be related to regional variations in rainfall. In the North, yields were highly variable, associated with excess rainfall during sowing, flowering and maturation (SMN, 2017). This led to more than 5% loss in the cropped area (Arias, 2017). In the South, excessive rainfall in the northern part (SMN17) also

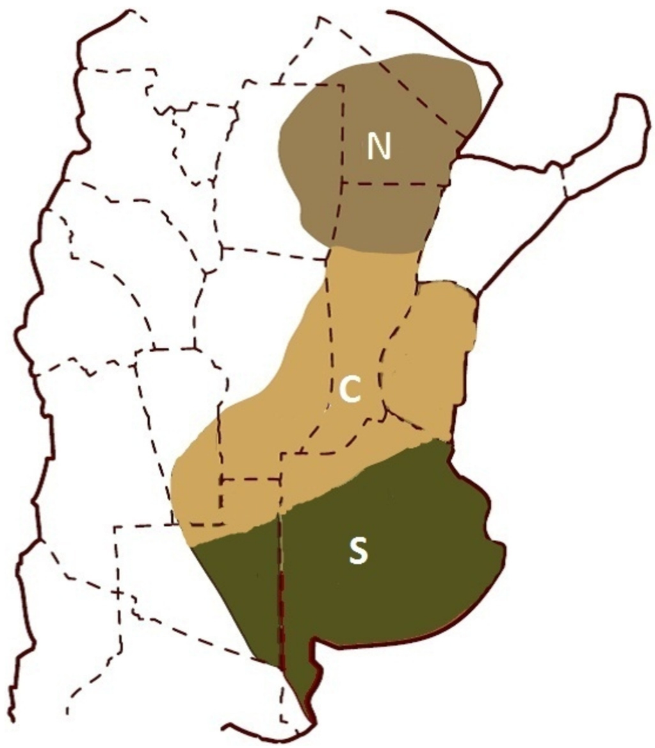

Fig. 2. Sunflower growing regions in Argentina (N: Northern, C: Central, S: Southern) (*Adapted from ASAGIR, 2017; BCBA, 2017*).

Table 1. Mean meteorological variables and photoperiods for sunflower crops over 18 years, measured in several locations of the Northern, Central and Southern regions in Argentina (A*dapted from de la Vega & Chapman, 2010*).

	(*)Rainfall (mm)	(*)T °C Mx.	Min.	(*)Photoperiod (h)
North	467	28.4	15.1	13.6
Central	492	26.7	15.3	14.7
South	453	26.7	9.9	14.9

(*) During the sunflower growth cycle: sowing-grain filling.

Table 2. Contributions of each region to the total area and production of sunflower during 2016/2017 in Argentina, and mean yields.

	Area (%)	Production (%)	Yield (ton/ha)
North	33	29	1.71
Center	12	14	2.20
South	55	57	2.02

caused a decrease in the yield and/or problems while harvesting (Arias, 2017) whereas in the southern most part crops in shallow soils suffered from water stress (SMN, 2017), and produced low yields (Arias, 2017). Pests such as Yellow woolly bear (*Spilosoma virginica*) and Tiny bug (*Nyslus simulans*) also played an important role in this season, reducing yields.

4 Crop management

Argentina is a pioneer of the system of direct sowing without soil removal, and it is preferred by Argentinean farmers. The AAPRESID (*e.g.,* a non-governmental body with interest in soil conservation) indicated that, in 2014/15, 90% of the total crops area used direct sowing (Nocelli Pac, 2016). It concerned 80% of sunflower (1.15×10^6 ha) but 92% of soybean and 94% of maize. This percentage varied little between regions. However, in 2016/2017, in the SW of the Southern region, only 60% of crops were sown in this way, mainly due to the appearance of Hairy fleabane weed (*Conyza bonariensis*), which became resistant to glyphosate and whose germination and emergence is significantly favored by direct sowing (Montoya, 2016).

Clearfield hybrids were widely adopted by farmers who use direct sowing (Vázquez and de Romano, 2006), more in the South region (75%), compared to the Center (60%) and the North, where, in 2016/2017, they were sown on only 1.5×10^3 hectares, equivalent to 3% of the total sunflower crop (Bertero, A. com. pers.).

In 2014/2015, 29% of sunflowers in Argentina were High-Oleic hybrids (HO) but the figure increased to 50% a year later. However, there was a record production by Black Sea countries in 2016, such that their exports, together with those from Argentina, flooded the market with HO sunflower. This oversupply caused a reduction in demand, a decrease in price and a loss of interest of local farmers (Adreani, 2016). It is thought that, the area under HO sunflower was significantly reduced in 2016/2017.

In Argentina, lack of nitrogen (N) and phosphorus (P) in the soil could limit production, since these elements are essential to obtain potential yield. It is assumed that 80% of sunflowers are fertilized with N and P, a proportion higher than the average for other extensive crops, but at a lower rate, which covers only 20% of the requirements of the sunflower crop, compared with 40% for soybean and maize. In spite of the good responses for seed yield when water is sufficient, in Argentina, sunflower receives the lowest nutrient input (Díaz Zorita and Fernández Canigia, 2010). To obtain yields of 3 ton/ha, 120 kg N/ha (soil + fertilizer) are necessary (Zamora, 2009) and also 35–50 kg/ha of P, as Diphosphorus pentoxide (Berardo *et al.*, 2003). However, these values are far from being supplied by farmers. In 2011, 7–17 kg N/ha, and 10–13 kg P/ha were applied (RETAA, 2017), although there was more N fertilization in the Northern region and some locations in the Central and Southern regions while higher rates of P fertilization were applied in certain areas in the center and south (RETAA, 2017).

Weeds are an important problem. A survey conducted by Gries (2003) in SW Central region, and NW; SW and S of the Southern region, showed the frequent appearance of *Digitaria sp.*, *Chenopodium sp*, and *Setaria sp.*, as well as Annual bastard cabbage (*Rapistrum rugosum*), Bathurst burr (*Xantium spinosium)*, Bermuda grass (*Cynodon dactylon*), Common purslane (*Portulaca olebreedae),* Fierce thorn-apple (*Datura ferox*), Mexican marigold *(Tagetes minuta*). This range still remains to a greater or lesser degree in all three regions, caused by the misuse of herbicides and/or direct sowing (Guevara, 2016; Montoya, 2016; Bedmar, pers. com).

For weed control, some specialists suggest the development of a chemical fallow by applying glyphosate mixed with some pre-emergence herbicides such as Sulfentrazone, Diflufenican or Flumioxazin (according to the type of weed). In Argentina in 2010/2011, common glyphosate was used at an average rate of 3.5 l/ha and concentrated glyphosate at 1.2 l/ha. (RETAA, 2017). For the same season, the national average use of pre-emergent herbicides, Acetochlor and Flurochloridone (which are both of low cost), was 1 l/ha, to control grass and broadleaf weeds respectively (RETAA, 2017). For early post-emergence, Imazapir (from the imidazolinones group) was used for Clearfield hybrids (IMI) and Imazamox and Imazapir herbicides on Clearfield Plus hybrids only. There is no national data on the intensity of use of these broad-spectrum herbicides.

Unfortunately, in Argentina, the emergence of weeds resistant to herbicides is occurring with all crops. A network coordinated by AAPRESID alerts on the levels of threat of those weeds that showed resistance to a specific herbicide and/or its mode of action, and their dispersion. Currently there is a red alert (*i.e.*, maximum level) for 28 biotypes of 17 weed species, including several found in sunflower: Field mustard (*Brassica rapa*), Goose grass (*Eleusine indica*), Italian ryegrass (*Lolium multiflorum*), Johnson grass (*Sorghum halepense*), Jungle rice (*Echinochloa colona*), Mucronate amaranth (*Amaranthus quitensis*), Palmer amaranth (*Amaranthus palmeri*), Sourgrass (*Digitaria insularis*) and the already mentioned Hairy fleabane (*Conyza bonariensis*) (REM, 2017).

It is very likely that the emergence of weeds resistant to glyphosate, is due to the wide adoption of the technological package used in Argentina since the 1990s. Transgenic soybean monoculture and the use of high concentrations of glyphosate are probably the main factors responsible for the resistance problem. At present, to discourage the emergence of resistant weeds, much emphasis is made on the imperative need to use less residual herbicides, including some with different modes of action and, above all, at the rates recommended. Crop rotation and cover crops such as oats and common vetch during winter are also being taken into consideration, because not only do they delay weed emergence but they also help to improve soil infiltration and reduce soil erosion by water or wind.

In a few cases, pest control has been necessary. In the Southern region, some fields have had a large numbers of Gray field slugs (*Deroceras reticulatum*)/m^2, reducing emergence. Specific toxic baits were used, made with flour, semolina and 5% Metaldehyde. Other field pests including the measuring worm *Rachiplusia nu,* Mosquito head fly (*Melanagromyza minimoides*), Southern green stink bug (*Nezara viridula*), Brown-winged stink bug (*Edessa meditative*), as well as *Spilosoma virginica* and *Nyslus simulans*, have been controlled with Cypermethrin (broad spectre) and Chlorpyrifos (RETAA, 2017). Pesticides have also been used during grain storage, before oil extraction or export. In Argentina, the type of pest varies according to storage characteristics. In the widely used silo-bag, rodents and anaerobic bacteria cause a lot of damage while, in conventional silo-bins, the problems come from the insects, mites and aerobic bacteria.

For many years, ASAGIR has reported the need to control storage pests with Phosphine/Aluminum phosphate at the concentrations recommended. It is known that pesticides can contaminate oil, but as these products degrade with time, residues are limited. In Argentina, the maximum concentration permitted is 0.1 mg/kg, which coincides with the limit authorized by the EU. This has been a significant improvement; not long ago, pesticides such as Dichlorvos, Fenitrothion, Malathion, and Endosulfan, were mainly used at exaggerated concentrations. Certain exports to the EU had residue thresholds between 3.5 and 250 times higher than those allowed, which led to refusals of Argentine grain to this large region. Sunflower, as a summer crop, is affected by a number of important diseases, mainly fungal infections, during periods of medium-high relative humidity. In some fields, Triazole and Strobilurins have been applied, as a preventive measure, against Rust (*P. helianthi*), Leaf spot (*Alternaria helianthi*) and Black stem (*Phoma macdonaldii*), but their use is not widespread as it adds to production costs.

5 Argentine sunflower trade

Sunflower oil is not the most widely used in the world. In 2015/2016, of 175×10^6 ton of vegetable oil consumed, 34% was palm oil, followed by soybean, rapeseed and then sunflower. For every liter of palm oil, less than ¼ liter of sunflower oil was consumed (STATISTA, 2017). Why such a difference? Although palm oil is mainly composed of saturated fatty acids, considered as less healthy, it is cheap, and very versatile, being used in both cuisine and pastry, and in cosmetics, pharmacology, industry (biodiesel) and cleaning products.

However, forecasts are for a recovery in the demand for sunflower oil, due partly to a lesser use of palm oil, especially in the EU, due to health questions and because its production is regarded as environmentally unfriendly. There may also be a direct increase in sunflower demand. Research at the Oil World Statistics found that, in 2015, sunflower production grew 5% and domestic consumption 10%, compared with 2012. This increase, which was driven by lower production costs and increased quality, resulted in a world deficit, and the report forecasted a firm demand for sunflower oil, with sustained prices (Calzada *et al.*, 2015). In 2016, more sunflowers were grown worldwide than in previous years, 39.4×10^6 ton, giving 15.1×10^6 ton of oil (USDA, 2017). It was forecast that by 2030, production will increase by 16% and by 2050, 32%, reaching 58.3×10^6 ton of oil. In 2016, Ukraine, Russia, the European Union and Argentina, the main producers in decreasing order of importance, providing 82% of world sunflower oil (USDA, 2017). If predictions are fulfilled, all countries, including Argentina, could increase their production.

In Argentina, 98% of sunflower production is processed industrially (Añón, 2016), producing, in 2014, from 2.2×10^6 tons of seed, 9.3×10^5 ton of raw oil, 9.4×10^5 ton of meal and 7 ton of hulls (Calzada *et al.*, 2015). Local raw oil production was divided in fairly similar parts for domestic consumption and export. In 2016, about 5.6×10^5 ton of oil was exported to the main destinations, China, India, Malaysia and Egypt, accounting for almost 50% of shipments (Calzada, 2016). Within Argentina, production was used primarily for human consumption, with about 13 kg/year per capita (MAA, 2017). The raw oil is obtained in one of the 51 oil plants, belonging to 37 firms that process sunflower and soybean seeds (Añón, 2016). This oil is refined to limit acidity, eliminate waste and modify (if necessary) color and flavor. Refined oil production is mainly for domestic consumption, although there was also an exportable balance, especially for Chile and Paraguay. Meal and hulls are used in monogastric and ruminant animal production.

Sunflower oil is also used to produce biodiesel. Since 2008, 6 industrial companies and some independents are dedicated to biodiesel production. This activity has grown because, since 2016, at least 10% of diesel fuel must contain local biofuel (MEM, 2017). However, 50% is exported, about 1.4×10^6 ton in 2011, worth more than 2.1 million dollars. Eighty percent went to Spain, the Netherlands and Italy (Añón, 2016). A recent forecast suggested that biodiesel production from all oil crops, will reach 2.5×10^6 ton by 2024, equivalent to 64% of domestic vegetable oil consumption (OCDE-FAO, 2015). Of the total amount, an important part could be provided by sunflower.

In Argentina, a series of conditions must occur in order to increase the demand for sunflower oil. It was suggested that, by 2020, individual consumption should be increased from 1.4 to 2.3 kg/year/person (Domínguez Brando and Sarquis, 2012). For this, the product must have increased attractiveness and quality in terms of industrial functionality and nutritional content. Cultivars exist with a combination of saturated and unsaturated fatty acids in their oil, as well as high tocopherol contents (Pozzi and de la Vega, 2009). The use of sunflower proteins in human diets should also be considered. For processing, amounts of waxes and residues left after refining should be reduced, but without increasing costs and decreasing competitivity with, for example, soybean oil that generates less waste. A lower Biodiesel "cold filter plugging point" (freezing temperature) would reduce the addition of additives.

To increase the demand for sunflower oil, a relative decrease in production costs would be helpful. This could be by increasing seed-yields. A recent study has shown that, in several areas, sunflower has a potential yield of 4–5 ton/ha (Hall *et al.*, 2013). These authors attributed the gap between potential and mean yields to crop management, and to the presence of stresses during cropping. It should be possible to narrow this gap to obtain more stable yields over several years, of at least 2 ton/ha, as obtained in 2011, 2015 and 2016 (Fig. 1), and similar to those in France, Turkey and Ukraine but less than those reported in China (Vear, 2016; USDA, 2017).

Today, in Argentina, there are macroeconomic incentives to increase the sunflower crop, related to the elimination of export duties, known as "tax withholding", which are taxes levied on foreign trade. Until December 16th, 2015, sunflower export was practically unfeasible, due to a 32% tax withholding for seed and 30% for oil but then the levy was removed, while it was maintained at 30% for soybean. State intervention thus permitted an increase in farmers' incomes and, in 2016/2017 there was a 31% increase in the area of sunflower (Fig. 1).

To take advantage of "the best winds" for international sales, especially to the EU, seed, at the destination port, must contain negligible or no pesticides residues. This is not a minor issue, because of the long duration of storage and transportation whereas countries around the Black Sea do not have this problem since they are close to their destination markets. In addition, there must be no mix between HO and conventional seed. ASAGIR reports frequently on the need to indicate this characteristic on the loading bill, to make possible different destinations and industrial uses.

A recovery of the sunflower crop in Argentina should generate greater grain production and this may make evident structural constraints in relation to grain storage and conditioning capacity in Argentina. It could also highlight some problems in movement and transportation of grain and their by-products, either by land (road and rail) or river (Añón, 2016). Transport is expensive in Argentina, it appears important to reduce the incidence of freight rates on production costs for growers who are at greater distances from port terminals and final destinations compared with other sunflower growing countries.

In 2016, because of overproduction, HO oil that was a "speciality" became a "commodity" (Adreani, 2016) of less interest for farmers. With the aim of increasing sunflower acreage, this must be avoided so that farmers can continue to receive a premium for producing quality oil, which requires a high level of crop management.

6 Research and strategies developed aimed at the main problems for sunflower

Research by public (Universities and INTA) and private institutions (Seed Companies), unilaterally or with collaboration, aims at resolving problems of national and international interest, to try to ensure that potential yield of sunflower will be reflected at harvest. Collaboration is important since potential risks, capital and resources (almost always scarce) and "know-how" are shared. Some of the main results are very briefly presented below.

Biotic stresses, caused by a large number of organisms, produce substantial variations in yield across localities and/or years. The "Red Territorial de Sanidad Vegetal" involving professionals from the public and private sectors, has its headquarters at the "Unidad Integrada Balcarce-UIB (Facultad de Ciencias Agrarias-UNMdP / EEA Balcarce-INTA)." Its main objective is to implement alarm systems and advise on disease management through reports which can be accessed on-line, from the geo-referenced records of diseases detected annually in plots and fields of sunflower in a large part of the Southern region (RETSAVE, 2017).

To control Verticillium wilt *(Verticillium dahliae)*, the use of rotations with non-susceptible crops and sunflower cultivars with good resistance has been proposed (Quiróz, 2014). Breeding for resistance generally aims at combining resistance genes to the four prevailing Argentinean races, two of which (VArg3 and VArg4) have been recently described (Clemente *et al.*, 2017). At UIB, research suggested that the performance of cultivars could be measured through a selection test on seedlings grown under controlled conditions (Crova *et al.*, 2016).

Research on Downy mildew *(Plasmopara halstedii)* indicated that by 1998 races 300 and 330 predominated in the country. Then, when races 700, 710, 730 and 770 appeared, breeders had to introduce the corresponding resistance genes

(Vázquez and de Romano, 2006; Bazzalo *et al.*, 2016). The growth of direct sowing could be a cause of increased presence of Downy mildew. Also, application of Metalaxyl to seed of varieties without resistance may have favored the emergence of races resistant to this fungicide (Quiróz, 2014). Since 2013, the *Pl15* resistance gene has been overcome, indicating the appearance of a new race. Work on the identification of virulence genes could help the development of resistant hybrids (Bazzalo *et al.*, 2016). Integrated management of the disease is proposed, using of disease-free seed, non-susceptible crop rotations and fungicides, based on active ingredients such as Azoxystrobin or Fludioxonil + Metalaxyl (Quiróz, 2014; Bazzalo *et al.*, 2016).

Moreno *et al.* (2012) reported that race 700 of Sunflower rust *(P. helianthi)* was prevalent in Argentina and that the inbred-lines P386, HAR-3 and HAR-4 were reliable resistance sources. However, to increase accuracy in the detection of new races and thus assist breeding for resistance, it was proposed to increase the number of differential lines.

In Argentina, considerable research on White rot (*Sclerotinia sclerotiorum*), has been carried out, concerning field evaluation of the disease and control methods. In 1988/1989, when only 4% of cultivars grown were moderately resistant, there was a severe epiphytotic, mainly in the Southern region. In 2012/2013, this proportion had increased to 48% (Quiróz, 2014). Reactions of cultivars to *S. sclerotiorum*, *P. helianthi* and *V. dahliae* in the South region (Troglia *et al.*, 2016) are published by the "Red Nacional de Evaluación de Cultivares" coordinated by INTA and ASAGIR. This information helps farmers to choose the most adequate cultivar. To control white rot, it is recommended to regulate sowing date so that the flowering period (the most susceptible to infection) does not coincide with rainy periods and to use cultivars with good levels of resistance (Quiróz, 2014). Research programs at UIB have concerned: 1) Measurement of the stability of partial resistance to White rot across years and identification of cultivars that showed stability to the disease progression at its early stages (Dinon *et al.*, 2016); 2) Determination of molecular markers of resistance by association mapping, aimed at assisting breeding for resistance (Zubrzycki *et al.*, 2012); 3) Development of a strategy to increase the efficiency of distinction between cultivars with or without sufficient levels of resistance, making optimum use of the resources available (Delgado *et al.*, 2012).

None of the three growing regions are free from bird damage during grain filling. The areas most affected are the Center region and the southern part of the Northern region, mainly by Eared doves (*Zenaida auriculata*) and Monk parakeets (*Myiopsitta monachus*) (Canavelli, 2010). A strategy to moderate damage suggests the application of desiccants to reduce grain exposure time. The use of insect repellents and/or the sowing of tolerant cultivars has also been suggested. Cultivars with inclined capitula and large striped seeds appear to be less visited by Eared doves (Zuil, 2016).

Some economic damage by Gray field slug (*D. reticulatum*), Pillbug (*Armadillium vulgare*) and Greehouse slug (*Milax gagates*), in the sowing period, and by Tiny bug (*N. simulans*), during grain filling, has been reported in the South region, with possible control by insecticides (Faberi, 2014) or changes in sowing date (Renzi *et al.*, 2016).

Abiotic stresses, caused by environmental factors during crop development, reduce yield. They also limit expansion of sunflower to less favorable cropping areas. Water deficits are currently affecting some regions, and it is likely that this issue will grow due to global climate change. We need therefore to develop cultivars tolerant to drought and one of the traits to be selected is foliar growth during a water deficit period. At UIB, a low cost automatic platform for high-throughput measurements of plant water use and growth was developed. In a set of recombinant lines, this technology made it possible to detect a QTL associated with leaf growth response to water deficit and recovery after re-watering (Aguirrezábal, 2012). Currently, studies are oriented to the detection of this QTL in other genotypes and its validation for plants grown in the field.

Some morphological characteristics that allow sunflower to cope with high temperature during yield generation have been studied at UIB. It was found that, on inclined capitula, grain filling is less affected compared with those fully exposed to the sun. In the Northern region such genotypes would be desirable, in addition to limiting bird damage (Izquierdo, 2014).

Winter crops before sunflower are being grown increasingly by farmers, particularly those in the Southern region. It allows them to diversify production, use land intensively and, last but not least, increase their income by harvest of two annual crops. However, a winter crop can cause later release of the field, according to whether it is wheat, barley, rapeseed or pea, which means that direct sowing of sunflower may be carried out at a non-optimal date. Despite vegetative plasticity, water supply and radiation may not coincide with the demand by sunflower in its critical periods, especially during grain filling (Calviño, 2010). Lesser radiation and water availability during this critical period, can shorten the life of leaves and promote their senescence (Martínez Verneri *et al.*, 2016) and may also lead to a dilution of phytosterol concentration in oil (González Belo *et al.*, 2016) and/or reduce resistance to Black stem (*P. macdonaldii*) (Nuñez Bordoy *et al.*, 2016). All these effects may reduce yields and oil quality, so, in addition to appropriate agronomic management, specialists are advised to evaluate adequately the economic benefits of sowing sunflower crops at sub-optimal dates (Calviño, 2010).

The challenge to sunflower breeders in Argentina is the development of cultivars specifically adapted to the different regions to maximize genetic progress per unit of resource invested in breeding programs (de la Vega, 2012) and provide farmers with cultivars having improved performance for seed yield and oil quality and quantity.

7 Final considerations

In spite of variations in production, sunflower is a crop that is rooted among Argentinean farmers. However, growth of interest in the crop would be favorized by some internal and external conditions. Export duties were eliminated recently, which encouraged farmers to sow more sunflowers in 2016/2017 but municipal, provincial and national taxes still affect most sales of sunflower grain and their reduction would increase competitiveness and interest in the crop. Internationally, to favor Argentinean sunflower production, consumer demand must be maintained or increased, and there should not be too much increase in the crop in other producing countries. Nationally, the sunflower interprofession should consider Argentina as a reference, not only for its participation in international markets, but also for its research and technology development related to the crop.

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