Sunflower seed production: past, present, and perspectives

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ABSTRACT

- The goal of a sunflower seed production program is to produce seed that is genetically and physically pure, physiologically sound and relatively free of pathogens. High quality seed should be genetically identical to the cultivar released by the breeder, have a high germinative power, tolerate reasonable levels of environmental stress, be free of pathogens that can affect stand establishment or plant development, and be free of seeds of weeds, other crops, or inert material. At the same time, this high quality seed should be obtained at reasonably costs in order to support the seed industry business, and the subsequent investments in research and development activities. Undoubtedly, this later issue indicates that increasing the *number of seed bags produced per hectare* —and not simply and directly *seed yield*— is of paramount importance for sunflower seed production and the main focus of this review.
- During the last decade, the number of seed bags per hectare was increased over time by two different ways. Plant breeding contributed to this gain in productivity mainly by developing female parental lines with and increased percentage of seeds with high commercial value. On other hand, management systems to produce sunflower seeds changed over the years by (a) increasing the knowledge about female productivity, pollen production by restorer lines and its variability, and flowering synchronization of both parental lines; (b) optimizing the efficiency of traditional practices, such as planting, isolation, planting ratios of parental lines, visual rouging and pollination management, (c) introducing new practices, such as chemical rouging. The integration of quality assurance with the production practices led to a complete traceability of the sunflower seed production, from the field to the farmer. This, in turn, gave the opportunity to introduce timely corrective actions and to improve the whole process continuously.
- The perspective for sunflower seed production is to increase the number of seed bags produced per hectare and to reduce the yield gap that exists between the yield of the female lines evaluated in experimental plots under the best agronomic conditions and the actual yield obtained in the seed production fields.

Keys Word: management practices, seed production, seed quality

INTRODUCTION

Current seed production systems of sunflower evolved as a result of two significant events: the discovery of the cytoplasmic male sterility by Patrice Leclercq (1969) in France and the subsequent report of the fertility-restoring genes by Murray Kinman (1970) in USA. Both discoveries greatly enhanced expectations of successful hybrid sunflower seed production, since it became evident that the same biological systems used to produce hybrid cultivars of maize or grain sorghum on a field scale was possible with sunflower.

The goal of a sunflower planting-seed-production program is to produce seed that is genetically and physically pure, physiologically sound and relatively free of pathogens. High quality seed should be genetically identical to the cultivar released by the breeder, have a high germinative power, tolerate reasonable levels of environmental stress, be free of pathogens that can affect stand establishment or plant development, and be free of seeds of weeds, other crops, or inert material. At the same time, this high quality seed should be obtained at reasonably costs in order to support the seed industry business, and the subsequent investments in research and development activities. Undoubtedly, this later issue indicates that increasing the *number of seed bags produced per hectare* —and not directly *seed yield*— is of paramount importance for sunflower seed production and the main focus of this review.

Sunflower hybrid seed production, as it is the case in other crops, is mainly the result of the effect of the parental inbred lines of the hybrid cultivar, crop management practices, environmental conditions, and the interactions among these factors. Environmental variables such as precipitations and extreme temperatures during flowering seem to be the most important variables for yield determination (Chimenti et al., 2001; Connor & Jones, 1985). Selection of the most appropriate sowing date for each geographical region permits to alleviate the adverse effect of both variables. Likewise, aspects such as female productivity, pollen production, the management of floral synchrony between parental lines, are also of great importance in maximizing seed yield production. However, a great difference between the wind-pollinated cereals, like sorghum or maize, and the entomophilous sunflower is that the pollinator management plays a central role in the production of this crop. In this sense, the management of bees in the production fields will be discussed with greater detail.

SEED PRODUCTIVITY

Management systems to produce sunflower seeds changed over the years in order to increase the number of seed bags produced per hectare. To illustrate this issue, seed yield/ha of two representative hybrids of the same seed company during a period of 15 years were plotted in Fig 1A. Average seed per hectare can be divided in two different subperiods. From 1998 to 2006; average seed yield per ha was approximately 50 bags/ ha. From 2006 up to the present, on the other hand, average yield per ha increased to 75 bags/ha. Moreover, it can be observed in Fig. 1B that in the last 5 years the proportion of plots with seed yield below 40 bags/ha have been reduced, while the plots with average seed yield greater than 80 bags/ha have been increased (Fig. 1B).

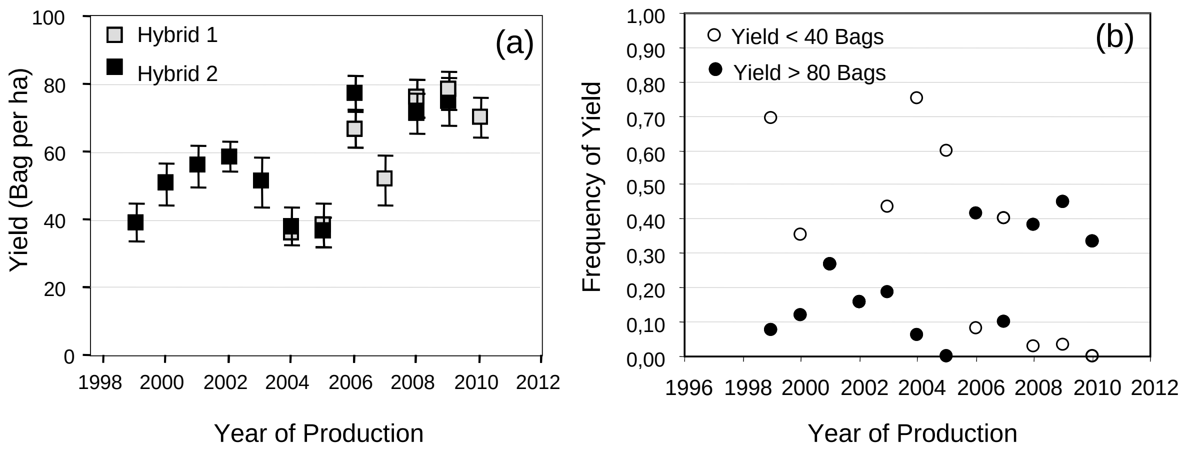

Fig. 1- Seed production for two representative commercial hybrids. (A) Yield evolution (bags/ha) during 1998-2011 (values are mean ± standard error). (B) Frequency of sunflower seed production fields with yield below 40 (○) or higher (●) than 80 bags/ha during the same period.

Several crop management strategies contributed to reach this yield improvement. Among them: (i) the adjustment of the floral synchrony of the parental lines of the hybrid, by the use of the thermal time concept that allow a better estimation of their phenology and the adequacy of their planting dates; (ii) the displacement of the sunflower seed production fields to geographical regions that permit to obtain higher yields and more stability; (iii) advent of post-emergent herbicides that permit a more efficient control of weeds; (iv) better pollinator management, especially the number of hives/ha to use, the right moment to introduce them, and the inspection and control of bee hive strength.

CHARACTERS OF PARENTAL LINES AFFECTING SEED PRODUCTIVITY

Female productivity

The number of bags produced per unit area, known as seed productivity, is determined by the average number of seeds per plant and the average size of these seeds. Both variables could be modified by management practices, such as the geographical region where the seed is produced, date of sowing, planting ratio of parental lines, and crop density, among others. The pattern of distribution of seed sizes of an inbred line grown in a given environment influences the number of bags produced by land area. For example, in our company seed sizes higher than 4.75 mm (>G3) are sold in 150 000 units bags, while seeds that measure between 2.5 mm and 4.75 mm (G3E) are sold in 250 000 units bags. Seeds that are smaller than 2.5 mm (<G3E) have no commercial value and are discarded.

The number of seeds, as well as the size of the seeds, is controlled genetically. Variability among female inbred lines is frequently found (Yue et al., 2009). In order to analyze this variability and the contribution of breeding on productivity, 10 lines belonging to different years of release were evaluate in nine environments sites (a combination of three locations and three sowing dates). It was observed that during the last decade seed yield of parental inbred lines showed a slight increased (Fig.2). However, the great change in female productivity was related with the size of the seeds. In fact, female lines were improved in order to produce more bags of the highest seed size (>G3) per hectare, with better commercial value, while decreasing the bags with smaller seeds size (G3E).

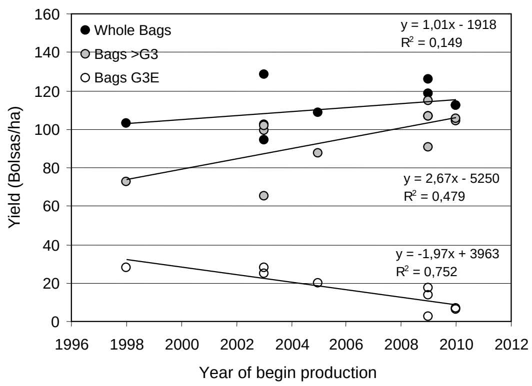

Fig. 2 - Yield (bags/ha). Total bags (●); bags with seeds bigger than 4.75 mm (G3; ○); bags with seeds between 2.5 mm and 4.75 mm (G3E; ○) for 10 lines released in different years.

Pollen production by restorer lines

Most of the sunflower restorer inbred lines have a compound inflorescence. It develops a principal head and a variable number of secondary or axillaries heads. This determines that pollen production usually spans during a period of 10 to 15 days. However, there is variability for pollen production among different inbred lines. For this reason, and in order to have enough pollen offer in production fields, variables such as plant population density and planting ratio of the parental lines must be taken into account. At the end of the flowering period of the female line, the remaining male plants should be destroyed to avoid seed contaminations during harvest, and, hence, to assure the genetic purity of the hybrid seed.

Flowering synchronization of parental lines

In sunflower, days to flowering is controlled primarily by genotype, photoperiod and temperature (Goyne et al., 1977; Mark and Palmer, 1981; León et al., 2001). Floral synchrony or nicking between parental lines used to produce the hybrid seed is obtained mainly by delaying the planting date of one of the parents (split). The objective is to optimize seed set by increasing pollen supply when the stigmas are receptive.

Assessment of days to flowering of each line is carry out using the concept of thermal time (ºC day or GDU); taking 6°C as basal temperature and 27°C as optimum temperature. As the method is independent of thermal differences between years, differences among lines for days to flowering arise basically because of differences in photoperiod sensibility of the lines. To characterize the photoperiodic sensibility of each genotype, parental lines of commercial and advanced hybrids are evaluated in trials across different regions and using an ample range of sowing dates.

MANAGEMENT PRACTICES TO INCREASE SEED PRODUCTIVITY AND QUALITY

Selection of the production area

Several variables are important to be considered when selecting the area to produce sunflowers seeds. High photoperiod, heliophany and low relative humidity during flowering, optimum temperatures during seed filling, the possibility to use irrigation systems and, hence, the quality of the water, are some of the most important aspects to be taken into account. However, each production area should be initially evaluated for their interaction with the parental lines to be produced.

Planting

It is important to establish a uniformly distributed plant population so that the maximum hybrid-seed yield of a desirable seed size can be obtained. Selection of a planting system depends on the equipment available, parental seedstocks, pollen-shedding ability of the male parent, field layout, and crop management system to be utilized. Seedbed preparation should facilitate a consistent seeding depth to ensure a uniform and predictable date of emergence. If moisture is not readily available, care must be given to place the seed into moisture, especially when split planting are necessary. Depth of seed placement, different planting dates, and split irrigation schedules aid in synchronization of flowering of parental lines. Seed treatment of parental seeds with fungicides and insecticides is recommended to minimize pathogen attacks and, hence, to maintain the desirable plant density.

Isolation

In order to ensure a higher genetic quality of the seed produced, the female inbred line should receive pollen only from the corresponding male inbred line. Because of this reason the production fields must be isolated from pollen from other sources. The isolation could be (i) *spatial*; the field must be isolated from another sunflower more than 1500 m or (ii) *temporal*; staggering planting of neighbor fields by at least 400 GDU.

Planting ratio of parental lines

The planting pattern for F1 hybrid seed production is alternating female and male rows. Yield per hectare is determined by the planting ratio of both parental lines. For example, in our company the 6:2 ratio (6 rows of female and 2 rows of male) was used during many years. This ratio led to a 75% of the area to be harvested. It was possible to increase this area by changing the female to male planting ratio. Currently, an 8:2 ratio is used which permitted to raise the harvested area to 80%. The main factors influencing the possibility to change this ratio are the pollen-shedding ability of the male and the female requirement for pollen.

Rouging

Rouging can be defined as the removal from the seed production field of all undesirable plants that do not meet the phenotypic description of the parental lines (offtypes). The aim of this operation is to ensure varietal purity required by commercialization standards. Although it is desirable to remove 100% of offtypes, this goal is difficult to achieve.

Parental seed with high levels of genetic purity significantly reduce labor requirements for rouging. There are different types of rouging. Chemical rouging is the application of a selective herbicide over the parental lines. It is used in the seed production of herbicide-tolerant hybrids and permits an important weed control plus a residual effect, and even most important, permits to kill sunflower susceptible plants, which are offtypes**.** Depending on the herbicide tolerance trait involved different herbicides can be used for chemical rouging. Visual rouging during vegetative stages is carried out between V4 and V8, and consists in removing off-type plants based on several characters such as height, and shape and color of the leaves. Visual rouging during reproductive stages is carried out from pre-flowering to the end of flowering using a different set of characters, such as neck position, size and shape of the bracts, type of branching, and color of the stem or the petiole. Especial consideration is given to the presence of fertile plants in the female rows and to the presence of sterile plants in the male rows.

Pollination

Honeybee (*Apis mellifera* L.) pollination activity is very important in seed production of hybrid sunflower although other insects can cooperate (Schmith et al., 1978; De Grandi-Hoffman & Watkins, 2000). Bees' activity and its visit to the heads of both parental lines are necessary for seed set. In some cases bees have differential preference for one of the two parental lines. This difference can be explained by differences between lines for nectar production, and for concentration and quality of sugars (Basualdo et al., 1999; Degrandi-Hoffman & Martin, 1995). At the same time, nectar quality and production is affected by temperature and relative humidity. However, differences on yield are mainly associated to the number of bees in the system. Some morphological traits of the lines, such as corolla length, could be a physical barrier for pollination. Lines with longer corollas or, those lines that elongate their corollas under certain environmental conditions, will not allow the bees to reach the base of the nectary. Under these circumstances, bees will look for another source of nectar and will not pollinate the sunflower (Shein et al., 1980). Honeybees show different levels of preference for the flora surrounding the hive. Both pollen and nectar foragers participate in the pollination of crops, being the nectar foragers usually in a larger number (Robinson, 1978). Even when the crop is in full flower, a good nectar or pollen flow from other plants can attract the bees away from it (Crane, 1990). Pollen sources nearby sunflower fields attract pollinating honeybees (Bedascarrasbure et al.1985; Andrada et al. 2004). In fact, bees that only get pollen from sunflower may suffer from moderate physiological and nutritional stress, as revealed by their reduced survival (Schmidt et al., 1995), while collection of pollen from different species ensures a varied diet, satisfactory for their development (Louveaux, 1968). For this reason, the inspection and control of bee hive strength during flowering is of vital importance.

QUALITY ASSESSMENT

Quality assessment should provide accurate and on time information to take the best decisions in order to reduce production cost, meet commercialization standards and customer expectations. To reach this goal, quality assurance should start in the production field and should continue until the seed is dispatched to the farmer. Hence, the integration of quality assurance with the production practices led to a complete traceability of the seed. This, in turn, gives the opportunity to introduce timely corrective actions and to improve the whole process continuously.

Quality assurance procedures start with the control of the isolation of the production fields, follow all the development of the crop and the management practices under field conditions, and continue after harvest, during seed transport, and arrival to the process plant, when the seed is pre-cleaned, sampled, and evaluated for its physical purity and physiological status using ISTA recommendations and rules. Seed dormancy is a key issue in this last process. Even though there are several procedures to break seed dormancy, the physiology and genetics of this trait continue to be active areas of research. Seed purity testing is also an area of continuous developments, especially when the first herbicide tolerance traits in sunflower were launched to the market (see, for example, Katz et al., 2012). Determination of off-types is carried out in off season nurseries and is complemented by the assessment of trait purity by bioassays and molecular markers (Bulos et al., 2010). All these points of monitoring and control permit to obtain a reliable, solid, and transparent quality assessment system in order to ensure the customer satisfaction.

CONCLUSION AND PERSPECTIVES

As was pointed out by Hall (2010), there exist a yield gap between the yield of the commercial hybrids evaluated in plots in the breeding nurseries (5 Mg/ha) and the actual yields obtained by the farmer (1.6 to 2.0 $Mg.ha^{-1}$). Similarly, this gap also exists between the yield of the female lines evaluated in plots under the best agronomic conditions (120 bags/ha) and the actual yield obtained in the seed production fields (40 to 60 bags/ha). Even though several procedures have been adopted to decrease this gap, there exist a long way ahead. Several causes can explain the current gap between the yield of parental lines observed in experimental plots and the actual yield obtained under field conditions, such as a less than desirable number of plants achieved under real conditions; reduced pollen availability or an inadequate pollination management; and seed losses during harvest and post-harvest processes.

Current research activities are devoted to search for better alternatives to honeybees as sunflower pollination vector, and *Bombus sp* appears to be an attractive substitute. Yield responses to fertilization with nitrogen and phosphorous are well known for commercial hybrids and for several ecophysiological variables of parental lines in production fields. However, the effects of mineral nutrition -including micronutrients- and several plant growth regulators over pollination interactions and, hence, seed set are not well established yet. Moreover, the effect of some molecules for increasing flower attractiveness to honeybees should also be investigated.

Finally, precision agriculture (PA) provides a practical way to automate site-specific management of seed production fields either to tailor input use to achieve desired outcomes, or to monitor those outcomes (e.g. variable rate application, yield monitors, remote sensing). PA will provide efficient solutions to several current problems of sunflower seed production: improved seed spacing and uniformity of plant emergence by using precision planters, coating of the seeds with only the necessary molecules of insecticides and fungicides in the right amounts, among others. Furthermore, the concepts of PA and sustainability are inextricably linked. Intuitively, applying fertilizers and pesticides only where and when they are needed, should reduce environmental loading and for this reason, the potential for environmental benefits of these practices is unquestionable. By this way, sunflower seed production not only tries to obtain economic benefits by producing seeds of high quality, but also tries to enhance environmental quality and the resource base in which agriculture depends.

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