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Salvatore Ceccarelli: Plant Breeder, Mentor, and Farmers' Friend

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ABSTRACT

Salvatore Ceccarelli is a geneticist, plant breeder, innovator, mentor, and farmers' friend with over 50 years of dedicated work to agricultural research for development. His major contributions have been in the development of breeding methodologies for barley and other important crops for the livelihoods of resource poor farming community in marginal environments. After a career in academia in Italy, in 1980 Salvatore moved to ICARDA, based in Aleppo, Syria, initially as a forage breeder and later as a barley breeder and manager of the barley improvement program until he left the center over 30 years later. It was while at ICARDA that he developed and adopted a new breeding strategy, based on decentralized selection for specific adaptation, a drastic departure from the dominant philosophy in plant breeding based on wide adaptation. A further development of this strategy was the idea of PPB, initially implemented in Syria and later extended to other Middle East countries, North Africa, Horn of Africa, and more recently to Italy, accompanied by a continuous refinement in experimental techniques and statistical analysis. When Salvatore recognized the limitation of PPB to ensure a continuous flow of new material to farmers, he proposed the use of EPPB to adapt crops to their specific environment and to climate change, while providing diversity for farmers to manage. His breeding program distributed new barley material to farmers worldwide and to numerous research institutions for basic and applied research, and generated information and methodologies to establish breeding programs for difficult and stressful environments. He has published over 270 scientific articles and been invited to countless national and international events. He has collaborated with researchers and mentored breeders and technicians

from around the world, helped establishing participatory breeding programs in several countries, supervised 25 MSc and PhD students, and conducted courses on participatory and evolutionary plant breeding in numerous countries. In 2017, he returned to Italy and continued to work as a consultant in national and international projects, which brings that decision-making process and seed ownership back in the hands of farmers. He is currently involved in projects in Bhutan, Ethiopia, Iran, Jordan, Nepal, Uganda, and Europe.

KEYWORDS: Decentralized breeding; participatory breeding; evolutionary breeding;

OUTLINE:

ABBREVIATIONS

BLUP
best linear unbiased predictor

EP
evolutionary population

EPB
: evolutionary plant breeding

EPPB
: evolutionary participatory plant breeding

GEI
: genotype x environment interactions

ICARDA
: International Center for Agricultural Research in the Dry Areas

IFAD
: International Fund for Agricultural Development

ILRI
: International Livestock Research Institute

PPB
: participatory plant breeding

I. BIOGRAPHICAL SKETCH AND BACKGROUND

Dr Salvatore Ceccarelli was born on September 7, 1941, in Fiume, today Rijeka in Croatia. At the outbreak of World War II, the family moved to central Italy, where he grew up with solid values of respect, personal responsibility, and accountability, and a strong commitment to perform to the best of his capabilities in the studies and all he was doing. He also developed a profound sense of curiosity and a desire to discover new things and come up with new ideas.

After graduating from high school with the highest grades, Salvatore decided to undertake agricultural studies and enrolled in the degree course in agricultural sciences at the University of Perugia. He studied a range of subjects related to agricultural sciences from soil physics and chemistry, to biochemistry, botany, agronomy, animal and crop husbandry, hydrology, and plant breeding. In 1964, he graduated in Agricultural Sciences with the dissertation “Morphological traits and nutritive value of *Brachypodium pinnatum* L.”

From 1965 to 1967 he attended the Advanced Specialization Course on Applied Genetics at the Institute of Genetics of the University of Milan. The director of the Institute was Professor Claudio Barigozzi, an Italian biologist and geneticist who had promoted genetic research in Italy since the early 1960s. During this period, Salvatore’s scientific preparation focused on genetics with particular attention to quantitative genetics, selection theory, mutation, cytogenetics, statistics, and advanced plant breeding. Salvatore refers often to this period as fundamental to setting the basis for his scientific formation and as very inspirational to developing his research, teaching, and mentoring approaches. In 1967, he obtained a PhD in Applied Genetics with a dissertation on “Biometrical analysis of natural populations of *Trifolium pratense*” (Ceccarelli 1968).

After serving in the military (at that time, service was unavoidable), Salvatore joined the Institute of Plant Breeding of the University of Perugia as assistant professor in plant breeding. To further strength his scientific knowledge, Salvatore spent a sabbatical year, from 1973 to 1974 at the Genetics Department of North Carolina State University in Professor Charles W. Stuber’s laboratory.

In 1979, while attending a meeting of the Italian Society of Agricultural Genetics, he was introduced by Professor Scarascia Mugnozza to the International Agricultural Research Centers, and in 1980 he joined the International Center for Agricultural Research in the Dry Areas (ICARDA) as senior scientist in the Pasture and Forage Improvement Program. Salvatore requested a two-year study leave from the university, keeping open the possibility of asking for an extension, but when he decided to do so, he encountered difficulties, and by the end of 1982 he went back to the University of Perugia, Italy. The following year he became associate professor in Plant Genetic Resources, and then in 1986 professor in Agricultural Genetics,

Shortly after his return to Italy, Salvatore became member of a Committee of the International Cooperation of the Italian Ministry of Foreign Affairs, in charge of advising how the funds in the CGIAR system should be invested. In that role, he was invited to ICARDA for a visit that would have marked a big change in his professional and personal life. Despite his career advancements at the University of Perugia, Salvatore was very enthusiastic about his experience at ICARDA and was convinced that his knowledge could serve not only as a basis for becoming an author specialized in the field but also to make a difference in the lives of the poor and marginalized.

After some negotiation, in 1984 Salvatore again joined ICARDA as a barley breeder, a position he held until he retired in 2006. His association with the center continued until 2015 as a consultant. This period has been certainly the most prolific of his scientific career, characterized by innovative research approaches, which included the use of what in the mid- to late-1980s was considered “unconventional” germplasm. Salvatore advocated the use of landraces and wild relatives in breeding barley for adaptation to stressful environments, when most of the breeding programs around the world would consider such material as “genetic garbage.” He also helped to develop a decentralized breeding approach that later evolved in a participatory breeding and more recently in evolutionary breeding.

His breeding program not only produced new barley material for distribution worldwide but also, more notably, generated information and methodologies to establish breeding programs that were facing difficult and stressful environments (Figure 1.1). The barley breeding program at ICARDA provided germplasm to numerous research institutions for both basic and applied research (some examples are Baum et al. 2003, Russell et al. 2003, Grando et al. 2005, Fufa et al. 2007, Russell et al. 2011, Varshney et al. 2010, 2012). Several of Ceccarelli's papers from this period were a source of inspiration for a number of breeders in developing countries and have been used in breeding classes in US and European universities.

Ceccarelli received the 2000 CGIAR Chairman's Excellence in Science Award for Outstanding Scientific Article on a methodological study on participatory barley breeding; the 2014 Farmers' Friend award designed and promoted by the Girolomoni Cooperative to enhance the farmers activity in Italy and around the world; and the 2015 Bologna Sustainability and Food International Award.

In 2017, he returned to Italy and continued to work as a consultant to both national and international projects, promoting the development of breeding methodologies, such as evolutionary plant breeding, that will bring the decision-making process and seed ownership back in the hands of farmers.

Fig. 1.1. Salvatore in the field (Stefania Grando).

Source: Stefania Grando.

As of 2019, Ceccarelli had published more than 270 scientific articles, of which over 150 appear in peer-reviewed journals. He has been invited to countless national and international events, spanning from local gatherings of organic farmers to international conferences.

Over the span of his career, he has collaborated on an ongoing basis with researchers from countries such as Algeria, Armenia, Bolivia, Brazil, Bhutan, Chile, Colombia, Cuba, Ecuador, Egypt, Ethiopia, Eritrea, the Philippines, India, Iran, Iraq, Kenya, Jordan, Libya, Mexico, Morocco, Nepal, Pakistan, Peru, Russia, Syria, Tunisia, Turkey and Uganda. He also worked occasionally with researchers in Afghanistan, China, Vietnam, South Korea, Spain, France, Germany, Great Britain, the United States, Denmark, Finland, Australia, The Netherlands, and Italy.

He has mentored several breeders and technicians from around the world, helped establishing participatory breeding programs in several countries, supervised 25 MSc and PhD students, and conducted several courses on participatory and evolutionary plant breeding in Australia, Bhutan, China, Eritrea, Ethiopia, Nepal, India, Iran, Jordan, Philippines, South Africa, Uganda, and Yemen.

He is currently involved in projects in Bhutan, Ethiopia, Iran, Jordan, Nepal, Uganda, and Europe. If anyone asks him when he will eventually retire, he answers, quoting Professor Miguel Altieri: “you can retire from a job not from a passion.”

II. RESEARCH

A. Breeding for Low-Input, Stress Prone Environments – From Conventional to Decentralized Barley Breeding Program at ICARDA

Plant breeding has been beneficial to farmers in favorable environments and to those who could profitably ameliorate the environment by the use of inputs. It has been less beneficial to the resource-poor smallholder farmers who cannot modify their environments by the use of inputs (Byerlee and Husain 1993, Eyzaguirre and Iwanaga 1996, Trutmann 1996) and have not known the benefits of the “green revolution” (Francis 1986, Pimbert 1994).

Given their success in favorable environments, plant breeders have tried to solve the problems of farmers living in unfavorable environments by applying the same methodologies and breeding philosophy used in favorable, high-potential environments, without considering the limitations associated with genotype–environment interactions (GEI). This has led to almost negligible progress for crops grown in unfavorable environments, often attributed to the difficult nature of the target environment (Blum 1988) with a consequent widespread habit of conducting selection under favorable conditions and sometimes only final testing in the target environments.

GEIs are considered to be among the main factors limiting response to selection and therefore the efficiency of breeding programs (Ceccarelli 2015), and they become important when the rank of breeding lines or varieties is different for different environments. Plant breeders have tried to avoid GEIs by selecting for widely adapted varieties; however, breeders can also exploit GEIs by selecting for specific adaptation (Ceccarelli 1989). This is particularly relevant when breeding crops for adaptation to unfavorable environments grown by resource-poor farmers.

In many developing countries, barley is a typical crop grown in difficult environments because of either climate stresses, low soil fertility, or both. In these areas, barley is often the only possible rainfed crop and the last crop possible before the steppe, and the desert, with a high risk of crop failures, and therefore there is low or no use of external inputs.

To generate valuable germplasm for these conditions, in the mid-1980s Ceccarelli challenged several concepts that characterized conventional plant breeding programs based on the assumption that breeding for environments with unpredictable and variable stresses is too slow and difficult. Many conventional plant breeders argued that the target was too difficult to define and heritabilities were too low to achieve significant results. As a result, the majority of the breeding for crops grown in stressful environments has been conducted using the same approach that was successful in favorable areas.

Breeding programs around the world share some of the following concepts: (a) selection has to be conducted under the optimum conditions of research stations where environmental influences can be controlled, error variances are smaller and responses to selection are higher (Ceccarelli et al. 1992, 1994); (b) cultivars must be genetically homogeneous and widely adapted (Ceccarelli 1989), locally adapted landraces must be replaced on the assumption that are low yielding and susceptible to diseases; (c) seed of improved varieties must be approved and dissemination through seed certification schemes and often inaccessible seed-production organizations; (d) the farmers or other end-users are only involved in the final stage of field testing of few promising lines, only to verify whether the choices made by others are suitable or not for them.

When breeders started questioning those concepts, it was found that: (a) selection under the optimum conditions of research stations produces varieties that are superior to local landraces only under improved management, not under the unfavorable conditions of resource-poor farmers, resulting on few or any new varieties grown by farmers in difficult environments; (b) resource-poor farmers in unfavorable environments tend to maintain genetic diversity by growing different crops or different and heterogeneous varieties of the same crop to retain adaptability (Simmonds 1962); diversity and heterogeneity are used to diffuse the risk of a total crop failure due to environmental variation; (c) resource-poor farmers often rely on their own or neighbors' seed and seldom rely on formal seed-supply systems (Almekinders et al. 1994); (d) when farmers participate in the selection process, their selection criteria may differ from those of the breeder (Sperling et al. 1993, Ceccarelli et al. 2000, 2001).

Because for so long those conventional plant breeding concepts were not questioned, the lack of adoption of new varieties was often attributed to the ignorance of farmers, the malfunctioning of extension services, and the inefficiency of seed systems – the hypothesis that the breeder might have bred the wrong varieties was rarely considered.

Ceccarelli demonstrated that breeding to improve the productivity of a low-input crop such as barley, grown in marginal environments by resource-poor farmers with limited or no access to inputs, is indeed possible provided is conducted using strategies and methodologies that little have in common with those used in breeding for favorable environment (Ceccarelli 1994, Ceccarelli and Grando 1996). He then developed a methodological package that comprised the use of four strategies:

1. Decentralized selection for specific adaptation in the target environment
2. Locally adapted and often neglected germplasm, such as landraces and wild relatives
3. Proper plot techniques and experimental designs to control environmental variation
4. Participation of farmers in selection in later stages

This resulted in the production of varieties adapted to the environments in which they must be grown. This approach has also been adopted by other international and national plant breeding programs (Ceccarelli et al. 1994).

This was a drastic departure from the dominant philosophy in plant breeding, based on the production of varieties that, with the input of water, fertilizers, pesticides and herbicides, hence with major environmental changes, were able to provide high production with a high cost in terms of environmental damage and genetic erosion.

International breeding programs usually aim to assist national programs to increase agriculture production through the development of superior varieties. This has been traditionally done through large breeding programs that develop and distribute fixed or semi-fixed lines selected with average good performance across environments, often high-input research stations. This approach has favored the distribution of widely adapted material, excluding the use of locally adapted germplasm. Although international breeding programs distributed segregating populations, those were the same for all countries and were not targeted to a specific environment.

To fully exploit specific adaptation and make a positive use of GEI, Ceccarelli et al. (1994) proposed that international breeding programs decentralize most of the selection work to national programs by gradually replacing the traditional distribution of breeding material with targeted segregating populations. This will reduce the risk of useful material being discarded simply because it had not been tested in the target environment.

In 1991, ICARDA’s barley improvement program initiated a gradual process of decentralization of selection work to Morocco, Algeria, Tunisia, and Libya (Ceccarelli et al. 1994). The process was extended to Iraq in 1992, to Egypt in 1995, and later to Ethiopia, Eritrea, Yemen, Uzbekistan, Kazakhstan, and Armenia. An important feature of the decentralization process was the active role of national program scientists in identifying the parental material, designing of crosses, deciding on material to be selected, and adapting the process to their own needs and capabilities.

While national programs were responding with enthusiasm to the idea of decentralization, Ceccarelli and co-workers recognized that decentralization *per se* may not respond to the needs of resource-poor farmers in unfavorable environments. In fact, the process, as originally designed, was from ICARDA's research stations to the research stations of the national programs that often did not represent unfavorable environments. However, the most serious limitation of decentralized selection for specific adaptation to unfavorable environments is in the large number of potential target environments. Moreover, while decentralized selection is a powerful methodology to fit crops to the physical environment, crop breeding-based decentralized selection can still miss its objectives if it does not consider the producers and the end-users of the crop (Ceccarelli et al. 2000, 2001). Therefore, in 1995, Ceccarelli proposed decentralizing the barley breeding program from research stations to farmers' fields, and to have farmers participating in the very early stages of selection as a solution to fit the crop to a multitude of target environments and users' preferences (Ceccarelli et al. 1996). This allowed for the development of methodologies to implement a decentralized-participatory barley breeding program.

B. From Decentralization to Participatory Plant Breeding

The idea of farmers' participation in the development of new technologies can be traced back to the inspiring paper by Rhoades and Booth (1982), introduced as "the farmer-back-to-farmer" model. The paper, together with the one that followed (Rhoades et al. 1986), emphasized the importance, when developing a new agricultural technology, of involving the farmers from the start, rather than ignoring them and then handing over a ready-to-use technology.

Although plant breeding programs differ from each other depending on the crop, the facilities, and the breeder, they all have in common three main stages defined by Schnell (1982):

1. Generate genetic variability (includes selection of parents, making crosses, choice of type and number of crosses, induced mutation, introduction of germplasm from genebanks, other breeding programs, and farmers).
2. Select the best genetic material within the genetic variability created or acquired in stage 1.
3. Test breeding lines emerging from stage 2. The number of crosses generated at the beginning of each cycle can vary from a few hundred to several thousand.

During stages 2 and 3, genetic variability is gradually reduced, and breeding lines are identified. While the number of breeding lines decreases, the amount of seed per line increases, as does the number of locations in which the material can be tested (Ceccarelli 2009). A breeding program handles considerable amounts of material on a yearly basis, whether a new cycle starts every year, or twice a year. Other important stages in a breeding program are social targeting and demand analysis (Weltzien and Christinck 2009), and dissemination of cultivars (Bishaw and van Gastel 2009).

A breeding program becomes participatory when farmers as well as other partners, such as extension staff, seed producers, traders, and final users participate in the development of a new variety. Participatory plant breeding