N. C. Subrahmanyam (1943–2019)

Nekkalapudi Chinna Subrahmanyam (NCS), fondly called Prof. NCS, a world renowned plant geneticist and former professor at the School of Life Science, University of Hyderabad (HCU), died on 14 February 2019.

Subrahmanyam was born on 5 October 1943 in Manthena village, Krishna district, Andhra Pradesh to Nekkalapudi Satyanarayana and Anasuryavati. His early education was at the nearby Zilla Parishad High School (ZPHS), Manthena, and Akkineni Nageswara Rao College (ANR College), Gudivada. His favourite subjects were science and mathematics. He obtained his Bachelor's (1962–66) and Master's (1966–68) degrees, both in agriculture, from Banaras Hindu University (BHU), Varanasi with BHU Gold Medal and Binani Gold Medal respectively. NCS was awarded with the ICAR Merit Scholarship to pursue his Bachelor's degree and ICAR Fellowship for Master's degree. After postgraduation, he worked for more than a year as Research Assistant at the Maize Research Station, Andhra Pradesh Agricultural University (the present-day Acharya N. G. Ranga Agricultural University), Hyderabad. As a true son of the soil, during his free time and vacations, NCS used to help his parents in the farm; agriculture was his passion. To earn a stable income, his economically poor parents wanted NCS to take up the job of a Farm Officer in the Government sector. However, the practical experience gathered in farming by working in the field and the scientific knowledge gathered in agriculture from university education prompted NCS to choose a research career in crop science. With financial support from Nizam Trust, he travelled to Canada in 1970 and joined the Crop Science Department at the University of Guelph, for doctoral studies.

Professor K. J. Kasha, a world-renowned plant breeder and geneticist was his research supervisor at the University of Guelph. By the late 1960s, several research groups, including that of Kasha, reported an invariable production of haploids following hybridization between diploid barley (*Hordeum vulgare*) and its diploid wild congener *Hordeum bulbosum*. The haploids produced in the interspecific hybridization between *Hordeum* spp. found limited applications in barley breeding as the cytogenetic basis of this haploid production was unknown. Results of the doctoral studies of NCS on the cytogenetics of embryos and endosperms harvested following the interspecific crosses between *Hordeum* spp. led to a path-breaking discovery, and it added new dimensions to crop science research in general and to barley breeding in particular. Using the squash preparations of chromosomes from the hybrid embryos and endosperms harvested at different days following *vulgare–bulbosum* hybridizations, together with the evaluation of barley chromosome-specific

markers in the resultant haploids, NCS unequivocally proved that *H. bulbosum* chromosomes are selectively and completely eliminated by the 14th day following the hybridizations, resulting in an embryo with full haploid complement of *H. vulgare*[1,2]. The application of haploidy in breeding can be realized only when a large number of haploids are produced and their chromosome numbers subsequently doubled (doubled haploids). In subsequent experiments, NCS demonstrated an efficient method for producing doubled haploids in barley by treating the interspecific haploids with a combination of colchicine and DMSO[3]. In 1973 he was awarded the Ph D with distinction in genetics. When Kasha once visited the University of Hyderabad, he praised the research contributions of NCS and remarked that his thesis was the first one to receive a distinction in the 99-year history of the Department. The doubled haploid production methodology developed by NCS, widely known as 'bulbosum technique' or 'bulbosum method', was soon adopted in crop improvement methods and over 20 countries once integrated this method in barley breeding programmes. The success story of 'bulbosum technique' inspired researchers to perform analogous experiments in other species also, especially in Triticeae members, and they obtained great success in certain species combinations.

At the end of 1973, NCS returned to India and worked for a year as CSIRO (India) Pool Officer at the Department of Genetics and Plant Breeding, BHU. In 1974, he moved to the Research School of Biological Sciences, Australian National University (ANU), Canberra, Australia and worked there till 1979, initially as a Postdoctoral Fellow and later as a Research Fellow. At ANU, he continued his passion of barley hybrid analysis. NCS performed hybridization between different species of *Hordeum* and analysed the ploidy of the resulting hybrids. Further, he perfected the process of haploid production and subsequent chromosome doubling by evaluating different growth conditions of the parents used for the crosses, hybridization procedures, embryo rescue and *in vitro* culture conditions. His experiments furthered our understating of the genetics behind the selective elimination of chromosomes in the interspecific crosses between *Hordeum* spp. He demonstrated that the ratio of parental genomes in the zygote regulates whether haploids or hybrids will be produced in a cross-combination. He established the hierarchy of chromosomal elimination in different barley species and proposed stability factors that regulated this phenomenon.

In addition to profusely employing classical genetics tools in his research, NCS was always eager to adopt and diligently execute the newly emerging molecular biology methods as well. Another important set of experiments he conducted in ANU included the molecular characterization of barley genomes with emphasis on ribosomal RNA genes. He established the pattern of satellite DNA formation in different *Hordeum* spp. following Ag^{+}/Cs_2SO_4 density gradient ultracentrifugation and located the chromosomal sites of the isolated satellite DNAs by *in situ* hybridizations. Using DNA–RNA filter hybridization in all the seven primary trisomics of diploid barley, he confirmed the occurrence of

rRNA gene repeats (rDNA repeats) on chromosomes 6 and 7, and determined the number of rDNA repeats in them. Further, he discovered a 'hemizygous-ineffective' control of chromosome pairing in polyploidy *Hordeum* spp.

NCS was conferred Associate Professorship in the fast-developing HCU, which was founded in 1974. He joined the School of Life Science in 1979. He became Professor in 1987 and Dean, School of Life Sciences in 1992. During 1985–86 he served briefly as Professor and Head, Department of Botany, University of Poona. He really wished to work at HCU towards elucidating the molecular basis of selective chromosome elimination in the interspecific hybrids barley. But vernalization requirements in the wild *Hordeum* spp. for flowering proved to be a hindrance. However, NCS got an opportunity to continue work on barley hybrid analysis when he was a Visiting Professor (May to July each year) at the Swedish University of Agricultural Sciences, Svalov, Sweden from 1984 to 1989. His collaboration with Prof. Roland von Bothmer of the Department of Crop Genetics and Breeding in the University was productive and they co-authored several insightful papers on barley haploids. Bothmer remembered NCS as follows: 'I often think about him with great delight. He was kind and talented person. The friendship and pleasant company of Prof. Subrahmanyam will always be remembered.'

At HCU, work of NCS centred around three semi-arid crops: peanut (*Arachis hypogaea*), pigeon pea (*Cajanus cajan*) and pearl millet (*Pennisetum glaucum*). His warm relations with researchers at the International Crop Research Institute for Semi-arid Tropics (Hyderabad), was instrumental in this selection. Several of his doctoral students worked on these crops. His group established an *in vitro* regeneration system in peanut. They established a number of chromosomes having nucleolar organizing regions (NORs) in pigeon pea and *Atylosia*, and characterized the pattern of NOR activity in these species. The group perfected the method for raising hybrids in intergeneric crosses between pigeon pea and *Atylosia albicans*. They characterized NOR activity in the resulting intergeneric hybrids and established an allosyndetic recombination in them. His research team worked on plastid biogenesis and nuclear chloroplast interactions in pearl millet. They reported a pattern-dependent maternal inheritance for the first time in the mutant plastids of the crop. Genetic analysis of the mutant revealed that four loci in homozygous recessive condition can rescue this phenotype to normal green phenotype. Further, his group standardized the production of interspecific hybrids in *Pennisetum* spp. by embryo rescue, and also discovered the phenomenon of chromosomal elimination in these interspecific hybrids. Realizing that lack of primary trisomics is a handicap in the breeding advancements of pearl millet, the group developed a complete set of primary trisomics in the crop and used it to map 12 morphological markers and 16 RFLP markers onto the chromosomes. In addition, they cloned and characterized repetitive DNA sequences in pearl millet, and Southern analysis identified the conservation of certain repetitive sequences in cereals.

NCS taught genetics, cytogenetics, plant molecular biology and biotechnology to postgraduate students of HCU for 20 years. His lectures were thought-provoking and analytical in nature, enabling the students to grasp the subjects. He always gave his doctoral students full freedom and encouraged original thinking in choosing the topic to work for their thesis. However, he was a task master who would not be easily convinced without compelling evidence from the results of research experiments. NCS never tolerated a shabby attitude in research pursuits. He insisted on systematic and meticulous planning before initiating experiments, which then led to superior outcomes. His capability to assimilate and interpret genetics data was amazing.

NCS was an elected fellow of the Indian National Science Academy, New Delhi (1992); National Academy of Agricultural Sciences, New Delhi (1993), and Indian Academy of Sciences, Bengaluru (1995). He served on important academic and scientific committees of many universities, research institutions and organizations.

NCS took voluntary retirement from HCU in 1998 due to health reasons. In 1999, he moved to Australia where his children lived and served at C.S.I.R.O. Division of Plant Industry, Canberra, Australia as a visiting scientist and as a scientist at the Victorian Institute of Dryland Agriculture, Victoria, Australia until 2001. Thereafter, he gave up active research due to frail health, and lead a peaceful and contented life with his family in Australia. NCS has left behind a rich reminiscence of a landmark era in crop genetics, which will be cherished for a long time.

NCS is survived by his wife, daughter, son and two granddaughters.

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2. Subrahmanyam, N. C. and Kasha, K. J., *Crop Sci.*, 1973, **13**, 749–756.
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