Knowledge and Practice:
A Study of Influence of Molecular Biology on the Profession of Plant Breeding

A Thesis submitted to the University of Hyderabad for the award of the degree of the

Doctor of Philosophy

In

Sociology

By

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December 2002

DECLARATION

I hereby declare that the research embodied in the present thesis entitled, "**Knowledge and Practice: A Study of Influence of Molecular Biology on the Profession of Plant Breeding"** is my original work carried out for the award of the degree of Doctor of Philosophy from the University of Hyderabad.

I declare to the best of my knowledge that no part of this thesis earlier submitted for the award of research degree of any university.

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This is to certify that I, T. Laxmi have carried out the research embodied in the present thesis entitled **"Knowledge and Practice: A Study of Influence of Molecular Biology on the Profession of Plant Breeding"** for the full period prescribed under Ph.D. ordinances of the university.

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Dedicated to

My Family

And Sweet Little

TARUN

Acknowledgements

The present study could not have been possible without the support I have received from many different sources. First and foremost, 1 would like to thank Prof. E. Haribabu, Professor and Head, Department of Sociology who had been instrumental in choosing the research problem and also providing the necessary guidance right from the beginning. My association with him started right from my M.Phil days and it has been a pleasure working with him. Also 1 would like to thank him for providing me the opportunity to work in his research project on the community of rice researchers in India, which provided me with useful insights for carrying out the present study. Also the current research question arose from the project. I also would like to thank the faculty members in the Department of Sociology. 1 extend my sincere thanks to the Rockefeller Foundation, New York for the financial support they had extended to my study even after the completion of the research project. In particular 1 would like to thank Dr. John O' Toole for his interest in my work.

The scientists of my study were very cooperative and helpful in accommodating time for the interviews despite their busy schedules. They had been very patient and conducting interviews was a pleasant experience. I extend my sincere thanks to all of them for making time for the interviews. I would like to thank in particular Dr. Shailaja Hittalmani and Dr. Shashidhar from the University of Agricultural Sciences, Bangalore and also Dr. N. P. Sarma from Directorate of Rice Research, Hyderabad for elaborating on various issues which have been quite useful in the present study.

I would like to thank my parents and my sisters for having the confidence that J could do it and putting up with my moods all along. Words would not suffice to express my sense of gratitude to them. I would like to thank Padmavathi, Ambika for providing me accommodation during my visits to Bangalore and also clarifying my doubts regarding the technicalities included in plant breeding. Dr. M. Shailaja from Directorate of Oilseed Research had been patient enough to go through the draft and clarify the doubts. My thanks also to Sirisha, Kishore and Ramana Rao from Central Rice Research Institute (CRR1) for making the trip to Cuttack a pleasant one. Also I extend my thanks to Lalitha and Aparna who have been the best pals since my PG days.

Staying on campus was a pleasant experience among the company of friends like Charu, Vani, Kanchan, Parvathi and Harish (Sr. n Jr.). Also I enjoyed the company of Richa who made a world of difference. 1 thank all of them for being there whenever 1 needed them the most. I would also like to thank Raghava Reddy, Nagaraju and Kaushal for undertaking proof reading of the thesis. In the department I would like to thank all the colleagues and juniors for their warm and pleasant interaction.

1 would like to thank the staff at the department for the administrative support they had extended during the course of the project and also during the course of my Ph. D. I would also like to thank the staff of Indira Gandhi Memorial Library, University of Hyderabad and the staff of library at Directorate of Rice Research.

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Introduction

Modern science and technology have an important role to play in industrial and agricultural sectors of all societies. It is because of the advancements in science and technology that the quality and quantity of food production is maintained at a level to offset the rate of population growth. This is despite the fact that the area under cultivation has been gradually decreasing while the demand for food has been increasing. Specifically, in the field of agriculture, there have been advances to check both biotic and abiotic stresses in the food crop plants to eliminate or minimize their effect on the growth of the plant, to ensure the quality and quantity of what is produced. Research efforts in understanding crop plants with the goal of improving yield and other qualitative traits through technological interventions have been going on. The watershed in understanding genetic basis of traits was ushered in by Gregor Mendel in his pioneering work in 1865.

It is the Mendelian paradigm that guided the understanding and intervention at a phenotypic level. The discovery of the double helical model of the DNA by Watson and Crick in 1953 resulted in a paradigm shift in biology, The Watson and Crick discovery enabled scientists to understand life processes at molecular level and also intervene at molecular level. Research efforts related to crop plants have been directed at understanding molecular basis of several traits with a view to evolve intervention strategies at molecular level. The paradigm shift and the new research agenda at the molecular level, and the social process of application of the new paradigm and the new paradigm-based social organization of the scientific community are important issues from sociology of science perspective.

The present study attempts to look at the influence of molecular biology knowledge and techniques on the profession of plant breeding. More specifically the research attempts to trace the changes that have occurred and/are likely to occur in the plant breeding profession after the introduction of the new paradigm. Changes have occurred and/are likely to occur are at three levels namely: changes at the level of cognition i.e., the level of understanding of the object of research i.e., the rice plant; at the level *of* strategies of intervention and at the level of associated practices. Finally the study attempts to look at the changes at the level of organization of the profession of plant breeding in terms of physical resources, human resources and economic resources.

Sociological literature on science

For a long time, sociologists have held the view that science was an esoteric activity and scientific knowledge was invariant, universal and objective. This leaves no scope for sociological analysis of science. According to Mulkay (1980), sociology of science addressed a restricted set of questions relating to the social conditions in which the scientific community emerges and the social arrangements within science which could be addressed.

Mertonian Framework

There have been many attempts to formally examine the social structure of the scientific community. One of the earliest and most influential writers in this field was Robert Merton (1972) who using the then fashionable structural-functional approach in sociology and also the rationalist-positivist philosophy of science painted an ideal view of the scientific enterprise. According to Merton (1972), the research community has a well-defined and over-riding social objective i.e., the extension of certified knowledge. He viewed science as a social institution with its own values, norms and rules, which tended to keep its social system continuing in its pre-set plan. The scientific community therefore is a self-regulating and self-correcting community, the members of which had internalized an ethos, the components of which are universalism, communism, disinterestedness and organized skepticism. These ethos according to Merton are institutional imperatives.

In a sense, Merton's community of scientists was an impersonal, truth-seeking apparatus, which operated as a "smoothly progressing machine" gradually accumulating new concepts and discoveries. The central logic regarding the framework of norms is that if scientists fail to abide by these norms, their knowledge claims would tend to be distorted by personal inclinations and social interests. The nature of the rules/norms, which are given out by Merton (1972), can be inferred to some extent by asking "what kinds of actions are required and what kinds of actions need to be avoided, if genuine knowledge is forthcoming?"

Critique of Mertonian Perspective

But subsequent empirical research has shown that this idealistic scientific community of Merton does not exist in reality. Thus Leslie Sklair (1972) observes that the Mertonian concept of a consensus in science is more honored in the breach than in the observance and therefore belongs to an ideology of science. Scientists in their day-to-day behavior are not solely governed by the norms and values of science held by the group. The impression of a community of scientists going through a careful process of assessing a mass of scientific papers and arriving at a consensus on high-quality contributions is partly true. Collins (1975) argues that there is no evidence suggesting that the Mertonian norms are the only ones and that they are institutionalized. More over, there is positive evidence to suggest that other norms are in use and are regularly employed. Further the Mertonian analysis does not provide an adequate account of change and innovation in science.

Thomas Kuhn's notion of Science

Thomas Kuhn (1970) stressed the need to look at science in its historical integrity. His notion of scientific community is a historically constituted one. Thus he defines scientific community in sociological terms. Kuhn argues that scientists are socialized into particular academic cultures and develop their own scientific communities based on a shared paradigm. Kuhn, unlike rationalist-positivist philosophers argues that scientific knowledge does not grow by accumulation of theories and facts in a linear fashion, but grows by discontinuous revolutionary shifts in the paradigms that guide their practice. His mode of analysis embraces the specific activities, theories and concepts of the scientists and has been taken up by a number of sociologists of science. Mulkay (1972, 1979) argues that scientists are predisposed to innovate when they occupy different roles in the scientific community (role hybridization), when they occupy peripheral status in their scientific groups (marginality) or when there is fierce competition between scientists for publication of research work. His studies suggest that it is the clash of beliefs and theories of knowledge, and the transfer of these norms from one scientific group to another that account for the process of innovation. The implication of this is that innovation often arises through scientific invasion - the transfer of normative frameworks from one field of science to another. The Kuhnian case studies suggest that products of scientific activity are shaped by social factors, thereby promoting skepticism about the impartial nature of scientific knowledge. The important implication of this is that scientific knowledge may be relative, not absolute and thus to some extent culture-specific.

According to Ben-David (1975), sociologists of science have concentrated on the characteristic of science as a tradition and as an institution. Sociologists of science have examined the ways in which scientists actually perfonn their work and how far scientific knowledge can be considered as a product of social life.

Collins (1975) on the basis of the studies of groups of scientists researching on lasers and gravitational waves argues that often there is no common assessment of experimental procedures of results by group participants, and that scientists 'negotiate' judgments concerning the merit of the knowledge-claims involved. Such studies indicate that the questions of the acquisition and use of information by scientists are not separable from questions of the production of knowledge and have emphasized the study of what questions produce 'meaningful' responses from scientists. By providing an excellent review of the 'interpretative' sociological case studies Mulkay (1979) points out that many sociologists and philosophers of science have converged on a conception of science as an interpretative enterprise where what is to be considered as scientifically valid knowledge is 'negotiated' by the scientific community and is not simply empirically discovered. According to this view, scientific knowledge is conditioned by the socio-political and economic context in which it is produced. Thus the personality and the reputation of the scientists, and the status of the professional bodies, which determine and disseminate scientific knowledge, are seen as important factors. These must be taken into account if a more comprehensive understanding of our body of scientific knowledge is to be achieved.

New Sociology of Science

From the late 1970s, the above approach has resulted in a large number of empirical studies of a) scientific controversies, b) of everyday life in the laboratory, and c) on the way in which scientific literature is constructed to present a sanitized and desocialized image of objectified knowledge and so on. This has been the result of the different approaches in their assault of the black box. The 'Interest Approach' and 'Ethnography and Discourse Analysis' were the two important approaches in this context.

The Interest approach has been associated with the historians and sociologists of science at the Edinburgh University. It argues that knowledge claims made by scientists will embody or be informed by certain social and political interests. These may reflect the disciplinary, professional or more generally ideological interests and objectives of the scientists. They shape the ideas and are implicated in the scientific debate. Studies by Shapin (1979) and Mackenzie (1979) provide some of the more detailed illustrations of the Interests approach.

Collins can be regarded as a member of the core set of sociologists who have been involved in the debate over the Interests Approach in the sociology of science. He and his colleagues who have been associated with him at the University of Bath (Pinch 1981, Travis 1986) together with the Edinburgh group articulated this approach. Collins says:

> "The new sociology of science has found itself in the fortunate position of being able to generate any number of fairly small, manageable, self-contained studies. The subject has, as it were, a 'granular' structure. This has helped to maintain a vigorous empirical tradition." (p. 86)

The interests approach seeks to understand the conditions by which certain ideas are accepted as true and some others as false. This approach has been adopted by many sociologists of science in exploring a wide range of debates featured in the construction of particular areas of cognitive fields of scientific knowledge. Collins has focused on the 'core set of scientists' involved in specific controversies. The core of set of scientists form an elite group and are at the core of a particular scientific specialty. The members of the elite group are located in prestigious academic and research positions. Collins (1981) argues that these scientists play a crucial role in determining the outcome of scientific debate; hence they must form the key but not the sole focus of any sociological inquiry.

In *Changing Order,* Collins (1985) attempts to look at the construction of scientific knowledge by looking at the activity of the two sets of protagonists i.e., the allies and enemies in scientific controversy. Collins demonstrates that a consensus over scientific knowledge-claims emerges only through negotiation and debate and not based on rigorous procedures laid down by scientific method. The reason for this kind of strategy is that the practitioners of science draw from a wide range of socio-technical strategies to produce an ultimate consensus out of controversy.

More notably, Collins (1985) demonstrates how replication of experiments, which is considered as one of the principles that lie at the heart of scientific method, is a methodological impossibility. This is because of the fact that experiments cannot replicate prior experiments exactly since any one experiment embodies specific skills - typically 'tacit' or hidden - which others do not exactly share. Hence "it can never be clear whether a second experiment has been done sufficiently well to count as a check on the results of the first." This leads to the 'experimenter's regress' where each test of a prior experiment is itself susceptible to testing, and so on. Scientists endeavor to stop this (potentially infinite) regress through tactics that close off the debate. Collins' empirical studies on gravitational waves and on parapsychology demonstrate his argument more clearly.

Woolgar (1981, 1989) argues that though the Interests approach is right to show how judgments about knowledge are always socially informed, but its supporters fail to recognize that their own judgments about science are similarly mere constructions, versions of reality that cannot be given any special authority. Hence, their attempts to provide explanations of the way certain ideas are accorded "scientific" status are just as much socially constructed as any set of knowledge-claims. Any sociological accounts that are offered as explanations for the status of phrenology, parapsychology, plant classifications systems and so on are based on an unwarranted assumption that it is possible to produce an authoritative statement about "the world" that does not embody any particular interests-model. This is the very assumption that the advocates of the interests approach want to challenge in their deconstruction of science.

Woolgar (1988b), Gilbert and Mulkay (1984) and Knorr-Cetina and Mulkay (1983) argue that sociology of science must abandon such an assumption and recognize that an analysis it produces is merely yet another possible 'representation' of the 'world' and has no special authority. They call for a strong reflexive attitude towards one's claims about reality. However these pronouncements need to be deconstructed through a self-reflexive process. Knorr-Cetina (1981) in her work 'Manufacture of Knowledge' argues that scientific knowledge is an outcome of the constructions based on a series of interconnected selections - theories, methods, experiments and interpretations. She argues that scientists deploy practical reasoning, analogical reasoning and socially situated reasoning in the process of production of scientific knowledge. These selections are influenced by local contingencies and cultural contexts.

The other important approach is the Ethnography and Discourse Analysis, the origins of which lie in the wider sociological approach of Ethnomethodology. Ethnomethodologists explore the techniques that people use in their everyday life to accomplish successful social interaction. Analysts focus then on the context and dynamics of social encounter and the signs and symbolic resources, especially discourse that makes it possible. But they deny that they are thereby producing definitive accounts of this interactive drama, only their own understanding of the processes at work.

This technique, which developed over the past twenty years or so, produced a vivid and lively sociological analysis as well as raising serious methodological questions over the strategies of sociological research. One of the earliest detailed ethnographies was that of Latour and Woolgar (1979), which provided an analysis of "laboratory life" at the Salk Institute in California.

There have been subsequent case studies of "science in the making" at the level of the laboratory (Ex. Goodfield, 1981, Zenzen and Restivo, 1982). The objective of all case studies was to demonstrate the process through which propositions, claims or ideas of scientists come to take on - for a time at least - the status of 'facts.' A whole range of strategies and resources is required to persuade others of the 'truth' of one's claims. Some times these 'facts' are questioned and reconstructed in new ways as scientists deconstruct 'ready-made science.' One implication of this is that what counts as a scientific 'discovery' can no longer be regarded as in anyway a straightforward recording of an obviously innovative or novel phenomenon. What is and is not discovered is itself a matter of negotiation.

The temporary instability of scientific facts and the way they might be reconstructed has been explored most fully by Latour (1987) who argues that all science is janus-headed, i.e., it presents itself in one (public) way as firm, solid reliable knowledge about which all agree, while simultaneously experiencing (private) uncertainty, controversy and debate. Latour requires that we look at the career of claims and counterclaims in order to plot the transformation of science-in-the-making into ready-made-science. This transformation depends upon the power of scientists to use critics, doubters or 'dissenters.'

Through a large number of varied illustrations from within and outside 'science', Latour shows how knowledge-claims are constructed as facts through their originators establishing alliances, networks of associations with significant others who will lend their authority to what is being said, without at the same time trying to change what is being said:

> "The paradox of fact-builders is that they have simultaneously to increase the number of people taking part in the action - so that the claim spreads and to decrease the number of people taking part in the action - so that the claim spreads as it is." (p. 207)

According to Rosenberg (1976), Marx and Engel's position is to affirm that science is a fundamental factor that accounts for the growth in resource productivity and man's enlarged capacity to manipulate his natural environment for the attainment of human purposes. But this statement requires two immediate and highly significant qualifications namely:

1. According to Marx, science does not function in history as an independent variable; and

2. Science has come to play a critical role as a systematic contributor to increasing productivity only at very recent point in history.

Further Rosenberg (1976) argues that Marx treatment of scientific progress as being consistent with his broader historical materialism. Scientific activity of man is shaped and influenced by the economic sphere and the requirements of the productive process. According to him, science does not grow or develop in response to forces internal to science or the scientific community. It is not an autonomous sphere of human activity. Science needs to be understood as a social activity, which is responsive to the economic forces.

Scientific knowledge, according to Marx, is acquired when a social need for that knowledge has been established. However science is not an initiating force in the dynamics of social change. Developments in this sphere are a response to forces originating elsewhere. Marx and Engels appear to be presenting a purely demand-determined explanation of the social role of science. Scientific enterprise caters to the demands of the industry and therefore the changing direction of the thrust of science needs to be understood in terms of the changing requirements of the industry. Post-Kuhnian approaches and Marx's views seem to have parallels.

Sociological literature on occupations and professions

As mentioned earlier Thomas Kuhn defines practitioners of a paradigm as a community with shared cognitive and social norms. Pre-Kuhnian sociological approach to professions characterizes practitioners of a profession in terms of attributes. According to Turner and Hodge (1970), Spencer and Durkheim were very much concerned with the transformation and development of societies, and viewed the division of labor as a critical element in the processes involved. Spencer attempted to differentiate analytically between conscious and coercive division of labor, a basis for his ideal type 'militant society', and unintentional and non-coercive division of labor that is a basis for his ideal type 'industrial society.' Spencer was well aware that both these strands of the division of labor were complexly intertwined in any actual society. Durkheim's prime concern was to understand as to what happens to societies when they begin to modernize, when they begin to industrialize and labor becomes increasingly specialized. He utilizes the concepts of mechanical solidarity and organic solidarity to understand this kind of change. The modern societies characterized by organic solidarity, unlike in mechanical solidarity, there is complex division of labor wherein the individuals do not perform the same tasks.

According to Macdonald (1995), an emphasis on knowledge as a 'core generating trait' of professionalism is to be found in all sociological treatments of the professions. It is more so in the works of Larson (1977) and Abbot (1988). Sociologists generally take a model of rational, formalized scientific knowledge as their starting point in the study of the epistemological base of professions and then elaborate in relation to a number of other features of professions and their social context.

The pre-Kuhnian notions of professions, which took the universality, invariance across time and space for granted, characterized the professions as based on universal, rational and invariant knowledge. The literature on professions does not look at the consequences of changes in the paradigms within a given discipline. These received notions have been questioned by post-Kuhnian approaches to the sociology of science. Knorr-Cetina and Mulkay (1983) argue that science should not be regarded as some sort of fixed body of (objective) knowledge, closed, finished and intact and it is in this sense that they call for epistemic relativism. This approach suggests that 'knowledge is rooted in a particular time and culture' and 'knowledge does not mimic nature.' Instead of seeing science as a 'black box', a closed, authoritative system, sociologists approach science as a continually constructed system of ideas, as Latour (1987) says as, 'science in the making.' Sociologists have sought to open the black box, to reveal the uncertainties, the negotiations, the dilemmas, and controversies that inform the very making of 'science.'

These approaches postulate that, to paraphrase in Bloor's (1982) terms, scientific knowledge is socially caused. The approaches suggest that the dividing line between the internal world of science and the external world is not rigid but porous. Kuhn's work suggests that the acquisition of a paradigm create conditions for the emergence of professional scientific community based on shared cognitive beliefs, shared system of beliefs and practices. When a new paradigm replaces an old one there is a shift in the world-view. The two paradigms not only see the world differently but see different worlds. For instance the shift in the geocentric universe to the heliocentric universe represents not only looking at the world differently but looking at different worlds. This may be seen in the context of modern biology. The discovery of the double helical structure of the DNA represents a new paradigm and is a revolutionary shift.

Pre-Kuhnian notions of science as rational, universal, invariant across time and space formed the basis of conceptualization of professions in sociology. However Kuhn's contribution locates science in a historical context and the notions of universality, invariance and *atemporality* are paradigm bound. The paradigms themselves are replaced by newer paradigms in a revolutionary shift. What are the implications of such a conception is an important question. Earlier sociological conception of practitioners of an epistemology was considered a profession, whereas Kuhn's conception characterizes the practitioners as a community. Science, which began as an amateur activity in the 17th century, became professional activity by the late 19th century.

Modern society and knowledge

Professions became possible only when knowledge emerged as a socio-cultural entity in its own right, independent of established social institutions and when society came to be based on knowledge in a way quite different from earlier periods. At this stage, the market had reached sufficient salience as a feature of the society for the private provision of knowledge based services to become viable. This change has been termed as the great transformation by Polyani (1957) and a European Miracle by Jones (1981).

The origins of the professions may be traced to the feature of modern society that Gellner (1988) sees as possibly the most important, namely the development of knowledge as an independent element in the society, rather than something bound into number of other social institutions. Gellner's thesis may be précised as follows:

> 'In modern times, the cognitive referent - i.e., our yardstick for assessing the truth or validity of knowledge - is the empirical world of nature: in all earlier forms of society that reference point was one of a number of social institutions."

This formulation offers an explanation for a variety of puzzling features in pre modern societies. It can account for the apparent childish modes of thought of some tribal societies because it demonstrates that their contradictions stem not from a failure to grasp the nature of reality, but because they have two (or more) systems of ideas, which they bring to bear on the world according to circumstances. Different circumstances are governed by different social institutions and hence by different modes of thought. As societies become more complex and more technically advanced, thought systems become more elaborate, extensive and unified, but remained as watertight as ever. It is within these compartments that fact and values are fused thereby joining together social, moral and cognitive hierarchies.

The cognitive system that has been essential to European culture for the past 400 years is practically unique in human history and it distinguishes the contemporary form of knowledge from that of previous forms of knowledge in the society. Without it the modern science would be impossible because earlier forms of cognition were not unified nor were they distinct from other social institutions, but were intrinsically bound up with them.

Such a cognitive system would render impossible the establishment of an independent group of specialists in a particular branch of empirical knowledge, because all approaches to the empirical world are already foreclosed and tied to the normative and moral structure of the society.

Nature of professional knowledge

Professions are knowledge-based occupations and therefore the nature of their knowledge, the socio-cultural evaluation of their knowledge and the occupation's strategies in handling their knowledge base are of central importance. Having indicated what is distinctive about modern knowledge, it will be useful to have a definition of this concept. For this purpose, one may cite Murphy (1988):

> "The process of formal rationalization has generated a new type *of* knowledge, namely the systematic, codified, generalized (abstract) knowledge of the means of control (of nature and humans). Most importantly it has resulted in the knowledge of how to acquire new knowledge of such means. S & T are important elements of this new knowledge, but it cannot be reduced to S & T. This formally rational abstract utilitarian knowledge has resulted in new means of control and is a form of knowledge which is quantitatively and qualitatively different from the previous practical knowledge and the status - cultural knowledge."

This definition is not only valuable in its own right but also refers to the unique and revolutionary change that occurred in cognition as part of the 'European Miracle.' The term 'status-cultural knowledge' corresponds to Gellner's view of pre-modern knowledge being compartmentalized and incorporated into social institutions. It means that it inheres in culturally defined statuses, rather than being an independent unified system theoretically open to all, irrespective of status. It conceives knowledge as abstract, generalizing and self-expanding. Any part of it is available to be applied to any problem or aspect of the world.

Knowledge and Credentials

There are a number of related features of the knowledge that provide the basis for professional practice, which need to be identified individually for analytical purposes, but are indissolubly linked to the real world. This amalgam is considered by Turner and Hodges (1970) in their examination of the way society may make distinctions between occupations, one element of which is the 'degree of substantive theory and technique.' This conceptualization seems to lack the cutting edge, because it does not specify any means of characterizing the kind of knowledge that they are referring to. However, this was matter on which Weber (1978) was quite explicit: the knowledge in question is that which is certified and credentialed.

Credentials can be very explicitly characterized - they may be degrees, diplomas, certificates etc - and these may be obtained from establishments or organizations whose standing is widely known and understood. So the kind of knowledge that can underpin a claim of professionalism in the modern world is that which is credentialed by a relatively high level qualification, typically a degree, or by a relatively high-ranking establishment.

If the qualification is one that is granted by the professional body itself, then the entry standards required constitute the basis for judgment. Thus there are everyday practical means of distinguishing between the knowledge base of doctors, bank officials, printers and plumbers and there is no great sociological puzzle to be solved as Turner and Hodges seem to imply, when they state in their conclusion.

However, the sociologist can add the observation that generally speaking the services provided by holders of high level knowledge do not involve manual work, and where they do, that work is carried out on the body of the client (for example, by surgeons, dentists and physiotherapists etc). The sociologist would offer an explanation for the prestige being accorded differentially.

Relationship between science and technology

Researchers concerned with measuring the exact interdependence between science and technology seem to have asked the wrong question because they have assumed that science and technology are well-defined monolithic structures. In short, they have not grasped that science and technology are themselves socially produced in a variety of social circumstances (Otto Mayr 1976). It does seem that there is now a move toward a more sociological conception of the science and technology relationship. For instance, Layton (1977) writes:

> "The divisions between science and technology are not between the abstract functions of knowing and doing. Rather they are social." (Layton 1977, p. 209)

Barnes has recently described this change of thinking:

> "I start with the major reorientation in our thinking about the science and technology relationship which has occurred in recent times. We recognize science and technology to be on par with each other. Both sets of practitioners creatively extend and develop their existing culture; but both also take up and exploit some part of the culture and other. They are in fact enmeshed in a symbiotic relationship." (Barnes 1982a: 166)

Though Barnes may be overly optimistic in claiming that a "major reorientation" has occurred, it can be seen that a social constructivist view of science and technology fits well with his conception of the science-technology relationship. Scientists and technologists can be regarded as constructing their respective bodies of knowledge and techniques with each other drawing on the resources of the other when and where such resources can profitably be exploited. In other words, both science and technology are socially constructed cultures and bring to bear whatever cultural resources are appropriate for the purposes at hand. In his view, the boundary of science and technology is, in particular instances, a matter of social negotiation and represents no underlying distinction. It then makes little sense to treat science and technology relationship in a general unidirectional way.

According to Palladino (1993), all through history, there have been attempts to interpret the relationship between science and technology. Mario Bunge (1980) argues that successful technological practice depends upon the systematic application of scientific knowledge. Donald Cardwell (1965) argues that the growth of science owes a great deal to technological practice as the technological artifacts have provided tools and techniques for exploring the new ideas.

Yet another view is that though both science and technology focus on same object i.e., the natural world, their aims are quite different and radical from each other. Otto Mayr (1976) has put forward the argument that treating science and technology, as invariant across different time periods across history is erratic. Instead these terms should be treated as historical objects, which change and adapt with the passage of time and hence deserve analysis about what they were in the past and what they are at present.

Palladino (1992) argues that in the context of plant breeding, technological advance derives quite directly from scientific work. Mendelian Genetics was promoted in order to increase the productivity. By the 1930s, this resulted in a new and revolutionary technology i.e., hybridization.

In the context of agricultural research, science and technology components have a symbiotic relationship. Roli Srivastava and G. C. Srivastava (1993) mention that green revolution in the Indian context is the result of the systematic application of improved agricultural technology for crop production. The next section deals with the significance of technological interventions in agriculture.

Agriculture and technology

According to the 1997 World Bank Report, about 12% of the world's total land surface is used to grow crops, about 30% is forest or woodland, 26% is pasture or meadow. The remainder, one-third, is used for other human purposes or is unusable because of the climate or topography. In 1961, the amount of land supporting food production is 0.44 hectares per capita. Today it is 0.26 hectares per capita and based on population projections, it will be in the vicinity of 0.15 hectares per capita by 2050. The rate of expansion of arable land is now below 0.2% a year and continues to fall.

Under these circumstances, there is a need to increase productivity per hectare to feed the increasing population with the decreasing amount of land available for cultivation.

Global agriculture's steady gains in production over the past few decades have not been successful to overcome the problem of rising demand, which is a result of the increasing population. The challenge is immense because by 2050, global demand for food maybe three times greater than today. Moreover, during the past two decades the production growth has declined, dropping from 3% annually during 1960s to 2.4% in the 1970s and finally to 2.2% in the 1980s.

On a global basis, average yields per hectare of wheat, rice and maize haye climbed fairly steadily since 1961. The aggregate figures nonetheless mask some disturbing regional trends. In Asia, for instance, rice yields raised drastically in the 1960s with the introduction of new varieties and management practices. Yields continued to increase in the 1970s, but in the 1980s began to level off or decline.

According to Wenke (1980), agriculture was made possible by advancements in technology and concentration of technology, Similarly, agriculture allows for further increase in population. As people come into contact with one another, there is diffusion of crops, which has resulted in increased diversity of foodstuffs to consume. Norman Borlaug (1981) lists twenty-three plants that form the base of world agriculture, as indicated in Table No. 1.1.

Table No. 1.1: The twenty-three main crops that form the base of world agriculture

Category	Varieties
Five cereals	Wheat, rice, maize, sorghum and barley
Three root crops	Potato, sweet potato and Cassava
Two sugar crops	Sugar cane and sugar beet
Six grain legumes (pulses)	Dry beans, dry peas, chick pea, broad bean, ground nut and Soya bean
Three oil seeds	Cotton seed, sunflower and rape seed (the pulses groundnut and Soya bean are also oil seeds
Four tree crops	Banana, coconut, orange and apple

Source: A Theory of Technology: Continuity and Change in Human Development, Thomas R. DeGregori, Ames: The Iowa State University Press, 1982.

Over 80% of the harvested food by the weight is from plants, and just about half of all food and calories are from the five cereal grains. When domesticated plants were diffused to new regions, varieties are bred and adapted to fit the environmental circumstances. Most of the plants have been crossed with local varieties to fit micro-climatic and cultural needs. It is interesting to note that majority of wheat and rice production of the world comes from the plants, which share a common ancestry. This is a cause of concern as this is a prescription for disaster because this would lead to loss of genetic diversity among the crops.

According to Krimsky and Wrubel (1996), though cultivation of crops was carried out through the past ten to fifteen thousand years, the technological advancements started only 200 years ago. These include mechanization, plant breeding, hybridization, chemical based pesticides and herbicides and chemical fertilizers. Green Revolution, a set of techniques involving use of high yielding varieties, assured irrigation facilities, use of chemical fertilizers and pesticides, institutional credit facilities, etc. has radically transformed the agriculture scenario in third world countries.

Green Revolution-milestone in agriculture

The Green Revolution is characterized as the new technological paradigm, which replaced the old one, which was characterized by subsistence fanning. The concept of Green Revolution has become familiar in the context of speedy and modern agricultural development around the middle of the 1960s.

The Green Revolution means revolutionary change in agricultural production and productivity caused by the adoption of new agricultural technology in a very shorter period of time. This new farm technology consists of seeds drawn from research in laboratories in agricultural universities and institutions, chemical fertilizers, adequate irrigation facilities, pesticides etc and their proper combination.

In the Indian sub-continent, the phase during the 1960s can be termed as the 'period of Green Revolution' wherein the productivity in the agricultural sector has seen tremendous increase. The Green Revolution enhanced the productivity of major food grain crops of India, particularly Rice and Wheat. The high yielding varieties of rice suited to tropical conditions in South and South East Asia were developed by IRRI, Manila. These new high yielding varieties were extensively and successfully introduced in India. The High Yielding Varieties are defined as the early maturing semi-dwarf types that, under intensive agricultural practices provide a significantly higher yield compared to the traditional types. The public-sector institutions like the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) played a significant role during this period for the enhancement of the productivity.

The government had evolved the new agricultural strategy and put to use the High Yielding Variety (HYV) seeds. The earlier attempts aimed at increasing food production using traditional varieties were replaced by the HYV seeds of the green revolution technology. The rapid implementation of the green revolution technology can be gauged from the fact that the area under HYV seeds tremendously gone up by more than 35 times, from 2.2 million hectares in 1966-67 to about 72 million hectares in 1992-93 (Joshi, 1999). The country's irrigation potential has increased from 22.6 million hectares in the pre-plan period to about 85 million hectares at the end of 1993-94 consisting 31.8 million hectares under major and medium irrigation projects and 53.2 million hectares in minor irrigation projects. The consumption of chemical fertilizers, which has only 0.13 million tonnes in nutrient terms in 1955-56 increased to 12.4 million tonnes in 1993-94. With the adoption of new agricultural technology there was a change in agricultural practices, farm management and its approaches. Thus agriculture has become less dependent upon nature with the new farm technology.

However, with the increase in population and realization of limitations of green revolution technology in further increase in productivity, overcoming environmental constraints, etc. have posed a challenge for those who are involved in the process of scientific research in agriculture. This made the agricultural scientific community to look towards biotechnological interventions as alternative.

Biotechnology and agriculture

The discovery of recombinant DNA in the early 1970s rapidly opened new frontiers for the next generation of innovations in food production. The application of biological processes in agriculture involves the selection, modification or use of living organisms to achieve improvements in crop cultivating, animal husbandry or food manufacture.

Biotechnology has been variously described by different researchers working in this area. While biotechnology is described as a locomotive technology by Sharp (1986), Buttel describes it as a revolutionary and epoch-making technology (Buttel et al 1985). However in a later work, Buttel (1989) argues that biotechnology is more a "substitutionist" technology to be applied in declining sectors of the economy like the agricultural sector. Buttel (1989) claims that the improvements brought so far have been merely to serve to patch-up the problems of western agriculture and the related petrochemical industry.

According to Swarup and Srivastava (1994), biotechnology offers new ideas and techniques applicable to agriculture and offers tremendous potential for crop production, animal agriculture and bioprocessing. Biotechnology has provided scientists with new approaches to develop higher yielding and more nutritious crop varieties, to genetically alter crops to increase their tolerance to diseases and adverse conditions and reduce the need for fertilizers and other expensive chemicals. Biotechnology also offers a vast potential to improve forestry and its products, fibre crops and chemical feed stocks.

Improvements in agricultural production and in food and nutrition situation depend upon land, water and energy resources, which are generally considered limited. In this context, the research aims of the life sciences are to increase the productivity, maintain high nutritional value, greater plant resistance to adverse weather, pathogenic agents and pests. The contribution of plant genetics to this research is essential as much as its concepts and methods develop rapidly because of the recent developments in molecular biology and the exploitation of certain characters that are peculiar to plants.

Biotechnology has opened as exciting frontier in agriculture and offers opportunities for increased sustainability, profitability and international competitiveness in agriculture. Biotechnology tools complement rather than replace the traditional methods used to enhance the agricultural productivity and the new techniques provided are relatively fast, highly specific and resource efficient.

Biotechnology thus emerged as a tool in the hands of the plant breeders and geneticists for further improvements of economically important crop plants. It is of paramount importance to identify which tools in the emerging areas of technology would help us in reaching our research goals, economically and speedily. It is also important to understand what types of genetic alterations are appropriate for the needs of the third world agriculture.

Biotechnology is knowledge-intensive and advances in biotechnology require considerable scientific personnel and investment. There are at least four ways in which biotechnology is likely to have a significant impact on agriculture. These are:

- Through the substitution of renewable (agricultural) for non-renewable (fossil fuel) energy sources;
- Through the substitution of one crop for another, or alternatively a synthetic for an agricultural commodity;
- Through the adaptation of existing crops to different environments; and
- Through the shift in marketed surplus to farmers, to regions and to countries with high productivity or with protectionist policies.

Status of Crop Biotechnology in India

It is well recognized that biotechnology is not a new field but an age-old practice. A majority of the biotechnological processes have their origins in ancient and traditional fermentation such as the brewing of beer and the manufacture of bread, cheese, wine and vinegar. However, with the advent of recombinant-DNA technology, immuno-chemical technology and plant as well as animal tissue-culture methods, biotechnology has assumed a totally new relevance and significance. Biotechnology utilizes techniques derived from chemistry, microbiology, biochemistry, chemical engineering and computer science. Today, biotechnology is an interdisciplinary field and production of knowledge involves utilization of theoretical and methodological inputs from the diverse disciplines. According to Markle Gerald and Robin Stanley (1985), biotechnology has altered the position of molecular biology by giving it new financial resources, establishing pressure for regulation, changing the reward structure of science and altering the choice of problems.

In the Indian context, the importance of biotechnology was greatly realized during the mid-seventies with the possibility of changing the activities of life forms through recombinant-DNA techniques and the use of biotechnology for human welfare becoming more and more possible and assuming greater importance. The Government of India realized the need of the hour and established the National Biotechnology Board (NBTB) in early 1982, which was later, renamed as the Department of Biotechnology (DBT) in 1986.

Research in Agriculture

Global investment in public research in agriculture climbed substantially between 1961 and 1985. During this period, the total number of agricultural researchers rose at an average annual rate of 4.2% - 7.2% in the developing countries and 1.7% in industrialized nations. While the developing world enjoyed 6.3% annual growth in research expenditure, the average for 1961-65 and 1981-85, this rate slowed down considerably in the early 1980s.

Based on a study of 83 countries, 68% of agricultural researchers are engaged in crop research, 19% in livestock research, 7% in forestry research and 6% in fishery research. In 1971, 20 donor countries established the Consultative Group on International Agricultural Research (CGIAR) as an umbrella body, which included 13 countries and 40 donors. The budget of the CGIAR rose from $20 billion in 1971 to $280 million in 1990.

Rice, a major staple crop of three fourth of world population has been given due importance in crop research programmes. Rice is probably the world's most diverse crop, which is grown as far north as Czechoslovakia and Manchuria and as south as Uruguay and Australia. Rice grows at more than 3,000 meters elevation in Nepal and Bhutan. Rice is planted on about 145 million hectares, which amounts to 11% of the world's cultivated land. The total production of rice in the world is 468 million tons per year. The country wise distribution of the production of rice is as follows:

Table No.1.2: Rice Production in various countries

Country	Production (in million tons/year)
China	175
India	87
Indonesia	40
Bangladesh	22
Thailand	19

Source: Gangadharan. 1985. 'Breeding' in Rice Research in India, New Delhi: Publications and Information Division, ICAR

Global Rice Research

In the rice growing countries, population pressures are so intense that rice is consumed within a few kilometers of where it is grown. The International Rice Research Institute (IRRI), which was established in 1960 by the Ford Foundation and the Rockefeller Foundation in cooperation with the Philippine government, was the first serious effort to apply modern agricultural science to farm technology in the Third World. The main objective of IRRI is to increase the quantity and quality of rice production in the tropics.

By the late 1960s, around 25% of the third world's rice land was planted with IR8 and other similar semi-dwarf varieties developed at the IRRI. Rice breeding grew increasingly complex as scientists strive to breed combinations of as many desirable traits as possible into the seeds that farmers plant. IRRI's international Germplasm Centre (IRGC) preserves 84,000 rice varieties of the estimated 120,000 rice varieties in the world. IRGC safeguards thousands of traditional varieties that are threatened with extinction by replacement with modern varieties or with natural and social disasters.

Rice Research in India

According to Grist (1975), rice breeding in India started in undivided Bengal in 1911 with the appointment of Dr. G. P. Hector as the Economic Botanist with his headquarters in Dacca, now in Bangladesh. The period between 1911-1979 may be considered under three distinct periods as far as rice breeding in India is considered viz.,

1. Of mainly pure line selections and very few hybridizations (1911-1949);
2. Of inter racial hybridization between japonicas and indicas (1950-1964); and
3. Of inter racial hybridization with semi dwarfs, especially Taiwanese indicas (1969-till date.

Prior to 1930, Bengal and Madras were the only provinces, which had full time specialists for the crop. When the Indian Council of Agricultural Research (ICAR) was established in 1929, it initiated rice research projects in many states, which did not have a rice program, and this gave an impetus to the development of rice research in India. By 1950, there were 82 research stations devoted to rice in 14 states of India. These research stations released 445 improved varieties mainly by the pure line selection. The establishment of these different stations was promoted by the need to cater for different ecological conditions. Ghose et al. (1960) had listed the broad breeding objectives that made possible the development of 445 varieties in the country. These objectives are earliness, deep water and flood resistance, lodging resistance, disease resistance, non-shedding of grains, dormancy of seed, control of wild rice, disease resistance, and higher response to heavy manuring. Since 1965 there has been tremendous increase in the number of hybrid varieties produced in the country in the wake of the green revolution. During this period, 123 varieties were released in 12 years, compared to the 51 hybrid varieties released during the four decades prior to 1965. This surge in hybrid releases was facilitated when semi-dwarf plant habit became one of the easily identifiable selection criteria for the breeders. After the establishment of the Central Rice Research Institute (CRRI) in 1946 at Cuttack, there has been a systematic screening of exotic types from the genetic stock and many Chinese, Japanese, Taiwanese and Russian types were tested for the purpose of direct introduction in the country. The end of the Second World War and the subsequent population explosion stimulated the Food and Agricultural Organization (FAO) of the United Nations to take up the problem of improving the production of the major Asian and world cereals on an international basis and the result was a collaborative project of japonica x indica hybridization in the South East Asian countries. The rationale of the FAO project was to transfer the high yielding ability and response to heavy fertilizer inputs that characterize the japonicas into the local indica varieties, which were adapted to their respective conditions of culture and had tolerance to the prevalent diseases and pest of the region.

Scientific communities in India

Modern science was institutionalized in India during the colonial period. In the second half of the 19th century a few pioneering Indian scientists initiated attempts to build a nationalist scientific community against the background of British imperialism. After independence, state policies (for example, the Scientific Policy Resolution of 1958) realized the significance of modern science as an important input in the socio-economic transformation of Indian society, which led to the establishment, and expansion of institutions such as the Council for Scientific and

Industrial Research (CSIR), Indian Council of Agricultural Research (ICAR) and Indian Council of Medical Research (ICMR) and universities. Over time there has been substantial quantitative growth in scientific personnel. However, there have been very few attempts to understand the structure and culture of paradigm-guided scientific communities in the country. But there have been efforts to understand the specific features of the organization of science in the Indian context (Haribabu, 1991).

It has been argued that though in numerical terms the scientific community in India is large, it is fragile (Shiva and Bandhopadhyay 1980). Indian culture has been shown to be incompatible with values of modern science (Parthasarathi 1969a, 1969b; Rahman 1970). The Shilsian idiom of 'centre' and 'periphery' explains the observed differences between the functioning of science among the early and the late starters. According to this view, the scientific establishments in the colonies were set up to meet the ends of the empire. Though independent, the scientists from the former colonies had to look to the centre for ideas and impetus, as scientific enterprise was not part of the indigenous culture. Kapil Raj (1988) argues that the way a given group views knowledge or its 'image of knowledge' is culturally determined. It forms part of, and plays a crucial role in the practice of a given local scientific community in particular and in the social interactive framework of the society in general. It provides the very structure that makes knowledge meaningful: it determines why a given society needs knowledge and manifests itself in the promise that knowledge holds out. It determines what will count as knowledge, what group inside that society that controls this knowledge and what power it gives them. It determines by what process knowledge is to be wrought, how it is to be communicated and validated etc. Kapil Raj (1988) maintains that it is necessary to grasp the specificity of the different images and concepts of knowledge operating within different cultures as lack of overtly identifiable reward or gratification system and the scientific profession not being the best paid in the country, yet most of the scientists devote their lives to research and are extremely satisfied with their achievements.

Seshachar (1972) argues that in India, science is administered by the government and an independent community is unable to develop under the auspices of the government. However, in the fields of space technology, nuclear technology and agriculture, Indian scientists have made a significant impact. Further, some individual scientists in different scientific disciplines made a mark and gained international reputation. In the case of agricultural sciences sociological studies emphasized social factors affecting the diffusion of agricultural technology in the wake of the Green Revolution.

There are several sociologically significant questions regarding the dynamics of production of knowledge, in various sciences in general and agricultural sciences in particular, which remain unanswered. Adhikari (1991) attempts to address this question partially by focusing on rice research. She points out that in India exploration and exploitation of natural resources have played a major role in scientific development. She discusses the potential utility of demarcating a domain of knowledge production in natural science in which research and disciplines grow in distinct ways. As mentioned earlier, agricultural production based on Green Revolution technology has reached a plateau and there is need for a technological impetus to increase production. It is in this context that biotechnology assumes importance.

Perspective used in the present study

The perspective of the present study is informed by the sociological insights that one can garner from Thomas Kuhn's work. Kuhn (1970) by pleading for examining science in its historical integrity has opened up possibilities of a thorough going sociological analysis of the process of production of knowledge and the product resulting from the process. Further his notion of scientific community is closer to the sociological concept of community. His notion of paradigm enables us to understand the consequences of shift in the paradigm for the worldview and also the practices.

A new paradigm not only looks at the world differently but also a different world. Related to this is the shift in the practices - instruments and instrumentation techniques, experiments, standard ways of applying paradigm theory to different situations. In this process, practices of the professionals would change and bring new set of values - cognitive and social. These insights are useful in understanding the changes that are likely to take place in the case of the discipline of plant breeding and practices of the plant breeders. Kuhn argues that the scientific community gets 'insulated' from wider society and prepares its own paradigm-based research agenda. This is now being questioned as the character of science is undergoing change as science is becoming more closely linked to industrial research.

According to Kuhn (1970), 'Normal Science' refers to research firmly based upon one or more past scientific achievements that the scientific community acknowledges for the time being as the foundation for its future practices. These scientific achievements share two characteristics namely:

1. Their achievement was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of activity; and

2. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve.

These scientific achievements are called as paradigms, which are accepted examples of actual scientific practice that include law, theory, application and instrumentation, which provide models for the coherent traditions of scientific research. The study of paradigms prepares the student for membership in the particular scientific community with which he will later practice. His subsequent practice will seldom evoke overt disagreement over fundamentals. Researchers sharing a shared paradigm are committed to the same rules and standards of scientific practice. The commitment and the apparent consensus a paradigm produces are prerequisites for normal science i.e., for the genesis and continuation of a particular research tradition. Though scientific research is possible without a paradigm, the acquisition of a paradigm according to Kuhn signifies the maturity in the development of any given scientific field.

Paradigms acquire their status because they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute. The success of a paradigm is largely a promise of success discoverable in selected and still incomplete examples. Nonnal science consists in the actualization of that promise by extending the knowledge of those facts that the paradigm displays as particularly revealing by increasing the extent of the match between those facts and the paradigms predictions and by further articulation of the paradigm itself. Post-Kuhnian approaches to sociology of science not only look at the social norms but also the very content of science. Mertonian approach limited itself to looking at the social moral norms of scientific communities. Constructionist approach, one of the post-Kuhnian approaches which looks at both the process of production and the outcome of the process (Knorr-Cetina, 1981). As already mentioned, Knorr-Cetina argues that scientific knowledge is an outcome of constructions based on a series of interconnected selections—theories, methods, experiments and interpretations. The selections are influenced by local contingencies and cultural contexts. Scientists deploy practical reasoning, analogical reasoning and socially situated reasoning in the process of production of knowledge (Knorr-Cetina, 1981). This perspective is useful to look at the process of production of knowledge by the community of scientists engaged in plant breeding. Research in plant breeding involves a series of selections in the process of identifying and selecting varieties in hybridization programmes. In the context of application of molecular biology techniques plant breeders will be engaged in the process of selections, for example, of genetic markers and approaches to marker assisted selections (RAPD, RFLP, etc). Molecular biologists also take decisions with respect to achieving genetic modification by weighing the options of transformation--agrobacterium-mediated transformation, use of biolistic gun, electrophorosis~and then select one of these options.

Today there is a great deal of mutual interpenetration of science and technology (Ziman, 1998). Basic research is influenced by commercial considerations. Molecular biology as a paradigm is going to have enormous implication for crop improvement research. As mentioned earlier, crop improvement research was first based on mass selection, Mendelian genetics and hybridization. Plant breeders today have access to knowledge about plants at molecular level. How and in what ways plant breeders evaluate the new knowledge in relation to their professional work, which hitherto was based on Mendelian genetics and knowledge of several field-based parameters. If the plant breeders adopt the new molecular paradigm does this adoption change their profession? If it changes, in what ways and how does this change occur?

Statement of the problem

Plant breeding research based on conventional methods of improvement was based on Mendelian Genetics. In Mendelian genetics, the level of understanding of the object of research i.e., the rice plant is at the level of the phenotype. In conventional plant breeding, the commonly deployed strategy of intervention is hybridization. In hybridization, the changes/modifications that were required were to be brought about in the plant in terms of increase in yield, resistance to various kinds of stresses, diseases and pests had to be carried out by crossing the parent plant with the plant varieties which have the desired qualities. This would follow the tests, which would confirm whether the desired quality is present and dominant in the subsequent generations. This would take lot of time from the field-testing to be released as a new variety.

With the introduction of molecular biology techniques in the plant breeding programs, the time taken for the development of varieties has been shortened. In other words, while in conventional plant breeding programs, the development of a variety would have taken at least ten to twelve years. Using the molecular techniques in the breeding program, the time taken for the development of new variety would be shortened to four to five years.

Moreover, the molecular techniques would enable the plant breeder to incorporate genes of interest from any living organism either in the plant or animal kingdom. This process involves a shift in the way the plant breeder looks at the object of research i.e., the rice plant. But the changes that were to be incorporated would be at the molecular level i.e., at the level of the DNA. This would employ completely different set of strategies of intervention and imply a change in the associated practices to be followed by the plant breeders in the plant-breeding program. Mendelian genetics will play significant role in evaluating a variety in successive generations. The choice of a particular strategy of intervention would be based on a series of selections. The factors that influence the selections and ultimate choice of a particular strategy of intervention by the community of plant breeders are significant sociological questions.

The present exploratory study aims to make a sociological analysis of the nature of changes at the level of cognition, the level of intervention and also at the level of organization of the profession that are likely to occur in the conventional plant breeding practices when faced with the new form of knowledge i.e., the techniques of molecular biology. It is interesting to note that at present most of plant breeders seem to be learning/acquiring the techniques of molecular biology in order to carry out their work independently without having to depend upon the molecular biologists.

Argument of the thesis

Understanding life processes at molecular level also suggest interventions at molecular level. The present study is an attempt to analyze in what ways and how the molecular biology knowledge and associated techniques influence the profession of plant breeding at the level of understanding, strategies of intervention and associated practices.

Scope of the study

The study intends to capture social and cultural change in a profession that is experiencing a shift in its theoretical foundations. It is a rare opportunity for a sociologist to explore the situation. There are several extremely important larger questions arising out of developments in molecular biology and biotechnology. For example, genetic engineering has become controversial because of its implications for environment and ethics. The present study recognizes the sociological significance of these questions, however it is beyond the scope of the present study to address these questions.

Objectives of the study

The objectives of the present study are to:

1. Provide a demographic profile of the scientists who were included in the present study.

2. Describe the changes that have occurred and/are likely to occur at the cognitive level in the discipline of plant breeding with the introduction of molecular biology knowledge and techniques;

3. Examine the changes that have taken place in the strategies of intervention and the associated practices in the profession of plant breeding with the introduction of molecular biology techniques; and

4. Finally, examine the organizational imperatives for incorporating molecular techniques into plant breeding research.

Chapter scheme of the thesis:

The present thesis is divided into the following chapters:

Chapter I dealt with the relevant sociological conceptualizations on scientific communities and professions, relation between science and technology, scientific communities in India, statement of the problem, perspective of the study, and the objectives of the study.

Chapter II deals with the definition of concepts that are employed in the present study. It also deals with the methodology employed during the course of the present study.

Chapter III deals with plant breeding as an art and science as well as the techniques employed in conventional plant breeding. The chapter also gives an outline of the molecular biology techniques that are perceived to be useful and employed in conventional plant breeding.

Chapter IV provides a sketch of the organizations, which are sites of scientific action of scientists included in the present study. The chapter also includes the demographic profile and composition of respondents in the study.

Chapter V provides a benchmark description of the plant-breeding program using the conventional methods of plant breeding. The chapter also aims to describe the changes that have occurred and/are likely to occur in the plant-breeding program at various levels after the introduction of the molecular techniques into the plant breeding research.

Finally, Chapter VI summarizes the findings of the present study and draws some conclusions.

Chapter II

CHAPTER II

Definition of Concepts and Methodology

The previous chapter (Chapter I) dealt with the relevant sociological literature on science, relationship between science and technology, statement of the problem, and the objectives of the present study. The present chapter (Chapter II) would deal with the definition of concepts used during the course of the present study and also the methodology employed for the present study. The following definitions of the concepts employed in the study will enable us to understand the present study.

Laboratory

Karin Knorr-Cetina (1981) defines lab as "a local accumulation of instruments and devices within a working space composed of chairs and tables. Drawers full of minor utensils, shelves loaded with chemicals and glassware, refrigerators and freezers stuffed with carefully labeled samples and source materials i.e., buffer solutions and finely ground alfalfa leaves, single cell proteins etc. All of the source materials have been specifically and selectively bred. Most of the substances and chemicals are purified and have been obtained from the industry, which serves science, or from other laboratories. But whether brought or prepared by the scientists themselves, these substances are no less the product of human effort than the measurement devices or the papers on the desk. It would seem, then, that nature is not to be found in the laboratory, unless it is defined from the beginning as being the product of scientific work." Lab is the site where selections - of theories, methods, and experiments – are made. The lab is the site where decisions on the selections are made. Latour (1983) argues that lab is the link between the world of science and the external world. He argues that Pasteur brought into the lab the interests of several sections of the society while working on anthrax. In case of the plant breeding, lab is also the locale where the plant breeders take decisions on selections regarding phenotypes for breeding, breeding strategies are made.

The language of the scientists contains innumerable references to what is or what is not true. The scientist's vocabulary of how things work, of why they do or do not work, of steps to take to make them work, does not reflect some form of naïve verificationism. In fact it is a discourse appropriate to the instrumental manufacture in the workshop called a “lab.”

For the present study, one has to bear in mind that the laboratory is an integral part of the plant breeding programs whether it is based on conventional methods or based on molecular techniques. Also one has to bear in mind the changes in the nature of activities undertaken in the two situations. In the former context, the activities carried out in the laboratory are simple like taking different measurements like the plant height, thousand-grain weight, panicle weight and so on. Also it is also used to store the simple equipment that is used in the conventional plant-breeding program. The lab is the locale where decisions regarding the selection of phenotypes for breeding, breeding strategies are made on the basis of knowledge about the field situation. In essence the plant breeders bring in the interests of several sections - agronomists, pathologists and farmers into their lab space.

In the case of molecular biology laboratory, the scenario would be entirely different with the nature of activities being highly specialized. Hence there is a need for more of sophisticated and technical expertise on the part of the individuals/personnel to carry out the activities in the laboratory and operate the equipment and conduct the experiments. The level of complexity of operations increases in the context of the molecular biology laboratory.

Tacit knowledge

According to Koivunen (1998), Michael Polanyi coined the term Tacit Knowledge in the 1950s. Tacit knowledge is difficult to define, but according to one definition it includes all the genetic, bodily, intuitive, mythical, archetypal and experiential knowledge the human being has, even though it cannot be expressed by means of verbal concepts. Tacit knowledge is present in the human being as a whole: it includes manual skills, knowledge of the skin and of thoughts.

Sveiby (1997) argues that Polanyi's concept of knowledge is based on three main theses namely: First, true discovery cannot be accounted for by a set of articulated rules or algorithms. Secondly, knowledge is public and also to a very great extent personal i.e., it is constructed by humans and therefore contains emotions, 'passion'. Thirdly, the knowledge that underlies the explicit knowledge is more fundamental; all knowledge is either tacit or rooted in tacit knowledge.

Sveiby (1997) also argues that in every activity there are two dimensions of knowledge i.e., focal knowledge and tacit knowledge. Focal knowledge deals with the knowledge about the object or phenomenon in focus. Tacit knowledge deals with the knowledge that is used to handle or improve what is in focus. These two levels of knowledge are mutually exclusive. Also the focal and tacit dimensions of knowledge are complementary. Tacit knowledge functions as background knowledge to accomplish a task in focus. Sveiby (1997) gives an interesting example in which he mentions while reading a text words and linguistic rules function as tacit subsidiary knowledge while the attention of the reader is focused on the meaning of the text.

In the context of the present study, tacit knowledge refers to the knowledge regarding a particular disciplinary field and also the associated experimental techniques that are employed in that discipline. Laboratory seems to be the site where a scientist acquires tacit knowledge from his/her mentor and peer group. Tacit knowledge in the case of the plant breeders is acquired both from the laboratory as well as the field. Tacit knowledge also includes the local conventions and locally evolved methods in fabrication of equipment and experimentation. It would be interesting to note that the tacit knowledge required in plant breeding discipline using conventional methods would be quite different than that of molecular breeding. Having employed the molecular biology knowledge and practices into plant breeding program, the plant breeder would have to acquire and integrate the two different types of tacit knowledge.

Professions

According to Elias (1964), historically the term refers to the professions of divinity, law and medicine as the first occupations that gave to people not living on unearned income a chance to make a living, which did not involve trade or manual work. Later it came to include army and the naval profession. Elias (1964) also argues that with the development of industrial societies, the meaning of the term has been extended to include occupations that require some scientific training and knowledge, though not primarily of university standard, and a diploma or certificate, usually based on examinations, for the exercise of their specific occupational skills.

In a more general application of the term 'professions' denotes those occupations, which demand a highly specialized knowledge and skill acquired at least in part by courses of a more or less theoretical nature and not by practice alone. The skills, both theoretical and practical, should be tested by some form of examination either at a university or some other authorized institution and conveying to the persons who possess them considerable authority in relation to 'clients.' This kind of authority is carefully maintained and often deliberately heightened by guild like associations of the practitioners. These guild like associations, usually the professional associations, not only see to it that the standard of knowledge and skill of the practitioners is not lowered, but also defend the level of their professional remuneration. These associations also try to prevent competing groups from encroaching upon the boundaries of their professional activities, and watch over the preservation of their professional status.

According to Waddington (1985), though there appears to be no consensus among authors about the essential characteristics of a 'profession', there appears to be agreement on some of the most frequently mentioned characteristics. These characteristics of profession are:

1. Possession of a skill based on theoretical knowledge;
2. Provision of training and education;
3. Testing of competence of members;
4. Organization;
5. Adherence to a code of conduct and
6. Altruistic service

For the present study, the profession of plant breeding would imply scientists engaged in plant breeding research and having the above mentioned characteristics. The plant breeders execute the plant breeding programs on the basis of their knowledge base in genetics. The breeders acquire this knowledge by their training and education (usually masters degree and above) in genetics.

Values

In the social world, meanings, values, attitudes and actions are related to each other in a complex and dynamic way. Though the term value is used differently in different contexts, in the literature in Sociology and Social Anthropology, it denotes the shared cultural standards according to which the relevance - moral, aesthetic, or cognitive - of the objects of attitudes, desires and needs can be compared and judged. A set of interrelated meanings attached to objects and practices are also related to values. It should be noted that among the individuals who share the same set of standards, there is a belief that the set of standards are valid and should be employed in valuing an object i.e., relating it to needs, desires, or attitudes and in evaluating and object i.e., comparing its relevance with that of another object or other objects. In the case of plant breeding, the values relate to economic and cognitive interests. Meanings relate to desirability, aesthetics and so on.

According to Sveiby (1997), in dealing with Knowledge, Polanyi also emphasizes on the concept of 'tradition'. Tradition describes how knowledge is transferred in a social context. The tradition is a system of values outside the individual. Both language and tradition are social systems, which take up, store and convey the knowledge of society. A tradition, according to Polanyi, transfers its patterns of action, rules, values and norms. They create a social order because people can foresee both the actions of others and the implied expectations on themselves. More specifically about values, Polanyi argues that values are not subjective but they are part of a professional tradition outside the individual self. In the value, an individual's experience gets integrated with a claim of being general within the tradition of a profession. As time passes, some of these values are validated and transformed cognitively into beliefs about how things are.

The set of values as it was found in the context of the present study was different for the applied scientists and basic scientists. The plant breeders being applied scientists emphasize more on the development of varieties keeping the needs of the farming community in view. On the other hand the molecular biologists being basic scientists are publication oriented.

Role

In the sociological literature, there are two different overlapping yet different ways of treating role. Looked as an aspect of social structure, a role maybe defined as a named social position characterized by a set of personal qualities and activities. This set of personal qualities and activities are evaluated in normative terms both by the person who occupies it as well as the individuals out side. In essence, role may be defined as behavior expected of an incumbent of a social position.

Scientific community

One of the central concepts in the sociological analysis of science is the scientific community. The concept has been variously defined by different sociologists of science in their analysis of the scientific enterprise. Robert K. Merton first used the concept of scientific community in his sociological analysis of scientific enterprise. Diana Crane's concept of social circle is also relevant in the context because it closely resembles the idea of scientific community. The third important writer on the concept of scientific community is Thomas Kuhn. Kuhn (1970) in his influential writing "The Structure of Scientific Revolutions" argues that the scientific community is bound by a paradigm.

In the context of the present study, professions and scientific community are used synonymously. However it should be mentioned that scientific community becomes a profession once it organizes itself as a group that uses and articulates a particular paradigm at the level of pedagogy, research and advocacy of the strategies of intervention. In case of plant breeding, plant breeders were using Mendelian genetics, which was used in pedagogy, research and advocating strategies of intervention. But today molecular biology as a paradigm provides knowledge at the level of molecules and also suggests interventions at the level of the molecules. Now plant-breeding community is in a stage of transition to adopt a new paradigm and the scientists engaged in plant breeding seem to be evaluating the new paradigm for its efficacy in evolving new strategies of intervention.

Methodology employed in the study

The present study draws its conceptual and methodological inputs from a study on "Rice Biotechnology Research: A Study of the Community of Rice Researchers in India" during 1998-2000 carried out by Prof. E. Haribabu. The project was supported by the Rockefeller Foundation, New York. The out come of the study on the community of rice researchers led to research questions raised in the present study. The question was in what ways and how the molecular biology knowledge will impinge on plant breeding at the three levels: at the level of cognition, at the level of strategies of intervention and practices and the organization of the profession of plant breeding. The present study utilized data collected for the above-mentioned project.

For the fieldwork conducted for the purpose of the project, all the research groups that have been receiving support from the Rockefeller Foundation were included in the study. There were 40 research groups that received support from the

Rockefeller Foundation since 1989-1990. Some of the research groups continued to get competitive grants on the basis of rigorous review during 1989-1990 while others, which received grants in the earlier phase, did not succeed due to their failure to compete. However, thirty-three groups responded to participate in the study.

Out of the thirty-three groups, thirty of them were located in the public sector institutions like the general and deemed universities, state agricultural universities, and mission oriented research organizations supported by the government. Two research groups were drawn from private research foundations: one functioning in MAHYCO Research Foundation, and the other in SPIC Science Foundation. One research group located in International Centre for Genetic Engineering and Biotechnology (ICGEB) in India was also included. Among the thirty-three research groups that were included in the project, fourteen of them were led by molecular biologists and the remaining nineteen were led by applied scientists, majority of whom were plant breeders.

The fieldwork of the project was carried out over a period of one year during 1998 and 1999. The following institutes spread across the country were visited during the course of the fieldwork for the project:

1. Tamil Nadu Agricultural University, Coimbatore
2. University of Agricultural Sciences, Bangalore
3. Directorate of Rice Research, Hyderabad
4. Central Rice Research Institute, Cuttack
5. National Chemical Laboratory, Pune
6. University of Delhi, South Campus, New Delhi
7. Madurai Kamaraj University, Madurai
8. University of Madras, Chennai
9. University of Hyderabad, Hyderabad
10. Indian Institute of Science, Bangalore
11. Haryana Agricultural University, Hissar
12. Punjab Agricultural University, Ludhiana
13. Centre for Plant Molecular Biology, Osmania University, Hyderabad

14. MAHYCO Research Foundation, Hyderabad
15. SPIC Science Foundation, Chennai
16. International Centre for Genetic Engineering and Biotechnology, Delhi and
17. ICAR Research Complex for North-East Hill Region, Barapani

One of the significant outcomes of the project was that the interaction between the applied scientists (plant breeders, entomologists, pathologists, and geneticists) and the basic scientists on the other was marked by differences in perceptions regarding the efficacy of molecular biology techniques for plant breeding research. It was in this context that the current research problem was conceived to look at the changes that are likely to occur in the profession of plant breeding with the introduction of the molecular was chanced upon for the doctoral study.

With this kind of background, a questionnaire and an interview schedule were prepared for the purpose of data collection for the present study. The list of biodata/C. V. of the scientists were collected in addition to the questionnaires and in-depth interviews with the scientists. The lists of publications were important as they provide the patterns of collaboration of the scientists both within the organization and also outside the organization, both at the national and international level. Data on the patterns of collaboration between the applied scientists i.e., plant breeders, pathologists, entomologists, physiologists and geneticists on one hand and the basic scientists i.e., molecular biologists on the other were also collected. However a detailed analysis of the collaboration patterns on the basis of the publications was not undertaken, as the scientists have not provided their complete lists of publications. Analysis of the patterns of collaboration was based on the interviews conducted with the scientists.

One of the main objectives of the study was to look at the changes that have occurred and/are likely in occur in the profession of plant breeding after molecular biology techniques have been introduced into the discipline. The study aims to look at the changes that have occurred and/are likely to occur in the profession of plant breeding at three levels:

1. At the cognitive level or disciplinary orientation of plant breeding and
2. At the level of strategies of intervention
3. At the level of the associated practices of the plant breeders.

The other objective, which is important for the study is the nature of the organizational support, in terms of financial resources, human resources and physical infrastructure that are required to incorporate molecular techniques into the plant breeding profession. The organizations, which were selected for conducting the fieldwork for the doctoral study, were:

1. University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore;
2. Directorate of Rice Research (DRR), Hyderabad and
3. Central Rice Research Institute (CRRI), Cuttack

The fieldwork for the doctoral study was carried out in three institutes in two phases. The first phase consisted of a pilot study to make the necessary modifications in the questionnaire and the interview schedule. The first phase was carried out during May-June, 2001 in the University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore. After making the necessary modification in the interview schedule, fieldwork was conducted in Directorate of Rice Research (DRR), Hyderabad during August-September, 2001. One more round of fieldwork was carried out in University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore during January 2002. The fieldwork was wound up with a field trip to Central Rice Research Institute (CRRI), Cuttack in January 2002.

Nature of data

During the course of fieldwork, primary data pertaining to the organizational affiliation of the individual scientists, details about the highest degree obtained till date and the awarding institution, details of previous and present employment, details of post-doctoral training and the like were collected. All the above information was collected through the questionnaire (Annexure No. I). Through the interview schedule (Annexure No. II), the perceptions of scientists with regard to the changes that have occurred and/are likely to occur were collected.

Plan of Analysis

The analysis aims to provide a benchmark description of the community of scientists engaged in plant breeding who have been using Mendelian Genetics for crop improvement. The study then analyses the changes that have occurred/and are likely to occur in plant breeding because of the application of techniques based on molecular biology knowledge. The analysis employs qualitative techniques including content analysis of the interviews held with the scientists. In the analysis representative excerpts from the content of the interviews are used to illuminate the description and substantiate the argument. The words conventional and modern are used in the analysis in relative terms. In others words molecular plant breeding techniques are modern when compared to the conventional breeding techniques.

Having given the definition of concepts and the methodology employed during the course of the study in this chapter, the next chapter deals with plant breeding, which is considered as an art and science. It is necessary for a sociologist to have some knowledge about the domain hence the next chapter would deal with the various techniques that are used in conventional plant breeding. The next chapter would also provide an overview of the molecular techniques that are used in the plant breeding programs.

Chapter III

CHAPTER III

Plant Breeding: Art and Science

The previous chapter (Chapter II) dealt with the definition of the concepts and also the methodology employed during the course of the present study. The present chapter (Chapter III) deals with the history of plant breeding and also the techniques employed in conventional plant breeding practices. The chapter also gives an account of the revolutionary transformation of biology as a consequence of the Watson and Crick (1953) and the possibilities of understanding life processes at molecular level and intervening at the molecular level. In addition the chapter would also aim to provide an outline of the molecular techniques that are useful in plant breeding.

Humans have been breeding and selecting improved plants for centuries, choosing crops with better yield, bigger fruit or less susceptibility to pests and diseases. This is particularly true of annual crops such as wheat and corn, where many of the cultivars now grown have little resemblance to those of even last century. According to Chaudhari (1971), plant breeding is the applied branch of Botany that deals with the improvement of agricultural plants. This branch of agricultural sciences has contributed the most to the increase in food production all over the world.

Plant origins and development

Plant improvement started long before Mendel's discoveries. Plant improvement/crop improvement is closely linked to evolution of human civilization. Identification of crop plants and their cultivation have led to evolution and organization of human society with dynamic framework of norms with respect to control over land and organization of production. Initially when humanity lived as hunters, world populations were low and dispersal was the main characteristic feature of the population. It was in the Neolithic times that plant selection started. The most important feature of Neolithic plant domestication was that the genetic variability was available in the wild. This genetic variability was a result of the gene and chromosome mutations, which were basic to genetic differences on which natural changes occurred.

With the improvement in the modes of transport, seeds, roots and bulbs from different places were brought to be added to the existing genetic diversity. As a result, hybridization occurred naturally and added to the genetic variation available for selection. This has resulted in the increase in the productive capacity of crop plants, which, combined, with more efficient use of land and labor, led to the first great population expansion of the human species. Walton (1988) argues that the early history of crop development contains many features that are of major importance today. These are:

1. Plant transport and the accumulation of genetic variability in one area resulted in hybridization and gene transfer. By this means, new and favorable gene combinations developed. Such events are rare, and even when they occur, many changes are deleterious, so evolutionary advances and those made by human beings as a result of unconscious selection are slow;

2. In Neolithic times, progress would not be extensive because plant movement was slow and the genetic principles involved were not understood;

3. The object of modern plant breeding is to speed up this process and to assist humanity in the way in which we function as an "evolutionary force" to influence the genetic structure of our domesticated plants; and

4. Today, exploration, plant collection and speedy transportation enhance the progress started by the Neolithic peoples. The new knowledge that

plant breeding can provide comes from our understanding of the three aspects of genetics namely

a) Mendelian segregation and recombination;
b) interspecific hybridization and
c) polyploidy

Plant Breeding: Art and Science

Plant breeding as a science is of a recent origin. According to Chaudhary (1971), plant breeding can be defined as follows:

> "Plant breeding means the improvement in the heredity of crops and production of new crop varieties which are far better than original types in all aspects."

Smith (1966) defined plant breeding the following way:

> "Plant breeding is the art and science of improving the genetic pattern of plants in relation to their economic use. Usually and ideally it involves the effective cooperation with and help from the workers in somewhat remote disciplines."

Plant breeding is usually defined as the art and science for the improvement of crop plant science. Until about 200 years ago, plant breeding was practiced by the farmers and gardeners who selected seed from favored plant types for propagation of the next seed generation. Selection was largely an art based on considerations such as appeal to the eye, and farmers' view of an ideal. These considerations were based on the physical appearance of the plant, or what is called the phenotype. As an art the origins of plant breeding go back to the beginning of agriculture. A large number of most valuable varieties of fruit trees of the present time are the creation of the art of the plant breeder. According to Agrawal (1995), the plant breeder does not have to produce something out of nothing. However, he needs to provide the right direction. The art of plant breeding implies the ability of the plant breeder to discern by observation, the differences in plant material he handles and the selections he makes for further increase.

Vilmorin in 1850 suggested the practice of progeny testing as an adjunct to the previously used methods of individual plant selection. Progeny testing included evaluating a group (or family) of individuals that have descended from common individuals. In this manner, evaluations could be made for selected individuals that could be repeated in time and space. Progeny testing therefore was an important factor in changing the emphasis of selection based only on phenotype of individuals to selection based on progenies of individuals. Two other developments also had an important impact in changing the emphasis of plant breeding methods: a) rediscovery of Mendel's laws of inheritance of 1901 and b) the development of statistical concepts of replication and randomization for making valid comparisons.

These three components (progeny testing, Mendelian Genetics and experimental design) were instrumental in changing the emphasis of plant breeding from an activity based on art to one based on science. The art of plant breeding is based on an idealized mental concept of the breeder, i.e., and ideal type that is considered desirable and acceptable to the farmer and the gardener with regard to appearance, aesthetic qualities, color, stature etc. The idealized concept however, must be supported by performance, which may include yield, ease of handling, resistance to pests, drought tolerance etc. Hence modern plant breeding includes elements of art and science, with more emphasis in recent years based on science rather than the art.

The science of plant breeding implies the application of principles of genetics embodied in the study of heredity and variation, cytology and screening techniques and knowledge gained in related disciplines such as plant pathology, entomology, plant physiology, soil science etc. The science of breeding is the study of developing varieties for human needs. As a science, the scope of breeding is defined by the need for obtaining practical results.

According to Simmonds (1983a: 6) the process of plant breeding can be thought as "applied evolutionary science" because it encompasses all the features of the neo-Darwinian evolution. Medawar (1977) argues that the plant breeders collect the genetic material provided by nature and recombine it in accordance with the parameters of specification. In essence, they apply artificial selection to naturally occurring variance in the DNA 'messages' characteristic of the different genotypes.

Kloppenberg (1988) argues that in the process of plant breeding, the plant breeders will have to work within the natural limits imposed by sexual compatibility. In their work, the plant breeders have rearranged a given genetic vocabulary, but they have not been able to create new words or novel syntactical structures.

Aims and objectives of plant breeding

Goals of plant breeding are related to economic, cultural and agronomic domains. Economic considerations of plant breeding relate to increasing yield. Cultural considerations related to aesthetic qualities - like taste, color of a fruit, grain or flower. Agronomic considerations concern with suitability of a variety for a particular agro-climatic zone. Barden, Halfacre and Parrish (1987) argue that the ultimate goal of any breeding program is to produce a superior type of plant, which may be accomplished by any of the three general approaches namely increasing yield; improving quality and raising production efficiency.

According to Simmonds (1979), every plant-breeding program must have well defined objectives, which are both economically and biologically reasonable. Economic criteria are important in the sense that the breeder must be assured that he is trying to produce varieties, which farmers and end-users actually want. The biological objectives are determined by scientific knowledge and general feel for the crop. Yield and quality are important and invariable components of this set of objectives.

Simmonds (1979) argues that first among the decisions, which the plant breeder has to take, are the objectives of the breeding program. The other steps involved in the breeding program will follow from the nature of the crop, from the parental material in hand and from the objectives themselves. Thus the plant breeder will have to decide:

1. What parents to include and why?
2. What patterns of cropping and passage through the generations to adopt?
3. What methods of selection to use? and
4. How will he decide upon the ultimate release or discard of the products?

As mentioned earlier, plant breeders' selections are based on decisions on the above-mentioned dimensions. It should be noted that the second objective would be determined by the mating and propagation system of the crop. The third objective will depend largely on the genetics of yield and quality and the technology of the latter.

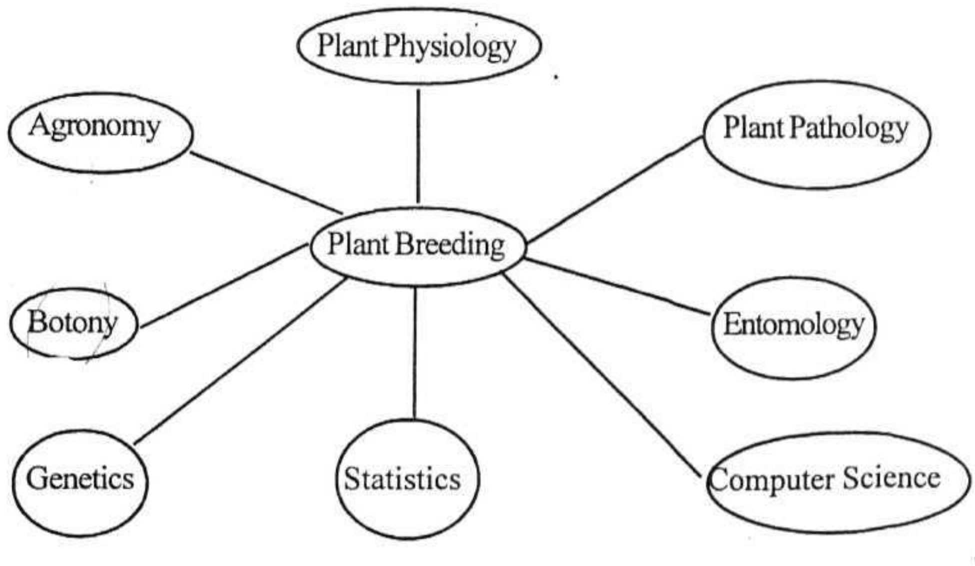
Chaudhari (1971) makes an interesting observation in this regard. He observes that the main objective of plant breeding, irrespective of the crop, is to produce new crop varieties superior to the existing types in all characters. However, some of the objectives are practically common in most of the crops. These are as follows:

1. higher yield of grain, fodder, fibre and other plant products;
2. better quality with regard to shape, size, color, nutrition, taste, malting, milling, baking, keeping, cooking etc in food grains, vegetables, fruits and flowers;
3. resistance to diseases, insects and pests, frost, flood, drought, wind storms, shattering, lodging and alkaline and saline conditions of soil;
4. change in duration, specially earliness or lateness in maturity as needed;
5. change in growth habits such as dwarfness, few branching and less tillering so as to prevent the crop plants from being blown down, or tallness, profuse branching and more tillering so as to increase the straw for fodder;
6. winter hardiness;
7. short and stiff straw to prevent lodging;
8. response to heavy manuring;
9. easier thrashability;
10. awned or awnless ears;
11. adaptability to wide regions; and
12. Suitability to machine harvesting in mechanized areas.

The traditional method of crop improvement is by sexual hybridization, making crosses between two plants with desirable characteristics. At fertilization, the genetic information from each parent recombines, so characteristics from each parent are inherited by the offspring. However, many other features are also inherited, along with the desirable one. A breeding program lasting for many years may be necessary to eliminate the unwanted characteristics, without losing the desired ones.

Over time, as the genetic basis of traits and interaction between the plant and its biotic and abiotic environment were understood, plant breeding has become an applied science drawing inputs from several disciplines. According to Poehlman and Sleper (1995), plant breeders must have some basics in botany, genetics, plant physiology, plant pathology, plant biochemistry, entomology, statistics, computer science, agronomy and horticulture. Chart 3.1 depicts the different fields of science involved in plant breeding.

Chart No3.1
Essential Components in Plant Breeding



Source: Jagkrit Parakarn, 2000, Chapter I: Introduction to Plant Breeding
Website: http://www.msu.ac.th/bio-dept/B1345/CH-1.html

Since 1900, Mendel's laws of genetics provided the scientific basis for plant breeding. Plant breeding principles consist of identifying and selecting desirable traits and combining these into one individual plant. Since all the traits are controlled by genes located on chromosomes, plant breeding can be considered as the manipulation of chromosomes.

Role of Mendelian genetics in plant breeding

According to Gupta (1995), Gregor Johann Mendel (1822-1884) formulated the laws, which explained the manner of inheritance of characters with the help of his experiments of garden pea. Mendel was not the first one to conduct hybridization experiments, but he was the first to consider one trait at a time, which was the secret of his success. His experiments were the extension and development of hybridization experiments on pea conducted by earlier workers like Knight (1799) and Goss (1824). Prior to Mendel, Kolreuter conducted hybridization experiments in tobacco and considered the hybrids with their parents to demonstrate that hybrids may resemble one or the other parent or may be intermediate between them. He also showed that both the parents make equal contribution to the hybrids. Another significant observation he 'made was that although the hybrids themselves may be fairly uniform, their off springs exhibit considerable diversity. He used tall and dwarf varieties of tobacco for hybridization and found that all the first generation hybrids had intermediate size. These hybrids in the next generation gave plants varying in size from tall to dwarf parents.

Mendel's experiments

Gregor Mendel was an Austrian monk and abbot in the monastery of Brunn, where he conducted his experiments in the cloister garden. After eight years of work, he published his results in an article in the "Proceedings of the Natural History of Brunn", which has become a great biological classic. Mendel wished to choose some plant with a short generation, and also one easily cultivated. Besides these features, the various strains/races of the plant should have sharply contrasted characters. He chose the common garden pea, which has thus become the classic plant in the history of genetics. It seemed to meet all the requirements he had in mind. These are well-defined characters; bisexual flowers; pre-dominantly self-fertilization and easy hybridization.

According to Rhee in the article on Gregor Mendel (source: http://www.accessexcellence.org/AB/BC/Gregor_Mendel.html) argues that the theories of heredity attributed to Mendel, based on his work on the pea plants, was so brilliant and unprecedented that it took thirty-four years for the rest of the scientific community to understand and appreciate its value. Mendel was the first person to trace the characteristics of successive generations of a living organism. His attraction to research was based on his love for nature. His interests, apart from plants, were meteorology and theories of evolution. The central question for Mendel was how plants obtained atypical characteristics.

On one of his walks around the monastery, he found an atypical variety of an ornamental plant. Then he planted this plant next to the typical variety. He grew their progeny next to each other to see if there is any impact of the environment on the plants, as proposed by Lamarck. In these experiments Mendel found that the plants' respective offspring retained the essential traits of the parents, and therefore were not influenced by the environment. This test gave rise to the idea of heredity. From his studies, Mendel derived certain basic laws of heredity: hereditary factors do not combine, but are passed on intact; each member of the parental generation transmits only half of its hereditary factors to each offspring (with certain factors 'dominant' over others); and different offspring of the same parents receive different sets of hereditary factors. The practical results of Mendel's research have implications not only for the way the world is perceived but also the way humans live in it.

Tracing the history of biology right from the days of Mendel to the modern day biotechnology, Martin Hewlett (1998) argues that the 1860s is an important in the sense that the key elements of what would become modern biology had been discovered and formulated. It should also be noted however that the period taken for the integration of various strands of knowledge into one discipline i.e., molecular biology took the next eighty years.

Martin Hewlett (1998) gives a brief outline about the social background of Mendel. He mentions that Mendel had received excellent training in both physics and chemistry at the University of Vienna. His work on the breeding patterns of the pea had been stimulated by earlier results of the botanists observing the products of crossing plants with different traits. But the significant difference with Mendel was that he brought to this work a tool, which the others lacked. This significant tool was quantification, which changed the science of plant breeding in a significant way.

Post-Mendelian Plant Breeding

The level of plant breeding has changed dramatically during the past 200 years. Initially, plant breeding included simple phenotypic (or mass) selection among the wild species of plants available at particular locations. Selection was for types that had particular appeal because of the quantity of the product produced, flavor, attractiveness, and availability for use as food, fuel and fibre. Although the methods of selection used by the early plant breeders would be considered as crude methods when compared to the present day standards, they were very successful in transforming wild species of plants into highly productive cultivated species that provided for the needs of the settlements. The impact of the early plant breeders was greater, however in the development of cultivable crop species than the recent efforts for improving the productivity, quality and pest resistance of major crop species. In general, there are four major ways to manipulate plant chromosomes namely:

a) similar chromosomes can be sorted out and retained in one individual plant to reach a homozygous state a method termed pure-line selection;

b) different chromosomes can be combined together to obtain a heterozygous state which is also known as hybridization;

c) new genetic variability can be introduced through spontaneous or artificially induced mutations; and

d) polyploidy, used only in vegetatively produced crops, also contributes to crop improvement. It is most commonly used in ornamental green leafy vegetables because the size of the fruit **and** leaf increases because of the number of chromosomes is doubled.

Certain traits like color of the grain, the length of the grain and flavor are influenced by cultural preferences of a given community. The technology of plant breeding has developed from the science of genetics. But as crop improvement by breeding depends on recognition of particular traits needed for achieving high and stable yield, pest and disease resistance and quality. Success in breeding also depends on an understanding of plant physiology, pathology and biochemistry.

The fundamental concept of genetics is the gene, the unit of inheritance. Each gene controls or influences some aspect of plant behavior and the gene complement or genome of a plant consists of 10^4-10^5 genes. Traditional plant breeding is concerned with the directed re assortment of the allelic variants to produce a combination or genotype, which best approaches a supposed ideal combination.

Plant breeding practiced till now involves hybridization process, which actually takes long duration of time before the actual plant variety is field-tested and released as a variety to be used by the farming communities. With the arrival of molecular biology tools, the period involved in development of varieties can be reduced to a considerable extent. But it should be noted that with the reduction in the time taken for the varietal development, the scale of specialization has increased considerably in the sense that the kind of technical expertise required to develop new varieties deploying the molecular techniques would be more specialized.

Post-Mendelian plant breeding involves the selection of a desired quality and then introducing it into the already available high yielding variety and then testing it in the subsequent seven generations before actually releasing it as a variety for the farmers. Breeders can produce high yielding varieties but it takes long period i.e., at least 12 years before the variety is field tested and released into the market. But with the advent of molecular biology techniques, it has become much easier at least theoretically to introduce the genes for desired quality into a particular plant variety. In the third world countries where agriculture forms the base of the economy, the new technology of knowledge can have a tremendous impact on productivity. It is often felt that the quality and quantity of the agricultural produce increases tremendously with the application of molecular biology techniques.

The level of plant breeding has changed dramatically during the past 200 years. Initially, plant breeding included simple phenotypic (or mass) selection among the wild species of plants available at particular locations. Selection was for types that had particular appeal because of the quantity of the product produced, flavor, attractiveness, and availability for use as food, fuel and fibre. Although the methods of selection used by the early plant breeders would be considered as crude methods when compared to the present day standards, they were very successful in transforming wild species of plants into highly productive cultivated species that provided for the needs of the settlements. The impact of the early plant breeders was greater, however in the development of cultivable crop species than the recent efforts for improving the productivity, quality and pest resistance of major crop species.

According to Simmonds (1979), plant breeding is the current phase of crop evolution and it proceeds in the same mechanisms that are responsible alike for the evolution of wild populations of plant of cultivated ones in earlier times.

Division among crop plants

For breeding purposes crops can be divided into two groups, they are either cross-pollinated or self-pollinated. They follow different breeding systems. These contrasting breeding systems generate very different populations, which require different breeding methods. Outcrossed species from populations that are highly heterozygous, and where inbreeding is enforced, such populations in such cases show a general deterioration in vigor. For such crops, heterozygosity has to be returned, or if it is lost during the breeding program, it must be restored. The reproductive biology of a species is the major determinant of how a plant-breeding program is structured. With each of these two breeding systems there are smaller deviations, which are also determined by the biology of the plant's breeding system.

Breeding self-pollinated species

The land races or locally adaptable crop types, which were found in the 19th century and are still used in many developing countries. These collections constitute a range of genetic variability that was achieved partly by human selection. For a plant-breeding program in a self-pollinated crop, such a reservoir of variability is an advantage. Adaptation to local environmental conditions is highly desirable and genetic variability may exist for traits under selection.

Breeding cross-pollinated species

These species are not only genetically heterozygous, but have a great variety of mechanisms that control cross-pollination. Some species are self-incompatible. Others self-pollinate rarely, or readily, or are entirely self-compatible. Where self-fertilization is possible the reduction in virto due to inbreeding may be little or none or maybe so drastic that self-pollination cannot be continued for more than two or three generations.

Methods of crop improvement

As already mentioned, the aim of plant breeding is to produce new crop varieties superior in all aspects as compared to the existing types. This objective is achieved through different methods of crop improvement as described below:

Selection

According to Chaudhari (1971), plant improvement must have started with the primitive man changing his mode of life from a nomad to an agriculturist who might have obtained the first crop growing as such in nature i.e., he had never sown the seeds to ensure the first crop. But to have crops the next season, he obtained seeds from the first crop. For this, unconsciously he practiced the selection. It is, therefore, the oldest breeding method and is the basis of all crop improvements. Selection as a breeding method can be distinguished into two categories namely:

Natural selection

Natural selection is a rule of the nature and has resulted in evolution. According to this, the fittest survives and rest gets wiped out. This natural principle resulted in cultivated crops and ecotypes in plants. The ecotypes are climatic or regional races the basis of artificial selection and hybridization. All the local varieties of crop are the results of such a selection. Many differences between species and sub-species have arisen due to this selection pressure. It remains operating in nature all the time and is one of the natural factors, which creates variation in already existing varieties of crops.

Artificial selection

The plant breeders/cultivators select certain types of plants from the mixed population for their own advantages. Artificial selection can be defined as follows:

> "Artificial selection is to choose certain individual plants for the purpose of having better crop from plants for the purpose of having better crop from a mixed population where the individuals differ in characters."

Artificial selection is done in the following three ways namely:

1. mass selection
2. pure-line selection and
3. clonal selection

1. Mass selection

It is followed both in self-defective and cross-pollinated crops and consists in selecting and collecting the similarly appearing best and most vigorous plants from the mixed population of a crop. The selected plants are thrashed together and a mixture of seeds is obtained. This mixture of seeds is a mass and therefore it is known as Mass Selection. The mixture so obtained is sown for raising the new crop from which the selection is made similarly the next year. This practice of selection is usually continued till the plants show uniformity in the desired characters and they constitute a new variety. If the population is already uniform, the mass selection cannot be practiced. Thus mass selections are based on the presence of variability in the population. Greater the variability in the plants, better are the results of selection. The plants are selected on the basis of phenotypic characters and therefoie the variety developed by mass selection is more or less pure in external features, which may be easily observed and used in identification. It should be noted that a lot had been achieved in the past and some of the outstanding strains till recently were products of this selection.

2. Pure-line selection

A pure line consists of the progeny of a single self-fertilized homozygous plant and is used for developing a variety. It is used in the mixed population of self-pollinated crops and consists of testing the progeny of single individual plants separately. It involves selection from the extremes for the desired phenotype. In genetic terms, a selected and inbred population is more homozygous than its wild relatives. Pure-line selection generally involves three distinct steps namely:

1. First a large number of selections are made from the genetically variable original population. The number of initial selections should be as great as consideration of time, expense, space and competitive plant breeding projects will permit.

2. Second, progeny rows are grown from the individual plant selections for observational purposes. After obvious elimination, the selections are grown over a shorter or longer period of years to permit observations of performance under different environmental conditions for making further eliminations.

3. Finally, when the breeder can no longer decide between lines solely on the basis of observation, he/she must turn to replicated traits, comparing among remaining selections with established commercial varieties in relative yielding ability and other aspects of performance. This stage of evaluation lasts at least three years.

If a large number instead of a single pure-line are likely to be retained, this procedure is usually referred to as mass selection. The most important feature of pure-line selection is the great precision with which they produce themselves. The variety produced is genetically pure and more durable. Associated with this advantage are some potential problems in unmasking some harmful genes as well as eliminating some desirable genes.

3.Clonal selection

It is practiced in vegetatively propagated crops such as sugarcane, banana, potato, sweet potato, mango, onion etc. In these crops, a group of plants is obtained vegetatively from a single plant, known as a clone. The method of developing varieties from the clones is known as clonal selection. Herein the superior clones are selected on the basis of their phenotypic characters of the individual clones. The selection is always between the clones and never within a clone, because all the individuals of a clone have the same genetic constitution. The selected clones are multiplied vegetatively and compared with the normal variety. The best performers are selected and tried at different stations for three years continuously. The best ones are given names and released as improved varieties. Clonal selection is just like pure-line selection in vegetatively propagated crops as the pure-lines are developed vegetatively form the basis of improvement. Bud selection is a form of clonal selection wherein the unit of selection is a bud.

Hybridization

According to Singh (1993), natural variability present in the self-pollinated populations is exhausted quickly when they are subjected to selection. Individual plant selection of pure line selection is the most common procedure applied to genetically variable homozygous populations of self-pollinated crops. As a result, the variability is soon exhausted as the land varieties are replaced by pure lines. For further improvement, therefore, new genetic variability has to be created by the plant breeder. This is easily and most commonly done by crossing two different pure lines.

Early work on hybridization

Hybridization offers far greater possibilities in crop improvement than any other breeding method and is the only effective means of combining together the desirable characters of two or more varieties. It is known that date palm was artificially pollinated by Assyrians and Babylonians as early as 700 B. C. But the main interest in hybridization was created with the discovery of sex in plants by Camerarius (1694).

The first natural hybridization was recorded by Cotton Mather (1716) in corn and first artificial hybrid was produced by Thomas Fairchild who crossed sweet william with carnation in 1717. The hybrid obtained from this cross was vigorous and is commonly known as Fairchild's mule.

The German Botanist Joseph Kolreuter (1760) was the first one to use hybridization practically for crop improvement. He fully realized the potential of artificial hybridization and his work marked the importance of crossing in crop plants. He did extensive crosses in many species of the genus Nicotiana and made the following very significant observations on crossing and pollination behavior:

- only crosses between related species would generally be successful, and even then not always;
- the F1 of some interspecific crosses were sterile;
- in most cases, reciprocal crosses were similar;
- continued self-fertilization of successive generations of hybrids includes types which closely resemble parents;
- there is a possibility that certain characters of one of the parents are dominant in Fl plants, and the others are intermediate between the characters of the two parents; and

- F1 plants sometimes exceeded the best parents in growing power.

Kolreuter was followed by Knight (1759-1838) and Goss (1822) in England, Caertner (1835) in Germany, Naudin (1863) in France and others. It indicates that a large number of workers were busy in hybridization work during the 18^{th} and the 19^{th} centuries but its significance in practical plant improvement was not clearly understood until Mendel's work came into light and laid down the basis of understanding the mechanisms of inheritance in plants. Table No. 3.1 indicates the three corner stones of hybridization and activities to achieve them:

Table No. 3.1: Three Corner Stones of Hybridization and Activities to achieve them

Corner-stone	**Activity to achieve the corner-stone**
Prevention of self-pollination in the flowers of the female parent	Emasculation of the flowers
Prevention of pollination of the female parent by undefined pollen sources	Bagging of the flowers
Ensuring pollination by the selected male parent prevention of contamination of the pollen used for pollination in a crop like maize	Hand pollination (Bagging of the male inflorescence)

Source: Singh, B. D. 1993. *Plant Breeding,* Ludhiana: Kalyani Publishers.

Definition of hybridization

Hybridization consists of crossing two or more plants, which differ genetically from each other in one or more characters and can be defined as follows:

"Hybridization is the method of producing new crop varieties in which two or more plants of unlike genetic constitution are crossed together."

The plants, which are crossed together, may belong to the same species, or different genera. According to this relationship between parental plants, the hybridization is divided into the following categories:

1. Intra-varietal hybridization
2. Inter-varietal hybridization
3. Inter-specific hybridization
4. Inter-generic hybridization

In contrast to pure-line selection, the most frequently employed plant breeding technique is hybridization. Hybridization demonstrated that crops such as maize could be inbred for six or seven generations until there is no further reduction in vigor and size. When these highly inbred plants were hybridized with other inbred varieties, very vigorous, large-sized, large-fruited plants were produced. This led to the origin of hybrid maize in 1919, then the most significant improvement in American agriculture at that time. The term "Heterosis" was used to describe this phenomenon of hybrid vigor. The possibility of hybridization marks the beginning of the entry of the seed companies in plant breeding because it enabled the hybrid seed companies to keep the information about the parental lines a trade secret. Later the hybrid seeds were given protection under breeders' rights (Kloppenberg 1989).

The first step in hybrid production is to generate homozygous inbred lines. This is normally done using self-pollinating crops where pollen from male flowers fertilizes with the pollen from the female flowers on the same plants. Once the pure-lines are generated, these are outcrossed. A problem with such hybridization is that the farmer must buy new hybrid seeds every year.

Another useful breeding technique is backcrossing. Backcrossing makes it possible to transfer specific genes from one plant variety to another. In this way, desirable characteristics of one variety can be combined with those of another variety. This trick circumvents the problem of trying to select simultaneously for many traits in the same variety.

Application and objectives

Hybridization is practiced in every type of crop, especially when no further improvement can be achieved in the local as well as introduced material *tot* any other method. This situation arises only when whole of the naturally occurring variation in the available material is exhausted by continuous selection. Its use, at such times as a method of crop improvement is commonly made with three main aims namely:

a) to combine all the good characters into a single variety;

b) to increase the range of genetic variability by introducing various recombinations of characters and

c) to exploit and utilize the hybrid vigor.

In the first two cases, the main objective sought is to create variability artificially by combining the characters of two or more than two plants, in which these valuable characters are found scattered, into one variety. This variation provides the plant breeder with basic raw material out of which selection is made to build up new crop varieties. In the third case, the aim is to restore the vigor lost during inbreeding or improve the level of productivity by concentrating the desired genetic factors.

Hybridization procedure

The various steps involved in hybridization are briefly described below:

- The first step is the selection of parents from the available material possessing desired characters;
- The second step is the selfing of parents to obtain homozygosity in desired characters so that they may easily be combined together. This

step is not practiced in self-pollinated crops because they are already homozygous due to natural selfing;

- The third step is the emasculation for female parents. In this step, the anthers are removed or killed before they mature and shed their pollen. The purpose of emasculating is only to prevent self-pollination. Therefore it is adopted in those crops where there is self-pollination, and never in unisexual crops;

- The fourth step is the bagging, tagging and labeling of males as well as females to be used in crosses. The females are bagged to prevent natural cross-pollination and males to prevent the contamination of pollens with the foreign pollen and collect pollen for crossing.

- The fifth step is the crossing in which the pollen from already bagged males are collected and dusted on bagged females and labeled;

- The sixth step is the collection of seeds from the crossed plants after maturity, maintaining them separately and sowing in the coming season to raise an F1 (First filial) generation. So obtained plants are called hybrids and defined as the "Progenies of cross."

- The seventh step is the handling of Fl and subsequent generations for production of a variety.

Plant introduction and acclimatization

Plant introduction and acclimatization is easiest and most rapid method of crop improvement method in which acclimatization follows introduction and both processes go side by side. Plant introduction and acclimatization can be defined separately as follows:

"Plant introduction is the process of introducing plants from their growing locality to a new locality."

Thus in this process the plants are transferred from one place to another having a different climate.

"Acclimatization is the adaptation or adjustment of an individual plant or a population of plants under the changed climate for a number of generations."

Modes of plant introduction

The plants of interest may be introduced in different ways. These are:

1. Inter-continental plant introduction where the plant variety is introduced from a country of another continent. Example would be ridley wheat variety from Australia.

2. Intra-continental/inter countries plant introduction where plants are introduced from another country within the same continent such as litchi and loquat from China.

3. Inter-state plant introduction where introduction occurs from another state within the same country. The instance of this type of plant introduction is the introduction of N.P wheat varieties from Delhi into different states within the country; and

4. Another district within the same state (intra-state or inter-district plant introduction) such as the distribution of state recommended varieties of different crops from one district to another within the same state for general cultivation.

Purposes of plant introduction

The purposes of introducing plant material from outside are for:

a) Use in agriculture, forestry and industry;

b) Studying the origin, distribution, classification and evolution of plants;

c) Fulfillment of aesthetic interest and

d) The genetic improvement of economic crops.

Mutation breeding

In a general sense, mutation means the sudden heritable changes in an organism other than those due to Mendelian segregation and recombination whereby the progeny may exhibit an altered shape, size, form or composition. According to Agrawal (1995), mutation breeding refers to the isolation and selection of desirable induced mutations in segregating generations that follow a mutagenic treatment of seeds or other plant parts. The selected mutants are used in breeding programs and are also released for commercial cultivation depending on their usefulness.

Plant breeding - Molecular biology techniques and after

In plant breeding, contributions from molecular genetics cell biology and tissue culture will increasingly contribute to the speed and extent to which the plant can be modified. The application of such techniques, however, will not change the requirements.

Techniques in biophysics, molecular genetics and cell biology are already contributing to the breeding process through new ways of manipulating genetic variation and through the development of new and extremely precise techniques of evaluation and selection. The prospect of being able to transform plants in directed ways opens up new possibilities for breeders, but does not justify undue optimism of entirely new plant types. In the future with the technological advancements, more general opportunities for applications of recombinant DNA technology in the evaluation and selection part of plant breeding process may arise.

New techniques of plant breeding

Though the use of biological process can be dated back to antiquity, it was only the 20th century that biological processes were used to produce commodity chemicals like acetone and butanol. After the Second World War, a number of biotechnology-based industries were established to produce substances including antibiotics, amino acids, enzymes etc. In the period from 1953 (from the discovery of the structure of the DNA) to the present, there has been an explosion in our knowledge of the molecular basis of the biological systems. This enormous increase in the new knowledge has led to the development of powerful new techniques with industrial applications. Two of the most important of these are recombinant DNA technology (genetic engineering) and hybridoma technology, which were discovered between 1970 and 1975. The emergence of the biotechnology industry may be seen as being shaped by four major factors namely:

a) Firstly, there are the market characteristics of those areas within which biotechnological innovation is occurring;

b) Secondly and related to the above factor are the characteristics that are found in any emerging industry such as embryonic companies, early entry barriers and technological uncertainty;

c) The special relationship between 'science' and 'technology' is also of major relevance both for the structure of the industry worldwide and the strategic behavior of the firms involved; and

d) Finally, the role of the government is assessed as national governments see biotechnology as one of the sunrise industries and it receives considerable attention from industrial planners wishing to enhance national competitiveness.

Genetic engineering involves the manipulation and transfer of genes/genetic material from one organism to another towards a desired end in a directed and pre-determined manner. This is alternatively called Recombinant DNA technology or gene cloning. Genetic engineering aims at isolating DNA fragments and recombining them. Two DNA molecules are isolated and cut into fragments by one or more specialized enzymes and then the fragments are joined together in a desired combination and restored to a cell for replication and reproduction.

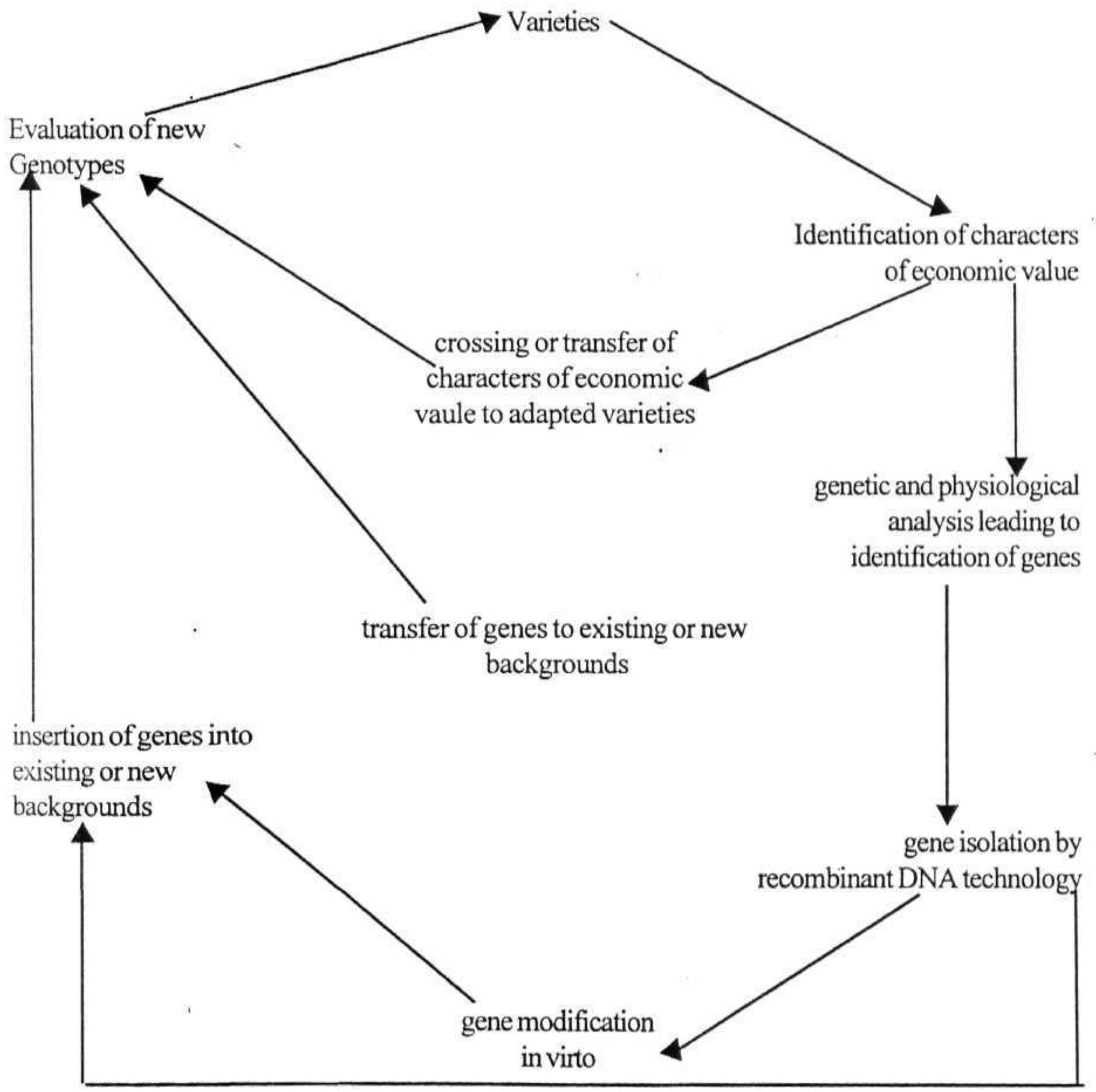
The term recombinant DNA is also specifically used to refer the physical combination of DNA segments derived from different sources. In this process, transfer between agrobacterium and certain plants provide scientists with a powerful tool for the production of genetically modified plants. The plant transformation procedures can break the sexual barriers, so that any gene from any organism can be introduced into a plant. To be useful, the genes must be correctly expressed at the right time and in the right organ i.e., cell or tissue and the protein that the gene encodes must have the right function.

Genetic engineering developed in the mid-1970s when it became possible to cut DNA and to transfer particular pieces of DNA containing specific bits of information, from one type of organism into another organism. As a result, the characteristics of the second organism (recipient) could be changed in a specific and pre-determined way. When the recipient organism is a microbe, such as a single celled bacterium, the specific fragment of transferred DNA is also multiplied many times as the recipient microbe multiplies. Millions of identical cells, i.e., a clone of cells, eventually arise. Consequently it is possible to obtain millions of copies of a specific region of DNA inside a bacterial cell by allowing the cell (and the piece of DNA) to multiply millions of times. Chart 3.2 shows the changes that have occurred in the conventional plant breeding with the advent of the molecular biology tools and their impact on agriculture.

The techniques of plant cell tissue culture are likely to continue to be of key importance in the application of molecular biology tools to crop improvement. In most cases, genetic engineering means adding one or more new genes to the plants' genetic material, so that a new enzyme will be made in the transgenic plant. However, genetic engineering also suppresses the appearance of a specific enzyme, by using 'antisense' genes. It is often felt that pest management can be improved by using herbicide tolerant and pest-resistant plants.

Chart No3.2

Breeding cycle showing conventional - new - and proposed genetic engineering methods of gene transfer and evaluation



Source: Molecular Biology and Crop Improvement: A case study of wheat, oil seed rape and faba beans, R.B. Austin, with R.B. Flavell, I.E. Henson and H.J.B Lowe, Cambridge: Cambride University Press, 1986

From Chart No. 3.2, it is evident that the identification of the traits, which are of economic importance to the market conditions, is of importance to the plant breeder in selecting a particular variety. The Report entitled "Biotechnology's Bitter Harvest: Herbicide Tolerant Plants and the Threat to Sustainable Agriculture" points out the following reasons for the burst of research aimed at creating herbicide-tolerant plants namely:

> a) Such work was easy to do because the genes could readily be isolated from microorganisms and a single gene could make a plant herbicide tolerant; and
>
> b) Many agrichemical companies invest heavily in the herbicide development and they want to get the most out of their investment. Herbicide tolerant varieties are protected under Breeders' Rights. There is a controversy whether herbicide tolerant varieties are needed at all, especially in the Indian context.

Another advantage of genetic engineering is the addition through "useful trait" of molecular breeding whereby it is easy to isolate and separate beneficial genes from deleterious genes when these are closely linked in one of the parents. By this method, the elite phenotype does not get disrupted. This new technology represents an important additional possibility for plant breeding which is the addition of desired qualities through single genes without really disturbing the already existing ones. With the new technology, the following tools are now available: a) one can isolate genes and introduce them in living plants such that they become stable component of the genetic program of these plants; and b) provided the foreign genes are appropriately restructured, they will usually function in a predictable fashion after their introduction in the plant cells.

Transgenic crops are a subset of the large number of living organisms that are being genetically engineered by agricultural, pharmaceutical, food processing and other industries for a range of purposes from food and fiber production to toxic waste degradation. At the core, the technique of genetic engineering has the power to produce combinations of genes not found in nature. Modern gene transfer techniques allow scientists to directly transfer functional genetic material to host organisms. These techniques vastly increase the ability to generate organisms with new properties.

Genetic engineering is no longer simply a research tool. Advanced techniques are poised to become the basis of new industries with the potential to transform the major sectors of human society and environment. The genetic transformation and other modern crop breeding techniques have been used to achieve four broad goals namely a) to change product characteristics; b) improve plant resistance to pests and pathogens; c) increase output and d) improve the nutritional value of foods.

Natural variability in the capacity of the plants to resist damage from insects and diseases has long been exploited by plant breeders. Biotechnology provides new tools to the breeder to expand plant capacity. In the past crop breeders were generally limited to transferring genes from one crop variety to another. In some of the cases, they were able to transfer useful genes to a variety from a closely related crop species or a related native plant. Genetic engineering now gives plant breeder the power to transfer genes to crop varieties independent of the gene's origin. Thus bacterial and even animal genes can be used to improve a crop variety. Genetic engineering has become controversial on moral, ethical, religious and aesthetic considerations. In addition, proprietary character of genetically modified seed has economic implications in terms of its accessibility to poor farmers in the developing countries. Further, technologies such as 'terminator' technology prevent farmers to use part of the produce as the seed for next season, which farmers have hitherto been using. A detailed discussion of these issues is beyond the scope of the present study.

In this chapter we provided a brief account of the evolution of plant breeding as an art and science and its intimate interrelations with economic, social and cultural contexts. In the next chapter, we shall provide a description of organizations in which scientists and their research groups included in the present study are located.

Chapter IV

CHAPTER IV

Scientists and their sites of Plant Breeding Research

Plant breeding as an art and science and the various techniques that are employed in conventional plant breeding along with the modern molecular techniques that are useful and employed in plant breeding have been provided in Chapter III. Chapter IV provides a description of organizations, which are the sites of plant breeding research and also the demographic composition of the scientists who were part of the present study. A description of the organizations will help us in understanding the organizational norms that impinge on plant breeding research community. In our study, the organizations in which plant breeding community practices its profession are spread across the country.

Organizational norms

Traditionally plant-breeding community has been operating in the context of the public sector institutions. In the Indian context, the public sector institutions have played a significant role in the ushering in of green revolution. The mandate of the public sector institutions requires that they fulfill the obligations of the society at large. On the other hand, the private sector institutions engaged in plant breeding have emphasized on the profit motive and also maintaining secrecy on the parental lines which are used for the development of new varieties.

Nature of organizations included in the study

As already mentioned in the methodology section of Chapter II, the scientists were drawn from organizations, which are spread all over the country. The scientists were drawn from a diverse range of organizations like the general and deemed universities, state agricultural universities, Council for Scientific and Industrial

Research (CSIR) organizations, Indian Council of Agricultural Research (ICAR) organizations, private research foundations, and an international organization, which has its center in India. Table No. 4.1 indicates the nature of organizations from which the scientists were drawn for the purpose of the present study. From fable No. 4.1, it is evident that twenty out of the forty-nine scientists were drawn from the State Agricultural Universities (SAUs) set up. There were sixteen scientists located in the Indian Council of Agricultural Research (ICAR) institutes located in different parts of the country. Two of the scientists who were included in the study were drawn from a Council for Scientific and Industrial Research (CSIR) organization. Two scientists were drawn from the private research laboratories. One of the scientists was located in an International organization, which has its centre in India.

Table No. 4.1: Nature of Organizations in which the scientists were located

S. No	Nature of Organization	No. of scientists
1.	State Agricultural Universities	20
2.	General and Deemed Universities	08
3.	ICAR Institutes	16
4.	CSIR Organizatioas	02
5.	Private Research Foundations	02
6.	International Organization	01
	Total	49

State wise distribution of scientists

Having given the nature of the organizations from which the scientists were drawn for the purpose of the present study, we look at the state wise distribution of the organizatioas in which the scientists were located. Table No. 4.2 provides a picture about the distribution of the organizations from which the scientists were drawn for the present study.

Table No. 4.2: Statewide Distribution of the scientists

S. No.	State (City)	No. of Scientists
1.	Tamil Nadu a. Coimbatore b. Chennai c. Madurai	14 10 02 02
2.	Andhra Pradesh a. Hyderabad	11 11
3.	Karnataka a. Bangalore	07 07
4.	Orissa a. Cuttack	07 07
5.	Delhi a. Delhi	03 03
6.	Maharashtra a. Pune	02 02
7.	Punjab a. Ludhiana	02 02
8.	Haryana a. Hissar	02 02
9.	Meghalaya a. Barapani	01 01
	Total	49

Table No. 4.2 indicates that fourteen out of the forty-nine scientists were drawn from the organizations located in Tamil Nadu. Out of the fourteen scientists who were located in the three organizations located in Tamil Nadu, as many as ten scientists were located in a single organization i.e., Tamil Nadu Agricultural University in Coimbatore. Two scientists were included in the study who were located in organizations in Chennai. One of the scientists was employed in University of Madras and the other scientist was located in SPIC Science Foundation. The two scientists from Madhurai were located in the Madurai Kamaraj University.

Table No. 4.2 indicates that there were as many as eleven scientists from Hyderabad who were included in the present study. Out of the eieven scientists who were included in the present study, eight of them were located at Directorate of Rice

Research (DRR), an Indian Council of Agricultural Research (ICAR) organization located in Hyderabad. Out of the remaining three scientists, one each of them were located in University of Hyderabad, Osmania University and MAHYCO Research Foundation respectively.

The seven scientists who were located in organizations located in Karnataka were located in University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore. The seven scientists who were from Orissa were located in Central Rice Research lastitute (CRRI), Cuttack. There were two scientists who were located in a general university and one more scientist was drawn from an international organization in Delhi. There were two scientists from the Maharashtra who are located in a CSIR organization. Two scientists were included from Haryana Agricultural University (HAU), a state agricultural university in HLssar. Two more scientists included from Punjab Agricultural University (PAU), Ludhiana. One scientist was included from Barapani who was employed in an ICAR organization.

Organizational Affiliation of the Scientists

In the present section, a profile of the organizational affiliation is provided. Table No. 4.3 indicates the distribution of scientists across various organizations throughout the country. From Table No. 4.3, it is evident that twenty out of the forty-nine scientists were located in the State Agricultural Universities (SAUs). As already mentioned in the chapter, ten out of the twenty scientists were located in Tamil Nadu Agricultural University (T'NAU), Coimbatore. Six of them were located in University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore. Two scientists each were drawn from Punjab Agricultural University (PAU), Ludhiana and Haryana Agricultural University (HAU), Hissar respectively.

Out of the sixteen scientists located in the Indian Council of Agricultural Research (ICAR) Institutes, eight of them were located in Directorate of Rice Research (DRR), Hyderabad. Seven of the scientists were drawn from Central Rice Research Institute (CRRI), Cuttack. One of the scientists was included from the ICAR Research Complex for the North East Hill Region.

Table No. 4.3: Organizational Affiliation of the scientists

S. No.	**Organizational Affiliation**	**No. of Scientists**
1.	Tamil Nadu Agricultural University, Coimbatore	**10**
2.	Directorate of Rice Research, Hyderabad	**08**
3.	Central Rice Research Institute, Cuttack	**07**
4.	University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore	06
5.	University of Delhi, South Campus, New Delhi	**02**
6.	National Chemical Laboratory, Pune	**02**
7.	Haryana Agricultural University, Hissar	**02**
8.	Punjab Agricultural University, Ludhiana	**02**
9.	Madurai Kamaraj University, Madurai	**02**
10.	International Centre for Genetic Engineering and Biotechnology, New Delhi	**01**
11.	MAHYCO Research Foundation, Hyderabad	01
12.	Indian Institute of Science, Bangalore	01
13.	SPIC Science Foundation, Chennai	01
14.	University of Hyderabad, Hyderabad	01
15.	Centre for Plant Molecular Biology, Osmania University, Hyderabad	01
16.	University of Madras, Chennai	01
17.	ICAR Complex for NEH Region, Barapani	01
	Total	**49**

Two of the scientists were drawn from National Chemical Laboratory (NCL), a Council for Scientific and Industrial Research (CSIR) organization located in Pune. Two scientists were drawn from the private research laboratories, one from MAHYCO Research Foundation, Hyderabad and the other from SPIC Science

Foundation, Chennai. One of the scientists was located in International Centre for Genetic Engineering and Biotechnology (ICGEB), an international organization, which has its centre in New Delhi.

Gender and organizational affiliation of scientists

In terms of gender composition of scientists across the various organizations, out of the forty-nine respondents, nine of them were women. The proportion of women scientists amounted to 18.36% of the sample. Table No. 4.4 provides a profile of the distribution of the scientists across the various organizations all over the country. From Table No. 4.4, it is evident that four out of the nine women scientists were located in the 1CAR organizations. Among the four women scientists employed in the ICAR organizations one of them was employed in Central Rice Research Institute, Cuttack and three of them were located in Directorate of Rice Research, Hyderabad. Three out of the nine respondents were located in the State Agricultural Universities - one woman scientist in Tamil Nadu Agricultural University, Coimbatore and two women scientists in University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bangalore. Of the remaining two women scientists, one of them was employed in a deemed university i.e., Indian Institute of Science, Bangalore and the other woman scientist was located in the CSIR institutional setup i.e., National Chemical Laboratory, Pune.

Table No. 4.4: Organizational Affiliation and Gender Composition

Organizational Affiliation	No. of Male Scientists	No. of Female Scientists	Total
Tamil Nadu Agricultural University, Coimbatore	9	1	10
Central Rice Research Institute, Cuttack	6	1	07
Directorate of Rice Research, Hyderabad	5	3	08
University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore	4	2	06
National Chemical Laboratory, Pune	1	1	02
University of Delhi, South Campus, New Delhi	2	-	02
Madurai Kamaraj University, Madurai	2	-	02
Punjab Agricultural University, Ludhiana	2	-	02
Haryana Agricultural University, Hissar	2	-	02
University of Hyderabad, Hyderabad	1	-	01
Centre for Plant Molecular Biology, Osmania University, Hyderabad	1	-	01
MAHYCO Research Foundation, Hyderabad	1	-	01
SPIC Science Foundation, Chennai	1	–	01
Indian Institute of Science, Bangalore	-	1	01
International Centre for Genetic Engineering and Biotechnology, New Delhi	1	-	01
ICAR Research Complex for NEU Region, Barapani	1	-	01
University of Chennai, Chennai	1	-	01
Total	**40**	9	**49**

As mentioned earlier, twenty scientists from the state agricultural universities were included in the present study. Out of the twenty scientists included from the state agricultural universities across the country, seventeen scientists were men and the remaining three were women scientists. Out of the seventeen male scientists, nine of them were located in Tamil Nadu Agricultural University, a state agricultural university situated in Coimbatore. Four of them were located in the University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK) Bangalore. Among the remaining four male scientists, two of them were located in Punjab Agricultural University (PAU), Ludhiana. The other two scientists were drawn from Haryana Agricultural University (HAU), Hissar.

Among the sixteen scientists located in the Indian Council of Agricultural Research (I CAR) organizations, twelve of them were men and the remaining four were women scientists. Out of the twelve male scientists, five of them were from Directorate of Rice Research (DRR), Hyderabad. Out of the remaining seven scientists, six of them were located in Central Rice Research Institute (CRRI), Cuttack. One of the scientists from the ICAR setting was employed in the ICAR Research Complex for North East Hill Region, Barapani.

Out of the eight scientists located in the general and deemed universities, seven of them were male scientists and the remaining scientist was a woman scientist. Out of the seven scientists who were men, two of them were located in University of Delhi, South Campus, New Delhi. There were two scientists who were included in the study from Madurai Kamaraj University, Madurai. There was one scientist each from University of Hyderabad, Hyderabad, University of Madras, Chennai, and Osmania University, Hyderabad respectively.

There were three scientists included in the present study who were from the private sector and an international organization, which has its centre in New Delhi. It would be interesting to note that all the three scientists who are employed in the private sector as well as the international organization who were included in the present study are male.

Age composition of the scientists

The age of the scientists ranged from 28 years to 64 years. The average age for the men scientists was 45.42 years while the average age for the female scientists was 40.3 years. Table No. 4.5 shows the distribution of scientists across various age groups in the study.

Table No. 4.5: Age Composition of the Scientists

S. No.	Age Groups	Frequency
1.	28-32	01
2.	33-37	09
3.	38-42	09
4.	43-47	17
5.	48-52	05
6.	53-57	04
7.	58 and above	04
	Total	**49**

Table No. 4.5 shows that seventeen out of the forty-nine respondents were in age group of 43-47 years. It also shows that there were nine scientists each in the 33-37 years age group and 38-42 years age group. There were five scientists in the 48-52 years age group while there were four scientists each in the 53-57 years and 58 and above age groups. Finally in the 28-32 years age group there was only one respondent who happens to be the youngest among all the respondents in the study.

Gender and Age

In terms of distribution of the male and the female scientists across the various age groups, from Table No. 4.6 it is evident that among the nine women scientists, who were included in the present study, four of them were in the 33-37 years age group. One of them was in the 38-42 years age group. Four of the women scientists were in the 43-47 years age group.

Table No. 4.6: Gender **Distribution of Scientists in various age groups**

Age Groups	No. of **Male Scientists**	**No. of Female Scientists**	**Total**
28-32	1	-	1
33-37	5	4	9
38-42	8	1	9
43-47	13	4	17
48-52	5	-	5
53-57	4	-	4
58 and above	4	-	4
Total	**40**	**9**	**49**

Among the male scientists, thirteen out of the forty scientists were in the age group between 43-47 years. As already mentioned, seventeen out of the forty-nine scientists were in this age group, the other four being female scientists. There were eight male scientLsts were in the age group between 38-42 years. There were five male scientists each in the 33-37 years age group and 48-52 years age group. There were four **male** scientists each in the 53-57 years age group and 58 and above age group. There **was** only one male scientist in the 28-32 years age group as already mentioned above.

Details of the highest degree

With regard to the details of the highest degree obtained at the time of the study, out of the forty-nine scientists who were included in the study, forty-five of had doctorate degree, the highest degree. The remaining four scientists had Master's degree. Out of the four scientists, three of them were pursuing their doctorate degrees at various institutes/organizations at the time of the study. It should be noted that the average age at the time of obtaining the highest degree for the women scientists was 29.2 years while it was 29.6 years for the male scientists.

Table No. 4.6 gives details regarding the organizations from which the scientists had obtained their highest degree. As mentioned already, forty-five out of the forty-nine scientists had obtained doctorate degree at the time of the study. Four of the scientists had masters' degree as their highest degree at the time of the study. Three of the scientists were pursuing their doctorate degrees at different organizations.

Table No. 4.6 indicates that among the forty-five scientists who had obtained Ph. D degree at the time of the study, forty-three of them had obtained their degrees from various organizations spread across the country. Two of the scientists had pursued their doctorate study in organizations abroad i.e., in the United States of America.

Among the scientists who had obtained their doctorate degrees from the institutioas located in India, eight of the scientists had obtained their degrees from Tamil Nadu Agricultural University, Coimbatore. Five of the scientists included in the present study had obtained their doctorate degrees from University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK) Bangalore. The interesting trend that was observed in the context of the public sector institutions namely the state agricultural universities and certain Indian Council of Agricultural Research (ICAR) organizations that most of the scientists have been employed as research personnel soon after the completion of their Masters' program and pursued doctoral program in the respective organization during their tenure of employment.

Table No. 4.6: Organizations from where the scientists acquired the highest degree

Name of the organization granting the highest degree	Nature of the degree	
	Ph.D	M. Sc.
National organizations:		
Tamil Nadu Agricultural University, Coimbatore	8	-
Indian Agricultural Research Institute, New Delhi	5	-
University of Agricultural Sciences, Bangalore	5	-
Punjab Agricultural University, Ludhiana	3	-
Osmania University, Hyderabad	2	-
University of Pune, Pune	2	-
Delhi University, New Delhi	2	-
Haryana Agricultural University, Hissar	2	-
Indian Institute of Science, Bangalore	2	-
University of Madras, Chennai	1	-
Annamalai University	1	-
Bharatiyar University	1	-
Jawaharlal Nehru University, New Delhi	1	-
Karnatak University, Dharwad	1	-
Andhra University, Vizag	1	-
Rajasthan Agricultural University	1	-
University of Hyderabad, Hyderabad	1	-
Acharya N. G. Ranga Agricultural University, Hyderabad	1	2
Central Rice Research Institute, Cuttack	2	-
IIT, Kharagpur	1	-
G. B. Pant University of Agriculture and Technology, Pant Nagar	-	1
Orissa University of Agricultural Technology, Bhubaneshwar	-	1
International Organizations:		
University of Hawaii, US	1	-
California Institute of Technology, Pasadena, US	1	-
Total	45	4

With regard to the scientists who had acquired Masters' degree as the highest degree, two of the scientists had acquired their Masters' degree from Acharya N. G. Ranga Agricultural University (ANGRAU), Hyderabad. Out of them, one was male scientist employed in University of Agricultural Sciences, Gandhi Krishi Vignana Kendra (UAS, GKVK), Bangalore and the other woman scientist employed in Directorate of Rice Research (DRR), Hyderabad. Another male scientist working in Directorate of Rice Research, Hyderabad had acquired his Masters' degree from G. B. Pant University of Agriculture and Technology (GBPUAT), Pant Nagar. One of the female scientists employed in Central Rice Research Institute (CRRI), Cuttack, had acquired her Masters' degree from Orissa University of Agricultural Technology (OUAT), Bhubaneshwar.

Gender and age of obtaining the highest degree

The present section deals with the gender distribution of scientists across various intervals indicating the age at the time of obtaining the highest degree. Table No. 4.7 indicates the gender distribution across various age groups.

Table No. 4.7: Gender distribution across various age groups

Age groups	**No. of male scientists**	**No. of female scientists**	**Total**
20-24	**02**	**02**	**04**
25-29	**20**	**03**	**23**
30-34	**10**	**02**	**12**
35-39	**07**	**01**	**08**
40-44	**01**	**01**	02
Total	**40**	**09**	**49**

The age group of 20-24 years is applicable to the scientists who have master's degree as their highest degree. Table No. 4.7 indicates that there were four scientists, two male and two female scientists, who were in this category. However the majority of the scientists were in the age group of 25-29 years. In this age group there were as many as twenty-three scientists. Out of the twenty-three scientists, twenty of them were male scientists who had acquired their doctorate degree between 25 years and 29 years. Then in the 30-34 years age group, there were as many as ten scientists who were men and two scientists who were women, amounting to a total of twelve scientists in this age group. Table No, 4.7 also indicates that there were eight scientists in the 35-39 years age group. Out of the eight scientists who were under this category, seven of them were male scientists who had acquired their doctorate degree between 35 years and 39 years. Also there were two scientists - one male and one female - who had acquired her doctorate degree at 41 years.

Having given the profile of the organizations from where the scientists were drawn to be included in the present study in this chapter, the next chapter provides a detailed description of the profession of plant breeding employing the conventional breeding methods and also provides a description of the changes that have occurred in the profession after the introduction of the molecular techniques into the plant breeding programs.

Chapter V

CHAPTER V

Molecular Biology: Influence on Cognition, Intervention and Social Organization of Plant Breeding Profession

In the previous chapter, the profile of the organizations from which the scientists were included in the present study was presented. The present chapter deals with an analytical description of conventional breeding methodologies. The description is based on the narratives of the members of the plant breeding community included in the present study. The chapter also traces the experiences of scientists on the changes that have occurred in the discipline – at the cognitive/theoretical level, at the level of strategies of intervention and at the level of the associated practices undertaken by the plant breeders. It is important to trace the changes that have occurred in the plant breeding to explore, and establish the influence of new knowledge i.e., molecular biology and the intervention strategies based on molecular biology on the plant breeding profession. Molecular biology enabled scientists to represent the rice plant in the molecular terms. Such a representation suggests possible interventions. Representation and intervention are intimately related. Earlier representation of the rice plant in holistic terms was accompanied by the strategies of intervention at the level of the phenotype.

As mentioned in Chapter II, forty-nine scientists employed in different organizational settings spread all over the country were included in the present study. In addition to part of data related to project on rice biotechnology research community in India (see Chapter II), included in the study, separate inquiry was conducted specifically to look into the changes that have occurred in the profession of plant breeding after the introduction of molecular techniques into the plant breeding discipline. The instruments of data collection were questionnaire and in-depth interviews with the scientists. Among the scientists interviewed, there were plant breeders who had received training in molecular biology techniques at different national and international institutions. This group, exposed to new knowledge, would be in a position to articulate the changes in the profession. In essence, this group may be treated as an experimental group, which earlier used one kind of knowledge and intervention and has been recently exposed to new knowledge. Inclusion of scientists who were involved both in conventional breeding research and molecular biology research was a conscious attempt to capture the social and cultural change in the profession.

As mentioned earlier in Chapter II, the lists of biodata/C. V. of the scientists were collected in addition to the questionnaires and in-depth interviews with the scientists. The lists of publications were important as they provide the patterns of collaboration of the scientists both within the organization and also outside the organization, both at the national and international level. Data on the patterns of collaboration between the applied scientists i.e., plant breeders, pathologists, entomologists, physiologists and geneticists on one hand and the basic scientists i.e., molecular biologists on the other were also collected. However a detailed analysis of the collaboration patterns on the basis of the publications was not undertaken, as the scientists have not provided their complete lists of publications. Analysis of the patterns of collaboration was based on the interviews material. The collaboration would suggest shifts in cognition/understanding and consequent changes in practices. An attempt has been made to look at the constraints faced by the scientists, both at the individual level as well as at the level of the organization, while collaborating with the other scientists within or outside the organization in the changing situation.

Conventional Plant Breeding

As mentioned in Chapter III, plant-breeding practices started several hundred years ago even before the emergence of modern science. It was practiced more as an art on the basis of empirical experience and trial and error methods. Mendelian Genetics played a significant role in the development of varieties since 1865 with the discovery of the laws of inheritance of Gregor Mendel. The most important thing in plant breeding is that there should be genetic variability because plant breeding heavily relies on the size and the richness of the variability available. The basic step in plant breeding is selection, which started ever since humans started cultivation. In the field when they grew lot of plants, if they found anything superior in the group, they used to identify and select it for the next season.

Genetic variability was enhanced during the mercantile era and colonial period. The merchants, naturalists and colonial administrators showed keen interest in collecting plant varieties from countries and continents they explored and later ruled. The Portuguese had played a very important role right from the 15th and the 16th centuries when they collected the germplasm from one place (centre *of* origin) and they introduced the germplasm to other places. Later on also, the British and the other colonial masters like the French, the Dutch, Spaniards and Germans also traveled from one place to another trying to colonize and grab the land from the land mass. They introduced the crop from the centre of origin to the new area they had conquered. During the 1920s and the period before that, Vavilov from the former Soviet Union had traveled extensively all over the world and gave the concepts of centres of origin and centres of diversity. He found that in certain areas all over the world, there is tremendous variability, which is distinct for a particular crop species. Based on that he proposed eight mega centres of origin. These are the areas where the crops have evolved long back and in these areas, there is tremendous genetic variability.

Plant breeding till the 1950s involved basically selection from the traditional land races. Selection is done from the traditional land races because they have evolved over a period of thousands of years of natural selection and they perform better than many of the crossbred varieties. After the domestication of various food crops or even any of the cultivated crops, there was tremendous variability in the centre of origin and centre of diversity. It took around 1700 years for the world population to reach twice its size from 50 million to double that population. But now in every 25-30 years the population is doubling and now the population of the planet is 6 billion people and another doubling will occur in much lesser period.

India was producing 50 million tonnes of food at the time of independence in 1947. Now food production reached around 209 million tonnes per year. In the last 50 years India has increased food production by 4 times. During this period, the population has increased almost 3 times. So with the growing demand of the food, new higher yielding varieties need to be developed. In response to the food crisis in the late 1950s and early 1960s, concerted efforts were made to increase food production. The semi dwarf high yielding varieties were introduced with appropriate agronomic practices and farm management techniques, the yield began to increase. The package - high yielding varieties of seeds, controlled water supply, chemical fertilizers, pesticides and insecticides and institutional credit – ushered in green revolution.

Productivity based on green revolution technology made India self-sufficient in food production. As mentioned above, it went up to 209 million tonnes. However, the green revolution package seems to have reached its limits - productivity has reached a plateau; environmental problems increased - soil salinity, water logging due to irrigation, excessive use of chemical pesticides and insecticides etc. It is in this context, plant breeding based on molecular biology techniques have to be examined as an alternative/additional techniques in plant breeding.

With the discovery of the double helical model of the DNA by Watson and Crick in 1953, it was realized that the DNA had a major role in controlling the functions of the genes. It was in the 1980s and the 1990s, the era of biotechnology had arrived when the genes were isolated and could be used for manipulation and the development of new varieties.

In the Indian context, the Government of India has been initiating policies to promote biotechnology in Indian agriculture. In this context, genetic engineering technologies are being evaluated for transferring them to the fanners. However, in India also the genetic engineering technology has become controversial.

Goals of plant breeding profession

Plant breeding is an applied science. The culture of plant breeding research community tends to be different from that of the basic science like molecular biology. Plant breeding research community places more emphasis on products - development of variety rather than publications.

Plant breeding as an applied science is a field-based science. Hence the nature and number of parameters that go into plant breeding research tends to be much greater compared to lab-based molecular biology research. As already mentioned in chapter III, the main aim of any plant-breeding program, whether the plant breeder deals with self-pollinated or cross-pollinated crops, is to improve the yield, which is a significant economic criterion. The strategies of intervention would be different for self-pollinated and cross-pollinated crops. It should be noted that the plant breeders aim at incorporating genes of interest, which confer resistance towards various biotic and abiotic stresses into the varieties that are high yielding. As already mentioned, the aim of any breeding program is to produce a superior type of plant, which may be accomplished by any of the three general approaches i.e., increasing yield, improving quality and raising production efficiency. Plant breeding research involves a series of selections - approaches to breeding and selection of traits for breeding. Hence plant breeding has features of being an art and science. Emphasizing the fact that plant breeding is a skill, one of the plant breeders argues:

> "Plant breeding is a skill, an art. The plant breeders have to visualize which of the plants give high yield and which can do well in different locations. The breeders have to be well acquainted with the plants and different segregating populations. They also should visualize the problems faced by the farmers."

Section I

Conventional Plant Breeding: A Bench Mark Description

The research questions of the present study are to explore in what ways and how molecular biology influences the art and science of plant breeding. As mentioned above, we may explore these questions at three levels namely: a) at the level of cognition/understanding, b) strategies of intervention and c) practices. Before we embark on the exploration, it is essential to provide the description of conventional plant breeding. This description would serve as a benchmark against which changes, as a consequence of the introduction of molecular biology techniques, can be assessed. In this section we shall present an account of the process of plant breeding as given by the scientists in the study and social organization of plant breeding research.

As already mentioned, conventional plant breeding is based on Mendelian genetics. The level of understanding is in conventional plant breeding is at the level of the phenotype. The strategies of intervention in conventional plant breeding are based on the expression of the traits at the level of the phenotype. The crucial step for the development of a new variety is the selection of parental lines. After crossing the parental lines, the plants of the F1 generation are tested for the next seven (F7) generations to obtain homogenous plants. The testing of the plants across the seven generations to obtain uniformity in terms of ripening, time for harvesting, color of the grain and so on. In conventional plant breeding, the development of a new variety would take anywhere between seven to ten years because of the time taken in the testing from F1 to F7 generations.

The activities of the professional plant breeder in conventional plant breeding research are field-based. There are numerous parameters that are taken into account while developing a new variety. The most economically significant parameter is the yield. The plant breeder makes a trade off between the criteria of high yield and resistance to at least some of the biotic and abiotic stresses.

In conventional plant breeding research, the plant breeder heads the group of experts. The applied scientists like the entomologists, pathologists, and geneticists also form part of the group of experts who are involved in the plant breeding research.

As mentioned earlier, we selected scientists who were trained both in conventional and molecular biology to see in what ways and how molecular biology influences the professional research activities of the plant breeders. In other words, the accounts given by the scientists will help us in answering the research questions. These questions will be explored at three levels: a) cognition/understanding; b) strategies of intervention and c) associated practices.

Methodologies employed in conventional breeding program

According to one of the breeders methodologies are the 'backbone' of crop improvement programs. In conventional plant breeding, the methodologies that arc employed would depend on the crop the breeder is working on and also the objectives of the breeding program. As mentioned in Chapter **III,** methodologies employed in conventional plant breeding would be different for the self-pollinated and cross-pollinated crops. The methodologies play a significant role in any breeding program and these methodologies are tested over time. The fact that these are tested over time makes them more reliable and replicable. Some of the important methodologies that are employed in conventional plant breeding, which have withstood the test of time, are:

1. Introduction is an important breeding method wherein the breeder identifies superior plants or new crops from different countries and introduces them in identified locations. In most of the cases, the crop that is introduced is from a different country. This method of plant breeding has enabled the movement of crops from one continent to another. Also it would be interesting to note that the crops adapt very well to the environment conditions in the

countries where they are introduced and these crops become the part of the cultural milieu of the population in that country. Chilli could be cited as an example in this regard.

2. Selection is the second important breeding method in conventional plant breeding programs. Among the introduced varieties, the plant breeder looks for variability and makes selection.

3. The third breeding methodology is Mutation breeding, which started in the 1960s. Mutation breeding is done by using some mutagens like physical mutagens (Examples are X-rays, gamma rays) and chemical mutagens (Examples for this are ethyl methyl sulphonate). But it did not pick up quickly because there is chance factor involved in mutation breeding in relation to getting a superior plant.

4. As already mentioned, polyploidy breeding is useful only in vegetatively reproduced crops only. This is most commonly used in ornamental and green leafy vegetables because the size of the fruit and the leaf increases because of the doubling of the chromosome number. But this method is not used in seeded crops because this method induces sterility.

Based on the nature of the crop and the methodologies that are employed in a particular breeding program, the strategies would differ from one breeding program to another. The strategy employed in a particular breeding program would depend on the genetics of the trait. In other words plant-breeding research involves series of related selections on the basis of evaluation of various options.

The two examples illustrated below would provide a picture about the way strategies are selected based on the methodologies. The first example is where the aim of the breeding program is to reduce the height of the plant. This trait is controlled by a single gene. In such instances, the strategy employed by the plant breeder would be hybridization and selection of the short plant in the subsequent segregating populations.

The other instance is where the trait is controlled by multiple genes. In this case the strategy deployed would be backcross breeding. The first task before the plant breeder in this instance would be the identification of donor for the gene and in every generation, the plant breeder undertakes backcrossing. At the end of the sixth or the seventh generation of backcross selection, the breeder would obtain the plant with the desired gene and also the desired traits of the original plant. The objective in backcross breeding is to have the entire genome of the original plant along with a new gene.

Backcross breeding would be different for the self-pollinated crops and cross-pollinated crops. In case of the self-pollinated crops, the plant breeder selects the plants with the desired genes and the parent variety and then obtains a plant with all the desired genes. This method is called recurrent backcross breeding in the case of self-pollinated crops.

In the case of cross-pollinated crops, this strategy is called poly cross breeding. The plants with the different desirable genes are put in an open and isolated area and allowed to intercross with no control mechanisms. The plants with all kinds of permutations of genes are obtained in the next generation. In this manner after six or seven generations, the plants with the desired genes are obtained.

One of the woman scientists located in state agricultural university mentions that in the context of the green revolution, the above-mentioned methodologies had done an excellent job. But after a period of thirty years, there is stagnation in the yield even after the existing methodologies have been tried. In this context, she makes the following observation:

> "In such changed context, we are looking for new avenues and biotechnology is one of them. Most of the high yielding plants are susceptible to diseases now over the years. If you want to make them disease resistant, there is no source of gene within our germplasm. Then what we do is identify disease resistant genes from other species. Now the biotechnology tools like transformation will come into use by the plant breeders."

Criteria of selection of method for a **given breeding program**

The methodology employed during a particular breeding program, as mentioned above, would depend upon the crop at hand, also the nature of the crop whether it is self-pollinated or cross-pollinated. Also the other interesting thing is that the various methodologies have contributed to the increase in the yield during the green revolution period during the 1960s in the Indian context. Introduction was an important method through which the high yielding rice varieties, which were developed at the International Rice Research Institute, Philippines were introduced in the Indian sub-continent. The introduction of the high yielding varieties has contributed to a yield enhancement by 50%.

Significance of Multi-location trials

Multi-location trials are carried out to evaluate as to what extent the output in terms of **some** parameters, such as yield and resistance to biotic and abiotic stresses, commensurate with the expectations in different agro-climatic conditions. The following are the important parameters that are tested in the multi-location trials.

The most important parameter that a variety is tested for in the multi-location trials is the yield parameter i.e. the variety should be giving the highest yield in adverse conditions as well. Obviously this has a lot of economic significance. It is felt that a high yielding variety having resistance to various biotic stresses like insects, diseases and pests and various abiotic stresses like the moisture resistance, drought resistance, salinity resistance and so on would be an ideal variety. One of the scientists located in a state agricultural university mentions states:

> "With regard to the parameters, of course it is biotic and abiotic stresses, diseases, pests and if there is moisture stress, then moisture stress resistance, and yield. Sometimes color of grain, cooking quality, milling quality depends on what quality is expected. If it is export quality, you need to compare the quality. Elongation and cooking volume and it depends on genetics. The implication of the test result would be that your variety might be rejected after 7-10 years of work. It may so happen that finally the selected material may be rejected."

Once the plant variety is developed through conventional plant breeding methods, then it is tested in various agro-climatic zones for its performance in the various/diverse climatic conditions across the country. The performance of the variety is compared with that of the local check of the respective state/region and also the national check. If a particular variety is doing well when compared to the local check, then the respective state/regional seed certification board will release it as a variety for that particular state/region. If the variety is doing well in more than two states/regions then it would be released as a variety at the national level by the national seed certification board. One of the retired scientists from one of the ICAR organizations, which conducts multi location trials, has observed:

> "When you conduct a trial, the constitution of the trial should be in such a way that includes a local check, a zonal check and a national check. You should use the kind of packages uniform in all locations. These are some of the parameters. Timely planting, timely harvesting,

recording of data, there are certain standards, timely supply of data for statistical analysis. All these things one has to take into account."

The main emphasis in multi-location trials is the representative nature of the location. If the location is not representative it would involve lot of wastage of effort and money on the part of the organization carrying out the trials. For example in the case of rice, the parameters that are taken into account are the color of the grain, cooking quality and elongation and cooking volume. With regard to the utility of the multi location trials, one of the senior scientists from a state agricultural university had mentioned:

"We test a variety with the farmers in mind. We have to give him certain insurance regarding consistency in performance and that is our main concern. The gene that has been added or the character that has been evaluated should also perform at least to a very great extent in the lines of what it has performed in the experimental sites in the farmers' fields. Most of out statistical techniques or field layouts, designs we follow is aimed at minimizing the error component in our evaluation. So therefore we tell the fanner with more confidence what he can do and with what level of confidence he can take it."

While testing a particular variety in the course of multi location trials, the environmental factors are also taken into account. As mentioned earlier, the country is divided into different agro-climatic zones and the needs of the farmers in the different climatic zones would be different. In this context the plant breeder should take care that the plant variety he/she develops should solve the problems faced by the farmers in a particular agro-climatic zone. One of the scientists from a state agricultural university mentions:

"We also take the environmental factors into account. We have a zonal priority. If you look at my state i.e., Karnataka, maybe in our university's domain, we have six zones. So the kind of objectives we develop for rice for zone 5 is different and for zone 6 it is different. Depending on a preconceived idea, we model these plants and select. Otherwise general appreciation is not possible these days. Environment amplifies certain characters in certain environments and we want to take advantage of that as well."

There seems to be a consensus among the majority of the scientists who were interviewed that the parameters that are tested in multi location trials. But a couple of scientists from one of the ICAR organizations (CRRI) argue that the parameters for the products developed through molecular biology techniques would be different from those tested for the products through conventional plant breeding. One of the plant breeder trained in molecular techniques from one of the organizations in the ICAR setting points out:

"The parameters will change with the introduction of transgenics. In case of transgenics it is not only the yield advantage but also resistance against a particular pest and also with reference to its biosafety to other plants, flora, fauna soil and its quality. This will happen because you will have to see the biosafety aspects as well. Now they will take all the aspects into consideration before releasing any variety. So it will be a multi location, multi tier system of testing, which involves soil chemistry, nutrition, food, and all different players will be there. In normal rice testing, they will not be there. Once Golden Rice is introduced, now they are going to test for higher levels of Vitamin A also."

The reasons for the change in the parameters is because of the fact that the impact of the products developed through the molecular techniques should be tested on the flora and fauna in a particular area and also its impact on the soil conditions of that region. So the products which are developed through these techniques should be tested in various locations and also at various levels i.e., their impact on the soil, the plant and animal kingdom.

Cognitive content:

At the cognitive level, the theoretical basis of the discipline of plant breeding is Mendelian genetics. Varietal development in conventional plant breeding involves series of selections - selecting parental lines, making crosses, looking for the inheritance of characters at the level of the phenotype - the external appearance of the plant, and testing the product plant for the next seven generations to make them homozygous. Homozygosity implies uniformity in the product plants in terms of the height of the plants, time taken for maturing, harvesting time, color of the grain and so on.

In conventional plant breeding, the plant breeder looks at the plant as whole and the strategies of intervention are at the level of the phenotype. According to Clugston (1998), the phenotype may be defined as 'the characteristics, both externally visible and physiological, of an organism determined by its genes or modified by the environment.' Also it should be noted that plant breeding seeks to intervene at the phenotypic level to develop new varieties. Emphasizing the significance of Mendelian genetics in conventional plant breeding, one of the scientists interviewed mentioned:

> "Mendelian Genetics is the only one which plays a significant role. It is the only way to do crop improvement. The new techniques will help you do the job better; that's the only role I can see. Otherwise there is no total replacement of the conventional plant breeding."

The most commonly used strategy of intervention in conventional plant breeding is hybridization. In hybridization, two parent varieties are selected - one of which would be high yielding and the other should have the desired traits and would confer resistance to the various biotic and abiotic stresses. Having selected the parents which are high yielding and with the desired characteristics, the plant breeder would cross these two parent varieties to obtain the desired variety, which has traits to confer resistance along with high yield. It is here that the plant breeder deploys practical reasoning and socially situated reasoning for the selection of appropriate parental lines. In other words, the plant breeder would take into account the requirements of the farmers and also the social and cultural preferences of the consumers at large.

In the context of the utility of hybridization as one of the technique employed in conventional plant breeding, one of the woman scientists from a state agricultural university mentions:

> "When you undertake hybridization, you are sure some plants will have combination of genes and you see it with you eyes right from day one. You see everyday it is growing big, flowering and yielding and harvesting. So it's more like your child, you see the changes from childhood to adulthood. It's more satisfying. You are sure you will get something at the end of the day."

Comparing the conventional and molecular methods of plant improvement, she states that in plant breeding programs based on conventional methods, the plant breeder is more certain about the results while the plant breeding programs based on molecular methods involve chance factor. In her words:

> "In conventional plant breeding you are more sure about the results. It is very satisfying. You see the plant everyday morning in front of your eyes when you go to the field. It is not like molecular biology tools where chance factor is involved and you may or may not get the result."

The requirements for the plant-breeding program employing the conventional methods of breeding would require requirements in terms of physical resources and human resources.

Physical resources

In conventional plant breeding, which relies heavily on the field activities, there is need for large areas of the land in which the activities of the plant breeder can be carried out, seed material to carry out the method of crossing and also a polyhouse/glasshouse.

Seed Material

Seed has become the pivot around which agriculture revolves. Similarly in any breeding program - whether conventional or molecular - seed material has a significant role to play.

Field

In conventional plant breeding, the activities of the plant breeder are mainly centered/located in the field. It is the field that determines the nature and number of parameters that the plant breeders have to incorporate in the breeding program. It is in the field that the segregating populations in the hybridization process are planted from where the homogenous populations are selected. Since the number of the plants, which the plant breeder handles is large, the field also is the 'touch stone' in the plant-breeding program, and the field becomes an integral part of the conventional plant breeding research. According to most of the scientists who were interviewed during the course of the present study felt that a typical working day starts with a visit to the field. It is one of the most significant parts of the work schedule of the plant breeder. In the field the breeder's empirical observation is so minute and is so close, to quote one scientist, the scientist 'talks to the plants'. A retired scientist from one of the ICAR organizations mentions:

> "Plant breeder has to speak to the plant because people say that plants speak. Unless the breeder goes closer To the plant, he will be not able to hear. So in other words what it means is that unless you are closer to the plant you have bred, you will not know its needs, where you have to correct, what you have to do."

The daily visit to the field by the plant breeder would provide him/her with a better understanding of the plant material at hand. There seems to be a consensus among the scientists about the fact that a "good" plant breeder should visit the field regularly. Another related fact is that the scientist would be able to plan and conduct research if he/she has a sound understanding of the plant material at hand. He further mentions:

> "There would be no change in the daily routine of the plant breeder once molecular tools are introduced. This is very important. Conventional plant breeding is actually the backbone for all our efforts to improve the crop plants. Whatever you are going to have, it is only to supplement that effort, whether it is mutation breeding or it is genetic engineering. Whatever it is, it is only to supplement the efforts. For example, that can certainly help to get the trait, which is not possible through conventional plant breeding. It can create genetic variability, which you don't have in your germplasm. But it cannot substitute conventional plant breeding."

Polyhouse

In conventional plant breeding, the polyhouse or the glass house has an important role to play. The role of the polyho use/glasshouse in the conventional plant-breeding program is to take up crossing by controlled pollination. The second important use of the glasshouse is to protect important plants from cross-pollination by wind, and also protect them from rats and other pests. One of the scientists compares it with the "Intensive Care Unit (ICU)."

One of the scientists located in a state agricultural university argues that in the Indian context all the varieties are tested only in the field. He feels that the testing of varieties in the polyhouse is a western concept as some of the varieties such as tomatoes are grown only in the polyhouse or glass house.

Laboratory

As already mentioned, the field is an important component in the activities of the plant breeder. Though the major activities in the plant-breeding program are undertaken in the field, the laboratory also forms an important part of conventional plant breeding. It should be noted that the laboratory in the context of the conventional plant breeding programs is used for measuring the weight of the panicles, different plant heights and their harvest index. In addition to the above activities, the laboratory is also used to store the harvested grain along with the simple instruments that are used in the breeding program.

Social Organization of Plant Breeding Research

Typically conventional plant breeding involves division of work and specialization of tasks according to the academic qualification and experience of the individuals involved in the group. The plant breeder heads the group in the hierarchy of authority. Along with the plant breeder, there would be a set of individuals who would assist him/her in the breeding program. The roles involved in the plant breeding can be divided into three categories. These categories are a) Experts; b) Technicians and c) Semi-skilled and unskilled workers.

> A) Expert Roles: The individuals possessing specialized training in theoretical and experimental aspects of plant breeding i.e., the plant breeders and other applied scientists associated with the development of new varieties.
>
> B) Technical Role: The second category of individuals involved in the plant-breeding program is the technical staff. This set of individuals would undertake activities like the crossing and taking routine measurements like the height of the plant; thousand grain weight and so on.
>
> C) Semi-skilled and Unskilled Roles: The third category of individuals who have a role to play in the conventional plant-breeding program are the semi-skilled and unskilled workers. The major tasks of this set of individuals are to prepare the field for sowing, then sowing the seeds, watering the field, manuring, weeding and harvesting among other activities. The technical staff would supervise the activities of the semi-skilled and unskilled workers.

The main activities of the field staff include the preparation of the field for sowing, and also other related activities like weeding, harvesting, and storing the grain in the packets for using it in the research activities of the scientists. The designations given to the field staff would differ/vary depending upon the organizational location of the staff. The following is the composition of the group in the conventional plant breeding program:

Expert Roles: Breeders trained in genetics and breeding techniques

As already mentioned above, the scientists with specialization in plant breeding heads the group of individuals involved in the breeding program. One of the most significant tasks, which the plant breeder will have to take up, is the development of new varieties. There seems to be a consensus among the plant breeders who were interviewed during the course of the present study that the development of varieties is the first priority for the plant breeder. The process of development of a new variety starts with the identification of the problematic areas in a particular crop. Having identified the problematic areas, the plant breeder would have to identify and select appropriate varieties as parental lines, which would cope up with the adverse situations. The identification of the varieties could be achieved by Screening the germplasm. In order to do this, the first and foremost requirement to be a competent plant breeder is that he/she should be thorough in their knowledge of genetics. Along with the thorough base in genetics, the plant breeder also should have the ability to identify the variation that exists.

In addition to the ability to identify the variation, the plant breeder also should have good understanding of the plant material at hand. The plant breeder needs to have minimum knowledge in the related fields i.e., entomology, physiology, agronomy, pathology and other related disciplines. One of the scientists from one of the Indian Council of Agricultural Research (ICAR) organizations mentions:

> "In addition to the knowledge of genetics, the plant breeder also should have knowledge from other disciplines because the plant breeder is central to all crop improvement programs. He is the key, he is the nucleus. He should be endowed with all the knowledge related to entomology, pathology and agronomy to a reasonable limit."

There seems to be a consensus among the scientists interviewed that the plant breeder has to look at the problems that the farming community is faced with in the specific location and try to develop a variety which would address to these specific problems. This kind of approach is significant since the country is divided into different agro-climatic zones and the requirements and the problems of each agro-climatic zone would be different from other zones. In essence the kind of varieties that are needed by the farming community should be able to solve at least some of the problems faced by the farming community in a particular agro-climatic zone. In this context one of the scientists observes:

> "The plant breeder has to think about the need of the future, what type of variety the country needs or the farmer needs so that we can increase the production and productivity. The plant breeder also has to keep in touch with the latest developments which will enable him/her to visualize a hybridization program that would be useful in the long run."

One of the scientists who is plant breeder observes that the knowledge about the cultivation practices of a particular crop and the stress situations would enable the plant breeder to do better plant breeding. In addition, if the plant breeder hails from a rural background that would provide him/her with the above information. The other significant aspect involved in plant breeding is that the breeder should be able to meaningfully interpret the data that comes from the field. In this process, the technicians also would be of help to the scientists. In other words, the plant breeders' work involves incorporating local specifities and solutions that are appropriate to a given context. Plant breeders' work is influenced by the local contingencies.

Interaction among applied scientists

Apart from the team mentioned above who assist the plant breeder in the breeding program, in conventional plant breeding the plant breeder needs to have some knowledge about all the related disciplines like entomology, pathology, physiology and genetics. In addition to the knowledge of the plant breeder's knowledge in the above-mentioned related disciplines, he also requires to interact and work as a team with the other applied scientists like the entomologists, pathologists, physiologists, geneticists among others in their day-to-day activities. There seems to be a consensus about the central role played by the plant breeder in the breeding program among the scientists who were interviewed. Plant breeding is a group effort. The plant breeder is the nodal person, as he only knows how to handle the plant and is aware of the biology of the plant, the pollination method, and the selection procedures to be employed. When it comes to verifying each of the parameters, the plant breeders seek expertise of the other applied scientists. It could be a physiologist; it could be a pathologist or an entomologist. With regard to the interaction between the applied and basic scientists, one of the scientists working in a state agricultural university makes the observation:

> "Plant breeder is like the head of the family. He is supposed to take care of all the family needs. He has that overall view. Other things are small items that are required for holistic approach. Ultimately technology is a variety. And a variety has a physiological character, entomological character, and pathological character. They are all inputs required for a particular output. That a breeder can give. Breeder has a holistic view of the crop, the plant and the farmers' requirement,

what the society requires. The physiologist will have a limited view be it photosynthetic efficiency or water use efficiency. He has a small window but breeder knows the whole house."

One of the woman scientists working in an agricultural university states that the plant breeder cannot work in isolation from the other applied scientists in the plant-breeding program. She argues that the plant breeder will have to work in close coordination with the other applied scientists at various stages of the breeding program. The aims of the breeding program will determine the nature of interaction between the plant breeder and other applied scientists. For instance she mentions that the pathologist will come into the breeding program if the aim of the program is to develop a disease resistant variety. The pathologist will determine the degree of stability of the resistance incorporated into a variety. Similarly the entomologist will be of help when the aim of the breeding program is to produce varieties, which would be able to withstand extreme weather conditions like drought and salinity. Thus, all disciplines of agriculture, plant pathology, agronomy and other disciplines have to work in collaboration and provide their expertise. But the plant breeder should be the leader because he/she acquires a comprehensive view, which helps in the ultimate selection process, and take the final decision. According to her:

"Actually plant breeders' job is more responsible one. He has to work in collaboration with the applied scientists depending upon the problem. He cannot work in isolation but the plant breeder should be the leader. Like this, all disciplines of agriculture, plant pathology, agronomy and other disciplines have to work in collaboration and take their expertise. But the plant breeder should be the leader because he has to do the ultimate selection process and take the final decision."

While pointing out the reasons for the lack of interaction among the applied and basic scientists one of the scientists located in a state agricultural university argues that in the Indian context, the disciplinary boundaries in science are zealously guarded with no scope for interdisciplinary research. He makes the observation that the respective disciplines have their annual meetings and there is no common platform for the applied and basic scientists to interact with each other. In this context he mentions:

> "In the typical Indian system, there is no interaction. Plant breeders have a separate meeting every year, physiologists have a separate meeting, and entomologists have a separate meeting. We don't get to talk science with each other. We discuss other things."

After the Rockefeller Foundation started providing funds for the scientists to carry out rice biotechnology research the scenario has changed as it encouraged and facilitated interaction between the applied and the basic scientists. Also the National Rice Biotechnology Network acted as a forum to facilitate this kind of interaction between the two groups of scientists. In this context he observes:

> "The Rockefeller Foundation has brought all these people together. In organizations like the National Rice Biotechnology Network (NRBN), people from all disciplines come together. They are forced to come together. One thing was that it was good to see each other and the second thing was is it's a nice way you are taken care of. Then people are happy and they discuss about science. When people are unhappy, they don't discuss anything. They will be worried about their TA bill and so many other things. In the NRBN meetings, all the things are well taken care of so people discuss science."

Emphasizing the significance of the applied scientists in the plant breeding program, one of the scientists a plant breeder during the course of interview mentions that right from the beginning plant breeding has been a collaborative effort between the applied scientists. But with the introduction of molecular component, the basic scientists would also form of the collaborative endeavor. He mentions;

> "In all my projects, all the associates like the entomologists, pathologists and if needed a biochemist are all involved. So always it is a collaborative work. But now molecular biology is not a single field like a plant breeding activity. All people will be having their own roles

to play. All the things the plant breeder will do but the others will also have to be in the picture."

Technical Roles

In addition to the scientists trained in plant breeding who play a major role in the plant-breeding program, technicians have a significant role to play in the breeding research. While the scientists have doctorate degree the technicians would be matriculates or graduates in science. The activities of the technicians would involve taking routine observations in the field. These routine observations pertain to plant height, grains per panicle, thousand-grain weight and other relevant data.

Semi **skilled and unskilled Roles**

The semi skilled and unskilled workers who form part of the group assisting the plant breeder in the breeding program would lay out the field for sowing, actual sowing of seeds, weeding, manuring, harvesting and other related activities. There is no specification regarding the educational qualification for these categories of workers, as the activities they undertake do not require any specialized training. They acquire skills as apprentices while on the job.

Though the designations of the field staff employed in conventional plant breeding program varies across different organizations within the institutions located in the public sector, basically there would be three categories of field staff helping the plant breeder in the conventional plant breeding program. In response to the question regarding the categories of field staff, one the scientists from one of the ICAR institutes mentions:

"It's a very subjective question. At our institute (CRRI), we will say the technical fellow, field assistant and other things. If you go to the university, they will say we have a field assistant, technical assistant and a helping hand. But few things are consistent if you don't bother for the words. You need two three groups of people. One group of people will take care of your field activities, taking care of the crop, harvesting and all that. Then you need some people to do the crossing and of course the skilled and labor class to do the planting work, sowing and related activities. You basically need two to three categories of people but wording used for them is quite different in various organizations."

Section II

Molecular Biology Techniques

As mentioned earlier, the discovery of the double helical model of the DNA has enabled understanding of the object of research i.e., the rice plant at the molecular level and also intervene at the molecular level. As mentioned in the previous section, the emphasis is placed on the phenotype in conventional plant breeding program. The emphasis and the strategy of intervention in breeding program employing the molecular techniques would shift from the 'phenotype' to the 'genotype.'

This kind of shift in the emphasis from phenotype to genotype is a significant change. What are the consequences of such a shift for the profession of plant breeding? Explaining the impact of the molecular techniques on plant breeding, one of the woman scientists trained in molecular biology techniques in a state agricultural university setting states:

> 'With the introduction of molecular biology techniques, there is much scope for manipulation. Then one will start long at the plant in terms of the genome structure. We feel very interested and we plan to try and find out why plants behave the way they do."

She argues that the exposure and training in molecular techniques brought about a change in the way she looks at the rice plant. She cites her experience as an example to illustrate the changes in the way she looks at the rice plant. She mentions:

> "Now as soon as I see a plant, I keep thinking about things like which new genes can be added to this variety, or which genes can be isolated from a particular variety, or whether a variety can be used for the

process of development of variety. All these questions would come to my mind; all these are in addition to the emphasis on the yield."

Utility of the molecular techniques in breeding program

It should be mentioned at the outset that the molecular biology techniques are still in the initial stage of introduction. These techniques can only augment the technical resources of plant breeding was the view expressed by the plant breeders who have not been using the molecular techniques in the breeding programs undertaken by them. One of the scientists from the State agricultural university makes the following observation with regard to utility of the molecular techniques in a breeding program. He mentions:

"Labor, land and time has to be managed efficiently. Land and manpower are scarce commodities. These are to be managed and the rapidity of the whole program is also at stake. Therefore we want to gain as much as possible with more precision. This is where molecular biology helps in."

The molecular techniques will be of significance to the breeding program in the context where certain problems cannot be solved through conventional methods of improvement. One of the methods of conferring disease resistance through molecular techniques is transgenics. In transgenics the gene, which confers resistance to a certain disease, the source being any organism in the animal or plant kingdom, is introduced into a variety to acquire resistance. The best example in this context is the Bt cotton, which has attracted so much attention and also has become controversial. In the context of the transgenics, one of the woman scientists located in a state agricultural university points out two dimensions of the controversy on transgenics. She mentions:

"Transgenics involves the introduction of a gene of interest. We really don't know how far it is going to be successful. The other dimension is

> the acceptance of the transgenics by the farmers who are the consumers and who are really important."

On the contrary to above view, majority of the scientists who are trained in conventional plant breeding, but have undergone training in molecular techniques, have expressed the view that these tecliniques are of significance in the breeding programs they undertake.

The molecular tecliniques can be useful in the breeding program at two different levels. As already mentioned in the section on conventional plant breeding, the aims of the plant breeding programs are to utilize the variation that exists in nature. In case this variation is not available naturally, then the plant breeder will have to create variation through artificial means.

It should be noted that the molecular techniques, which are used in the plant breeding programs, would be useful at the above-mentioned two levels. The molecular techniques are likely to offer solutions to the problems, which remain unsolved by the conventional plant breeding programs. One of the scientists gives the following instance to illustrate how the molecular tecliniques could be utilized to create variation. He gives a specific instance in case of rice. According to him:

> "In rice there are certain pest problems like stem borer, leaf folder for which there is no varietal control. In this case the only source for getting the variation among rice plant is to introduce resistance in the rice plant through transferring a gene for resistance to these pests. These genes can be from another organism be it bacteria or animal."

There are certain instances in the plant-breeding program where the molecular tecliniques such as the DNA analysis would enable the plant breeder to look at the plant at the micro level and select the appropriate parental lines. It is in this sense that the molecular techniques would make the selection process more precise. If the plant breeder looks at the morphological characteristics and tries to deduce which of the varieties is the best in terms of the traits the plant breeder is looking for. It is where the marker-assisted selection can be of use to the plant breeder. The other aspect where the molecular techniques can help is in the context of making crosses with a wild species. In this situation, the normal methods of conventional plant breeding are not of use. In the study majority of the plant breeders have expressed the view that the molecular techniques are surgical tools useful in the selection of appropriate parental lines for the development of new varieties. This argument is in line with that of Buttel (1989) who argues that biotechnology is 'substitutionist' in nature and not revolutionary.

In the changed context in which the plant breeding programs are executed, it implies a change in the way the scientist perceives the object of his/her research i.e., the rice plants. One of the scientists, a plant breeder who received training in molecular techniques and employs them in his research work, makes the following experiential observation. He mentions:

> "The plant breeder can see the chromosomes by looking at the plant. He can visualize the chromosomes of that plant. This is very important tool for him/her because by seeing four or five different plants, he can see what difference in these plants with reference to the chromosomes. A conventional breeder will not be able to do that."

The concept of 'molecular breeder', which is commonly used terminology in the Western context seems to be gaining prominence among the plant breeders who have received training in the molecular techniques and are employing the molecular techniques in the breeding programs in the Indian context as well. Elaborating on the activities undertaken by the molecular breeder, one of the breeders from one of the state agricultural universities mentions:

> "All that a conventional breeder does will have to be done by the molecular breeder as well. He has the extra tool to attend to a particular problem. In addition to what the conventional plant breeder knows, the molecular breeder will have to something more."

One of the scientists believes that plant breeding before the advent of molecular techniques as an art. In conventional plant breeding, the observational skills of the plant breeder would assume significance because the selection of the parents would be on the basis of characteristics expressed at the level of the phenotype. But with the introduction of the molecular component into plant breeding, the plant breeder can create variability and utilize it in developing new varieties. He makes the following observation:

> "As per conventional plant breeding which is regarded as an art, observational skills are more important. I am not arguing that these skills are not important now. But with molecular applications, I can see what I want to do with a plant, how I can create what I want and how to use it. These three are more easier if I have molecular tools at my disposal."

Section III

Changes with the introduction of molecular techniques

After having the detailed account of the plant breeding research deploying conventional breeding techniques in Section I, and the utility of the molecular techniques in the plant breeding programs, the present traces the changes that have occurred/and are likely to occur at different levels.

Cognitive level

In contrast to the conventional plant breeding research where the emphasis is on the phenotype, the emphasis of the breeding programs deploying molecular biology knowledge and techniques is at the level of the genotype. The emphasis shifts from the holistic level to the molecular level. The strategies of intervention shift from the phenotype to the genotype. Also the molecular biology techniques claim to render precision to the process of selection of the parental lines. In contrast to the conventional way of selection of the parental lines on the basis of the expression of traits at the level of the phenotype, the molecular biology techniques would look for the genes of interest at the molecular level and select the parental lines. In other words, the plants with the genes of interest are selected as parental lines after confirming the presence of the gene of interest at the molecular level. This is the way in which the molecular techniques are used to utilize the naturally occurring variation.

In case the variation does not occur naturally among the varieties in the same species, then molecular biology knowledge and research would provide for the isolation of the genes of interest from any organism of either the plant or the animal kingdom. This approach is called "Genetic Engineering" and the products are called "transgenics".

While analyzing the responses of the perceptions of the scientists towards molecular biology knowledge and techniques one should take into account of the fact whether the scientists have undergone training in the molecular biology techniques or not. This would account for the nature of perception, either positive or negative. In other words, if the Scientist is trained in molecular biology techniques, then it is more likely that they would support molecular biology research. In case they are not trained in molecular biology then they are more likely to be skeptical about the utility of these techniques. Another significant point is that in case of the scientists who have not undergone training in molecular biology techniques, it is more likely that they are less receptive to the new technology/techniques in the plant-breeding program.

Significance of the laboratory

As already mentioned in the section on conventional plant breeding program, the laboratory's role in the breeding program was minimal. In the conventional breeding program the role of the laboratory was restricted to making some routine observations like the plant height, panicle weight and thousand-grain weight. Once the molecular techniques like marker assisted selection, recombinant DNA technology into the breeding programs, the laboratory has become an important part in the activities of the plant breeder.

In the new situation, the laboratory comprising of equipment relating to the molecular biology research assumes significance. In this context, the plant breeder will have to establish and maintain a laboratory to carry out research on these lines. Also the plant breeder would have to reorient his/her values towards the object of research. The plant breeder will have to devote time and energy towards the molecular component of their research activities.

Majority of the scientists in the Indian Council of Agricultural Research (1CAR) organizations had suggested that instead of giving the plant breeder the responsibility of maintaining the molecular biology laboratory, the respective organizations should have it as a central facility for the organization as a whole. Here the plant breeders along with others can utilize the facility as and when required in their work.

Regarding the costs of establishment and maintenance of the molecular biology laboratory, there seem to be criticism from the plant breeders that the molecular biology research is an expensive affair. In response to this criticism, one of the scientists employed in one of the Indian Council of Agricultural Research (ICAR) organizations mentions:

> "As a molecular breeder 1 don't require an advanced facility where I have everything at my disposal. Even a basic facility which costs just Rs. 10 lakhs or Rs. 20 lakhs with the minimum needs that will be sufficient."

But also considering the fact that the conventional plant breeding does not involve such high costs, as does the molecular biology research, along with the uncertainty factor has developed the kind of resistance that is perceived in the minds of the plant breeders. The solution for this problem could be that the costs of the processes involved in developing these products along with the market price of the biotechnology products developed through these techniques should be low and affordable.

New skills required for integrating molecular biology techniques into plant breeding

The introduction of molecular biology knowledge into the discipline of plant breeding would bring in changes the way plant breeders problematize concepts and conduct their research. In the changed context, the plant breeder will have to unlearn some aspects of his/her training in conventional breeding. More than the unlearning process, they need to learn many more new aspects to be incorporated into their repertoire of concepts and techniques. The cognitive and social value system has to be reoriented on the basis of the new paradigm i.e., molecular biology. While arguing that with the. introduction of molecular biology techniques into plant breeding, the plant breeder's job would become more hectic as he has to balance between the activities in the field as well as in the lab, one of the woman scientists employed a state agricultural university makes this observation:

> "The aspect, which changes with the introduction of molecular biology tools, is the selection process. In the selection process, instead of going to the field and visually looking at the plant, he has to use some molecular techniques like DNA marker technology to identify the plants. So the work of the breeder is enhanced with the introduction of molecular biology tools, his work is more and it becomes more expensive also. So he has to spend more time to maintain the lab, train people to work and all that. So his work is increased. But the results are more precise and sometimes the duration may reduce. In short time, he can do good job."

There seems to be a consensus among the scientists who participated in the study that the molecular biology techniques would increase the amount of work on the plant breeder. Apart from the increased load of work on the plant breeder, there is more division of labor on the basis of specialization of tasks. Further the changed context would require trained personnel to take care of the specialized tasks in the laboratory. In the changed scenario, the research group would also include individuals who have to take care of the laboratory and carry out research.

Resistance among the plant breeders towards molecular biology techniques

The introduction of molecular biology techniques into the profession of plant breeding involves reorientation of cognitive norms and the plant breeders would have to start looking at the object of research i.e., the rice plant at molecular level compared to an earlier stage when they operated at a holistic and gross level. In other words, as mentioned earlier the introduction of molecular component into plant breeding program would involve learning the molecular techniques and adapting to the resultant changes in the way they undertake research. It involves a major reorientation on the part of the plant breeders who were hitherto employing conventional techniques. They will have to learn the new techniques on the one hand and integrate it with the conventional methods of plant breeding, which they had been doing in the past. Majority of the scientists in the study felt that the new technology should be adopted only if it is useful in the work of the plant breeders and makes their job more precise. It should be noted that the plant breeders in our study have acquired the molecular techniques to use it in their breeding programs. They are able to evaluate the usefulness of molecular biology techniques.

The scientists included in the present study were divided on the question whether there is resistance among the plant breeders towards molecular biology techniques, as they constitute new techniques and calls for reorientation. Some of the plant breeders feel that the molecular biology techniques are still in the initial stages and that they are yet to be tested extensive} to prove their worth. Interestingly the scientists who expressed this view were plant breeders who are very senior and some of them at the fag end of the career or are very senior and have been executing plant-breeding programs based on the conventional principles. In contrast to the above group, the younger generation plant breeders, who have acquired the molecular biology knowledge either through their educational career or through training programs undertaken by different national or international agencies seem to be enthusiastic about the molecular biology techniques.

Most of the scientists seem to agree that there is a resistance among the plant breeders, especially among the older generation plant breeders, to use molecular biology techniques. The reasons stated by the scientists included in the study for this kind of resistance are diverse. But the main reason for this kind of resistance among the plant breeders is stated to be "Ego clashes." Among the older generation of plant breeders, one of the reasons for the resistance towards molecular tools could be that they don't have enough knowledge about the utility of these tools in the breeding program. One of the scientists who is a plant breeder says:

> "Yes the older generation has the resistance towards the molecular biology tools. Now things are changing with the old people going away gradually. Now all people are employing these tools. Actually there is no consensus but majority of the plant breeders sees the reason that these tools can be used for the benefit. Once you don't know anything, you tend to treat it with suspicion. That is always there."

Biotechnology products are still at the level of field trials and they are yet to come to the farmers' field and prove their worth. The above mentioned factor along with the high costs that are involved in developing a transgenic variety are the reasons for the resistance among the plant breeders to utilize these techniques in the breeding programs. Once these techniques have proved their worth the hesitation that the plant breeders have towards using these techniques would go away. In this context, one of the scientists, a molecular plant pathologist from one of the ICAR organizations mentions:

> "There is resistance. As the products have not proved in the farmers' fields yet there maybe some resistance. In case of transgenics where the products have gone to the farmers' fields in other countries, we have most regulations, which are evolved. This is one of the reasons why plant breeders do not want to use these tools. The reason is the government policy in case of transgenics. But in case of molecular tools, I think this has to be demonstrated. Just now the products have started coming out. So when the products are demonstrated in the farmers' field, they feel the benefits out of it, definitely they will also be coming out with these techniques. The other thing is the cost and the facilities involved. We cannot expect a plant breeder to maintain a laboratory. If he has to maintain a laboratory, he has to spend maximum time under our setup. He has to sacrifice his fieldwork and other things, which he cannot do. That also has to change."

Mentioning that the introduction of molecular techniques into the breeding program would bring in the responsibility of maintaining a molecular biology laboratory to the plant breeder. The responsibility of establishing and maintaining the molecular biology laboratory would mean that the plant breeder would have to cut down on the time devoted for the field activities. During the course of the interviews, one of the scientists, a molecular plant pathologist from one of the organizations in the ICAR setting suggested that the respective organizations should have a provision for a molecular biology laboratory as a central facility. The central provision of the molecular biology laboratory would be useful for the plant breeders when they want to utilize the molecular techniques in the plant-breeding program. He mentions:

> "People are aware of the molecular biology techniques but the difficulty lies in the organizational support. If the organizations improve the methodologies, if someone maintains the lab where it is available for the plant breeders to come and use it and the necessary training of the plant breeders is also given, probably people will start using it."

The establishment and maintenance of the molecular biology laboratory by the respective organizations has certain advantages in the sense that the plant breeder can concentrate on the activities in the field and use the facility at whichever stage it is needed in the plant-breeding program. This would enable the plant breeder to strike a balance between the conventional component and the molecular component and incorporate the advantages of both in the plant-breeding program.

One of the scientists included in the study is employed in the state agricultural university and right now pursuing his doctorate program in one of the ICAR organizations at the time of the study. Arguing that all new technology would face some resistance because of the fact that it is new, he mentions that the molecular biology techniques also are faced with resistance because they are part of new technology. But he mentions that the plant breeders should not have hesitation in employing this new technology that would be of help in the breeding program. Also he mentions that there should be no resistance towards molecular techniques because these techniques are part of new technology. Arguing that there is resistance among the plant breeders towards the use of molecular biology techniques, he mentions:

> "Resistance is there and will be there and it was there. But now with changing times, plant breeders will also have to change his perception. His interest will remain the same and if any new technology comes up and offers him the help, then what is wrong in accepting it? One should be receptive to the new ideas and new technology. The plant breeder should be able to be receptive to new technology. If molecular biology techniques help the plant breeders in their work, I see no harm in accepting to new technology."

Among the other reasons, which could be the cause for the resistance that exists among the plant breeders towards the molecular techniques is the scale of operation. Here it should be noted that the plant breeders deal with large number of plants while the molecular biologists deal with less number of plants. Mentioning this as one of the reasons one of the plant breeders mentions who is currently pursuing his doctoral degree from one of the 1CAR organizations states:

> "Because the plant breeders handle large populations, they feel that molecular biology dealing with a single plant, and whatever comes from the single plant is not trusted by the plant breeders. This may be the reason the apprehension among the plant breeders towards molecular techniques."

Values in the profession of plant breeding

At the outset it should be mentioned that the plant breeders give more importance to development of products/varieties, such as new plant varieties than to publications. The molecular biologists would give more emphasis to the publications of their results rather than development of products. The culture of molecular biology tends to be papyrocentric while that of plant breeding is papyrophobic to borrow the terms coined by Price (1982). But with the introduction of molecular biology techniques into plant breeding, the plant breeders also give importance to publication of their results now than what used to be earlier. There is a consensus among the plant breeders who were interviewed that development of varieties is the first priority for the plant breeders. Publications are also important keeping in view the fact that they are important criteria considered in the promotion policy followed by the various organizations. One of the retired scientists trained in plant breeding from the one of the ICAR institutes mentions:

> "The plant breeder is supposed to develop varieties. So you may have any amount of knowledge, but if you are not doing what you are expected to give/deliver, you are a failed plant breeder. The first and foremost thing is to develop and give the kind of variety and the kind of material he has been asked to develop. That's the foremost thing for a plant breeder. Publications come secondary. Publication is also important because publication sharpens your knowledge. Only when you have the kind of scientific frame of mind, then your way of doing plant breeding research will be result oriented."

He argues that plant-breeding being an applied science emphasizes more on the development of new varieties. Apart from the development of new varieties, the development of a selection technique that could be of help to the other breeders could be a significant contribution in itself. Yet another plant breeder from the same organization mentions:

> "For a plant breeder, product is the most important thing because he is translating knowledge into technology. Technology means it's reflected only in the product. So for a plant breeder it is the product, which is important. Publications take a secondary position."

In contrast to the above point of view, one of the plant breeders from the other ICAR organization mentions:

> "Varieties should be developed, side by side publications also should be there. Unless you publish, others cannot know what you are doing. Work done but not published is as good as work not done. Nobody will know your work. How many people can you go and tell them about

your work you have done. So you have to publish your work. The second thing is when you publish something, besides developing varieties, you have gone with the intention of developing something and you have published. Somebody who is lacking in that, when he sees that he will get some idea from your work/publication and he does something new. That clue was missing previously. After getting your publication only he gets the clue. For this also, publication is important."

One of the scientists, a molecular plant pathologist employed in one of the ICAR organizations points out that the norms of recruitment and promotion in the public sector organizations emphasize on the number of publications of a scientist. He cites this as one of the reasons for the publications becoming important for the plant breeders. He cites the instance of the Agricultural Service Recruitment Board (ASRB), which emphasizes on the publications of a particular scientist before promoting him/her to a higher rank. He makes this observation:

"For the purposes of promotions, definitely publications are needed because that is what we have learnt from the experience of the Agricultural Service Recruitment Board (ASRB) recruitments and several other recruitments. They have to keep in mind the promotions, publications are also important. If they use the routine technology, for example, if you want to do marker assisted selection using biotechnology tools with the genes, which some people have already utilized, it may not be a prime publication. But still it can be published because he will be handling a new plant, new donors and new recipient parents. It is possible to publish the results."

Emphasizing the importance of both publications and also development of products in plant breeding, one of the scientists who is trained in molecular biology, mentions:

"I value both because I am in a competitive field of research in science and that too in an area of agricultural biotechnology. Without publications I cannot survive. The reason for this is that publications are the ones, which count for my career."

In the changing context, that is, utilization of molecular biology techniques publications seem to have become equally important. Emphasizing for giving equal importance to both publications as well as development of products, one of the scientists a plant breeder from a state agricultural university setting puts forward the following view:

> "There should be a hybrid between a conventional plant breeder and a molecular biologist. You need to have papers and you need to have varieties. Best of both should be combined into one in few individuals. Few individuals should have molecular techniques as well as the ability to publish papers and produce varieties. Right now plant breeders are also looking for papers. They also think about publishing papers. Molecular biologists also do that and they have the same kind of priorities."

Giving the reasons for the less number of publications in the profession of plant breeding, one of the women scientists interviewed for the present study mentions:

> "In plant breeding, the goal is the product, a variety and the farmers' requirement. In plant breeding, the publications are very few. Most of the times, it is not done very systematically. You cross and go to the field, select a plant and release a variety, which would be very useful to the farmer. But you would not have taken systematic statistical observations. So publications may not be there all the time. But you will always have a plant useful for the farmer. But in molecular biology you get very good research papers. When you integrate molecular biology into plant breeding, I think you get both product as well as publication."

Collaboration between the plant breeders and molecular biologists

Integration of molecular biology techniques into plant breeding requires a great deal of collaboration between plant breeders on one hand and molecular biologists on the other. Before looking at the extent and patterns of collaboration between the plant breeders and molecular biologists, it is necessary to define the term collaboration. In this context, Michael Schrage (http://www.dtic.mil/summit/ma01_2html) describes collaboration in the following way:

> "It is the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have come to on their own."

He further argues that the goal of collaboration is the creation of value, a value born from the exponential product of the collective interactions among the collaborators. Collaboration describes a process of value creation that our traditional structure of communication and teamwork cannot achieve. Schrage uses the concept of 'shared spaces', which are the collaborative tools that people wield to make sure that the whole of the relationship is greater than the sum of the individuals' expertise.

He argues that within the shared spaces, collaborators must feel free to play at their activities, to explore and to experiment without any constraints. This kind of work atmosphere is as much a product of the necessary mutual respect, tolerance and trust between the collaborators, as it is a product of shared space itself. The important task before the collaborators must be a shared and understood goal. It must be significant enough that it demands of the individuals more than they can accomplish by themselves.

Collaboration is not described in terms of the relationship but in terms of the objective to be achieved. Concomitantly, the demand of the task is to ensure that the collaboration is no substitute for a basal level of competence in each of the collaborators. This competence is the basis for mutual respect, tolerance and trust that lie at the foundation of every collaboration. Collaboration can compensate for an individual technical or conceptual gap, but cannot paper over a fundamental deficiency. Collaborations work in a range of formal and informal settings. As a result, collaborators require neither physical presence nor continual communication. There must be a continuity of interaction between them. The goals shared by the collaborators serve as an arbiter determining the shape, setting and communications of a collaboratorium.

In the present study, an attempt has been made to find out as to why collaboration between plant breeders and molecular biologists is not occurring. Even before the introduction of molecular techniques into plant breeding, the conventional breeding programs required that the applied scientists i.e., the plant breeders, entomologists, geneticists and pathologists collaborated as a group at various stages of the plant-breeding programs. After the introduction of molecular techniques, the group of scientists engaged in collaboration would include the basic scientists i.e., the molecular biologists along with the other applied scientists. There were varied responses to the question whether the collaboration between the plant breeders and molecular biologists has been occurring or not. But there seems to be a consensus among the scientists that the magnitude of collaboration as required for successful integration of both the fields does not seem to be happening in the Indian context. One of the scientists who is a molecular plant pathologist observes:

> "But this collaboration is not happening. It's happening in a small way. It's not happening in the magnitude that is required. Organizational weakness in the program of planning and execution, because we often encounter that a plant breeder comes and asks for a collaboration at some stage of project implementation, not in project development. See people should be involved right from the beginning itself, right from project development and identify the responsibilities. That's not taking place. There is some deficiency in the project formulation itself. At the end if you come and ask somebody, it's just irritating somebody. You don't wish to do that and there is no interest. He is not going to share any benefit from the collaboration."

One of the plant breeders from one of the organizations in the ICAR setting argues that the collaboration between the applied and the basic scientists is still in the initial stages. He observes that there will be an integration of the molecular biology techniques into the plant breeding profession despite the initial difficulties faced by both the groups of scientists.

The reasons for the low level of collaboration between the molecular biologists and plant breeders relates to the difference in the way both the groups of scientists - basic scientists and applied scientists - look at the rice plant. Also the professional orientation of both groups of scientists is varied and it is difficult to look at an aspect in the same way. At one level it could be said that the plant breeders do not realize the value of the molecular techniques and it is also true that the molecular biologists may not appreciate the value of conventional plant breeding technology. As one of the scientists puts it:

> "The reasons for the collaboration not taking place between the two groups are that the molecular biologists are basically basic scientists, academically oriented whereas plant breeders are applied scientists. To make both of them see reason on a single aspect is a difficult thing. Because the molecular biologists look at the plant at the level of the nucleic acid, so there is some clash. It's not a clash actually. But the molecular biologists may not realize the true value of the plant breeding and the plant breeder may not realize the value of molecular biology. Maybe the ego component may be there, but the technical aspects are also there. They may not be able to understand the subject very well."

With regard to the norms related to collaboration, one of the scientists, a plant pathologist makes the following observation:

> "Well I think the ego plays an important role. In case of biotechnology and molecular biology, one should take a strategy of grabbing whatever opportunity comes to collaborate. So one should be prepared to share the material, information that is available in a particular centre. It may not be possible to do everything in one centre. So

centres are coming forward, its not that they are not willing to collaborate. But this is only in a less way. So definitely in any collaboration there should be benefit for both. It cannot be a one sided thing. Both sides should get some benefit out of that. There are some collaborations, which are coming."

Organizing for the new context: Constraints on Public Institutions

In the context of the molecular biology tools being introduced in the profession of plant breeding, the plant breeders employed in the public institutions are faced with various constraints. These constraints are in terms of the current level of funding for research, existing infrastructure and also the lack of human resources both in quality and quantity for carrying out the research employing molecular biology techniques. If these constraints are not overcome, public institutions, which played a significant role in ushering green revolution, will be by-passed by R & D institutions in the private sector, a trend that has already become predominant.

Research Funding

At the outset, it should be mentioned that the research relating to introduction of molecular biology techniques into plant breeding would require substantial amounts of financial resources. As mentioned earlier, state of the art molecular biology laboratory is required by the plant breeders to carry out the molecular biology work. And it may be mentioned that in the context of the public sector institutions, the funds provided by the organization are very limited. There seems to be a consensus among the scientists with regard to this. One of the senior most scientists had the following observation to make:

"Biotechnology is a highly capital intensive area. Even big companies cannot be sustained. So there is lot of amalgamation. That is one problem because it is cost intensive. The second aspect is that in molecular biology if you really want to apply it to plant breeding whatever you may do, certainly there will be infringement of intellectual property. What I mean is that you may be developing a transgenic for a particular trait. Let us say, I am working for introduction of Bt gene in rice. Bt may be my own gene but all other things in the construct like the promoter, the reporter or marker, the regeneration protocol or the other transformation protocol are all already patented. So unless you get the agreement from all the patentees, you will not be able to commercialize it. That is one of the reasons even big companies cannot survive. They have to be interdependent. So in such a situation, small companies will go away as they cannot sustain themselves."

He also mentions apart from the high costs involved in biotechnology research, it also involves lot of issues related to Intellectual Property Rights (IPRs) which would in turn increase the cost of molecular biology research. With insufficient amount *of* in-house support funded by the public organizations, the alternative source of funding for the scientists is through projects. Various national and international funding agencies have been actively involved in funding scientific research especially in the context of molecular biology research. In the context of rice biotechnology research, various national funding agencies like Department of Science and Technology, Department of Biotechnology have been contributing. International funding agencies like the Rockefeller Foundation have a provided project grants for training and acquisition of the state of the art molecular biology laboratory equipment during 1990-2002.

There seems to be an agreement among the scientists that the funding provided by the national funding bodies is inadequate. Further the funding bodies have such rigid rules and regulations governing grants and management of grants that they cause a lot of delay. It is for this reason that the scientists seem to prefer approaching the international funding agencies for grants. One of the scientists during the course of the interview mentioned:

> "Well as far as we were having funds from the external aided projects there was no problem. But if you want to start anything, which is new, one has to go to other agencies like the Department of Biotechnology, Department of Science and Technology, ICAR and organizations and the like. It's still possible, but it takes time, because if you send a project to DBT or DST, then sometimes for years you don't hear from them. So I don't know who has to correct themselves but the problems exist."

As already mentioned, molecular biology research would require substantial amounts of money to procure bio-chemicals, enzymes (most of which are patented and have to be imported) and equipment to carry out the research. Arguing that the funds that the in-house support are provided by the institutions in the public institutions is very meager, one of the scientists mentions:

> "Funds which the organization is providing for this kind of work is very limited. It has to identify and instead of making people run to the donor agencies there, then the institute itself provides larger quantities of funds. If it becomes a priority item, institution can promote molecular biology in a big way."

Human resources

As already mentioned in conventional plant breeding research, there is no need for specialized training of manpower to participate in the conventional breeding programs. But once the molecular biology techniques are incorporated into breeding programs, there is a need for manpower trained in these techniques to execute the work in the molecular biology laboratory. It is mandatory on the part of the organizations to provide for skilled manpower trained in molecular biology techniques to meet the requirements of the scientists in the changing scenario. With regard to the constraints with regard to the human resources, one of the scientists makes the following observation:

> "There is a good establishment now. I don't think there would be any constraints in continuing the work. If they are trained thoroughly, we

can utilize the resources. I don't see any constraint in that if there is a good lab and good funding sources. The only problem is the funding source and if the personnel is well trained and enough funds are available, then we can carry out the work in a much better way. There are no constraints right now because the emphasis is now on molecular biology tools. At every institute they talk about molecular biology. In that scenario, we don't face any constraint in our organization."

In the context of the molecular biology tools getting incorporated into plant breeding, there is requirement for research personnel, both in quality and quantity, trained in molecular biology techniques. Apart from these measures, it was also felt by one of the scientists that there are different sets of rules for the universities and the ICAR organizations. He feels that there should be a change in the government's policies. He mentions:

"Human resource development is essential and it's also a continuous process. There are opportunities that are available for that. But again the government of India has got several restrictions for sending/moving people out and bringing them back. Because every time a scientist in the ICAR has to go out even for a short duration to participate in an international conference, he has to get the clearance from the Minister of Agriculture. But I don't know what is the policy behind it? Why a minister should permit a scientist to go out of the country, while it is not so in the universities? Then why this disparity between the university and the ICAR institutes? These I think they should think in a broader way."

Autonomy of scientists

As already mentioned above, large amounts of funds come to the various organizations when projects get approved from the national and international funding agencies. In the context of rice research, the prominent national funding agencies are Department of Science and Technology and Department of Biotechnology. Apart from the national funding agencies, the Rockefeller Foundation had a major share, in the funds granted for rice biotechnology research in India.

In this context of writing the projects, the scientists located in the public sector organizations seem to share the perception that the scientists are not given enough autonomy in matters relating to writing project proposals for various national and international funding agencies. One of the scientists during the course of the interview mentions:

> "There is no autonomy for making a project. It may not be exactly what you like, may not do it. They may have to change the project at the last minute according to the wishes of the people. This is the case with mostly the ICAR institutes. Bureaucracy still plays a major part. To solve the problems of the scientists, a clear-cut policy has to be defined and what are the projects likely for rice because rice is a major crop, what are the major activities and decide that this group will do this work and this group will fund this much, and this is the objective we have in mind. We will give you five years time, you either deliver the goods or else go. That kind of thing is not there right now. Each one is individually competing. Several people may be writing the same project. This is all likely to happen."

There is a need it is felt that clear-cut policy formulations should be evolved at the level of the ICAR to avoid duplication of research proposals sent for funding. And also the involvement and role of the bureaucracy should be lessened as much as possible.

Organizational support in the new context

The introduction of molecular biology techniques would require the organization to provide support to the scientists working to integrate molecular biology techniques into plant breeding. In this context, it would be interesting to take note of the observation made by one of the scientists:

> "Certainly I would like that the administration of our supporting unit should be sensitized to the specific needs which we face. After all the type of needs which we have as a department in biotechnology may not be the same as with respect to that of agronomy, where their requirement and their requirement with respect to maintenance and equipment is very much limited. But ours is lab based and partially

field-based work. So I believe we should be more actively supported by our institution, because after all the facilities, which we have created or are creating, it's for the whole institute as such. A molecular pathologist or molecular entomologist also can use our facilities."

As for the support that is provided at the level of the organization to meet the needs of the scientists in the new situation could be put under the following heads:

Rules of project formulation, implementation and collaboration

In the new context of molecular biology techniques being integrated into plant breeding, there needs to be a different set of rules for the project proposals and their implementation. There is a need to visualize projects, which would include the scientists from the concerned disciplines right from the stage of project formulation. In this context, one of the scientists, a plant pathologist, argues:

"Well a more open minded ness is needed. Probably they should give more importance to the man who is proposing the project. Because he is the one who is going to deliver the goods ultimately. That's more required."

One of the scientists who is a plant breeder from one of the ICAR organizations mentions:

"There should be a policy of what is the priority of the institute and whether that priority of the institute has the effect to use molecular biology tools or not. So what are the tools, what are the characters you need to transfer. To avoid duplication, there should be a national level consensus and adopt a consortia approach i.e., this university will do this part, the others will do this part and then pool the resources. But that is not happening."

Infrastructure in terms of water, space and electricity

It should be mentioned at the outset that molecular biology research requires infrastructure in terms of pure water, space for the establishment of molecular biology laboratory and equipment for the laboratory, and also continuous supply of electricity- As molecular biology research involves various equipment/instruments like the

Polymer Chain Reaction (PCR), Gel Electrophoresis and so on, provision for continuous supply of water and electricity is a necessity. Once the molecular techniques are introduced into the discipline of plant breeding, it would require the support for infrastructure from the respective organizations in terms of water, space and electricity. There seems to be a consensus among the scientists that there should be good organizational support when it came to the issue of the organizational support in terms of the providing the infrastructure in terms of water, space and electricity. With regard to infrastructure that has to be provided to the scientists to carry out research in molecular biology and integrate into plant breeding, one of the scientists mentions:

> "The institute has to provide all the facilities. Once these are provided, only then can research be carried out. We expect that all these will be provided in the parent institute for smooth functioning. While the project is being approved for any funding, they will take all these into consideration, whether they can provide these basic amenities. Only when they can provide these facilities, then the project will be moved forward. Suppose a scientist gets a project worth some crores, there is no building here you cannot start constructing the building here. So the institute has to take all these things into consideration whether we have enough infrastructure for our scientists to get some projects. Can we support him with the existing infrastructure or not is the basic question. Only after this is confirmed, the project proposal will be forwarded and basic amenities will have to be taken care of."

The above scientist has pointed out that the organization will take into account right at the level of project formulation whether the required infrastructure is available to support the project organization.

Shift of scientists from public sector to the private sector

While development of green revolution technology was located, primarily in the public sector institutions, development of biotechnology has been concentrated in the private corporate sector. In a sense, research projects have become proprietary.

This is assuming significance in the context of the WTO provisions on the intellectual property rights (IPRs). In the changing scenario, public institutions have not yet made systematic attempts - investments, development of human resources etc - to integrate molecular biology into their research.

At this juncture, one may expect a flow of scientists engaged in applied research to private corporate sector. Scientists were asked to indicate their perceptions regarding the movement of scientists from the public sector to the private sector. There were interesting responses when the scientists were asked whether there would be any shift of scientists from the public sector institutions into the private sector institutions. Though majority of the scientists seems to agree that there is a shift of scientists from the public sector to the private sector, one of the woman scientists from one of the 1CAR organizations does not support this view. She argues that while working for the public sector institutions the scientist would have the chance of interact with the students and other researchers in an academic way. This is seen as an advantage of working in the public sector institution, which the scientist would loose once he/she shifts to the private sector.

It would be interesting to note that there is a shift of scientists from the public sector to the private sector organizations; this shift cannot be directly related/attributed to the introduction of molecular biology techniques into plant breeding profession. The main incentive for this movement of the scientists from the public sector institutions into the private sector is the monetary/financial incentives offered in terms of more salaries and perks offered to the scientists/employees by the private sector companies. In addition to this, the absence of bureaucratic hurdles in the day-to-day activities of the scientists would also encourage the scientists to make such a shift. Mentioning that the industry is already involved in plant breeding, one of the scientists from the state agricultural university setting mentions that there are many advantages of working in the private sector institutions. He points that the scientists are likely to shift to the private sector because of the efficiency of the private sector. The other reason could be less bureaucracy intervening in the day-to-day activities of the breeders. Mentioning the efficiency factor in the private sector as a significant factor, he states that the private sector would be able to achieve things at a faster pace. He also mentions that there is lot of flexibility in terms of operation for the scientists, which is absent in the public sector institutions. He compares the private sector with the cheetah and the public sector is compared to an elephant. Another scientist who is working towards his doctorate degree at the time of the study in one of the ICAR organizations mentions that the public sector institutions have better facilities in terms of infrastructure and are more equipped to handle the long-term process when compared to the private sector organizations. Also the public sector institutions have certain social responsibilities to fulfill, which are of priority to the public sector institutions.

Among the other reasons for the shift of scientists from the public sector institutions to the private sector is the availability of the expertise in the public sector institutions and the demand for such expertise in the private sector. Among the reasons for the shift of the scientists from the public sector to the private sector, the introduction of the Voluntary Retirement Scheme in the public sector institutions would prefer to shift to the private sector according to one of the scientists interviewed. The younger generation, this scientist observes, is not inclined to join the public sector institutions. This is because of the fact that there is no scope for employment in the public sector institutions. The other reason for this kind of shift of the younger generation scientists is the nature and flexibility of working and less bureaucracy in the private sector.

As already mentioned, the public sector institutions played a significant role during the era of the green revolution. The public sector institutions were the loci of research and these institutions are equipped with infrastructure and also the technical expertise to execute the research programs. Once the scientists shift from the public sector institutions to the private sector organizations, the nature and quality of research that is carried out in the public sector institutions will be affected. Speaking about the impact of the shift of scientists from the public sector to the private sector, a woman scientist from the I CAR setting mentions:

> "The research in the public institutions will continue as it was because the private sector may compete in certain areas but then the private sector areas are so narrow and already decided by the management. The freedom of science as it is in the public sector will not be there in the private sector. The role of the public institutions, in my view, will continue because you will get the freedom to do a wide range of work, which we will not get in the private sector. Though you may not be able to make a dent like some private sector institutions, they are some specifities."

Talking about the influence of the shift of scientists from the public sector to the private sector, one of the scientists mentions:

> "The movement of scientists may bring about changes in the way research is carried out. In certain cash crops like cotton, sugarcane there are experts in a particular field like entomology or molecular plant pathology or molecular biology, Considering these are cash crops, there may be significant shift in terms of movement of staff. But for a crop like rice, considering its economic implications in India, I don't think there will be a significant move."

Stating that the private sector organizations would provide competition to the public sector institutions and shift the scientists from the public sector institutions to the private sector institutions. The private sector institutions will be able to withstand competition more effectively. But the ultimate concern of the public sector institutions will the cost of the product that will be delivered to the farmers. In this context of the scientists one of the scientists observes:

> "Definitely it will weaken the research activities because it's a competition. Private sector will be able to compete more effectively. But only thing we should be concerned is about the cost that is going to be for the farmers. Definitely the private sector people will be expecting some profits out of the product. There is a profit motive but how much it is going to cost the farmers is a crucial question."

From the above discussion of the data presented above the molecular biology knowledge and research has significant influence on the profession of plant breeding. This also means that there are significant shift in the way the scientists look at the rice plant i.e., from the level of the phenotype to the level of the genotype. Further the strategies of intervention would shift from the conventional method of hybridization to strategies like marker assisted selection and genetic engineering. The project data suggests that the plant breeders prefer marker-assisted selection to genetic engineering. Marker assisted selection is based on the intra-species transfer of genetic material and has the possibility of 'gene pyramiding' by accumulating genetic markers for desired multiple traits - higher yield, resistance against diseases, drought resistance etc (Haribabu, 2000). Transgenic approach involves the transfer of the gene of interest across different species and this approach involves ethical issues. As mentioned earlier, plant breeding profession is going to make a new of related selections of theories, experiments, techniques, genetic markers and so on. These shifts also call for changes in the organization of research management of research grants. One important change will be increased collaboration between applied scientists on one hand and the basic scientists on the other. The process of integration of molecular biology techniques into plant breeding has more support from younger scientists than older plant breeders.

Chapter VI

CHAPTER VI

Conclusion

Modern science and technology play an important role in the life of humans, and the field of agricultural research is no exception in this regard. The advanced techniques developed through scientific research have been successful in conferring resistance to various biotic and abiotic stresses in the various food and cash crops world over. These advanced techniques have assumed significance as the land available for agriculture has been decreasing and the world population has been increasing.

The present study explores as to what changes have occurred and/or occurring in the plant breeding profession with the shift in understanding life processes at molecular level as a consequence of the developments in molecular biology and how these developments influence the community of scientists engaged in plant breeding. These questions are addressed by focusing on the changes that have occurred/and are likely to occur at three distinct levels namely at the cognitive level of understanding the plant, the strategies of intervention and the associated practices of plant breeding research.

The current research problem was an outcome of the research project supported by the Rockefeller Foundation, New York. The project aimed at finding out whether the funding provided by the Rockefeller Foundation to the scientists working in the area of rice biotechnology research actually contributed to the emergence of a community of rice biotechnologists in the Indian context. The perspective of the present study is informed by the sociological insights that one can garner from Thomas Kuhn's work. Kuhn (1970) by pleading for examining science in its historical integrity has opened up possibilities of a thorough going sociological analysis of the process of production of knowledge and the product resulting from the process. Further his notion of scientific community is closer to the sociological concept of community. His notion of paradigm enables us to understand the consequences of shift in the paradigm for the worldview and also the practices.

A new paradigm not only looks at the world differently but also a different world. Related to this is the shift in the practices - instruments and instrumentation techniques, experiments, standard ways of applying paradigm theory to different situations. In this process, practices of the professionals would change and bring new set of values - cognitive and social. These insights are useful in understanding the changes that are likely to take place in the case of the discipline of plant breeding and practices of the plant breeders. Kuhn argues that the scientific community gets 'insulated' from wider society and prepares its own paradigm-based research agenda. This is now being questioned as the character of science is undergoing change as science is becoming more closely linked to industrial research.

According to Kuhn (1970), 'Normal Science' refers to research firmly based upon one or more past scientific achievements that the scientific community acknowledges for the time being as the foundation for its future practices. These scientific achievements share two characteristics namely:

1. Their achievement was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of activity; and

2. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve.

These scientific achievements are called as paradigms, which are accepted examples of actual scientific practice that include law, theory, application and instrumentation, which provide models for the coherent traditions of scientific research. The study of paradigms prepares the student for membership in the particular scientific community with which he will later practice. His subsequent practice will seldom evoke overt disagreement over fundamentals. Researchers sharing a shared paradigm are committed to the same rules and standards of scientific practice. The commitment and the apparent consensus a paradigm produces are prerequisites for normal science i.e., for the genesis and continuation of a particular research tradition. Though scientific research is possible without a paradigm, the acquisition of a paradigm according to Kuhn signifies the maturity in the development of any given scientific field.

Paradigms acquire their status because they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute. The success of a paradigm is largely a promise of success discoverable in selected and still incomplete examples. Normal science consists in the actualization of that promise by extending the knowledge of those facts that the paradigm displays as particularly revealing by increasing the extent of the match between those facts and the paradigms predictions and by further articulation of the paradigm itself. Post-Kuhnian approaches to sociology of science not only look at the social norms but also the very content of science. Mertonian approach limited itself to looking at the social moral norms of scientific communities. Constructionist approach, one of the post-Kuhnian approaches which looks at both the process of production and the outcome of the process (Knorr-Cetina, 1981). Knorr-Cetina argues that scientific knowledge is an outcome of constructions based on a series of interconnected selections—theories, methods, experiments and interpretations. The selections are influenced by local contingencies and cultural contexts. Scientists deploy practical reasoning, analogical reasoning and socially situated reasoning in the process of production of knowledge (Knorr-Cetina, 1981). This perspective is useful to look at the process of production of knowledge by the community of scientists engaged in plant breeding. Research in plant breeding involves a series of selections in the process of identifying and selecting varieties in hybridization programmes. In the context of application of molecular biology techniques plant breeders will be engaged in the process of selections, for example, of genetic markers and approaches to marker assisted selections (RAPD, RFLP, etc). Molecular biologists also take decisions with respect to achieving genetic modification by weighing the options of transformation — agro-bacterium mediated transformation, use of biolistic gun, electrophorosis---- and then select one of these options.

Today there is a great deal of mutual interpenetration of science and technology (Ziman, 1998). Basic research is influenced by commercial considerations. Molecular biology as a paradigm is going to have enormous implication for crop improvement research. As mentioned earlier, crop improvement research was first based on mass selection, Mendelian genetics and hybridization. Plant breeders today have access to knowledge about plants at molecular level. How and in what ways plant breeders evaluate the new knowledge in relation to their professional work, which hitherto was based on Mendelian genetics and knowledge of several field-based parameters. If the plant breeders adopt the new molecular paradigm does this adoption change their profession? If it changes, in what ways and how does this change occur? are significant sociological questions for the present study.

Plant breeding research based on conventional methods of improvement was based on Mendelian Genetics. In Mendelian genetics, the level of understanding of the object of research i.e., the rice plant is at the level of the phenotype. In conventional plant breeding-, the commonly deployed strategy of intervention is hybridization. In hybridization, the changes/modifications that were required were to be brought about in the plant in terms of increase in yield, resistance to various kinds of stresses, diseases and pests had to be carried out by crossing the parent plant with the plant varieties which have the desired qualities. This would follow the tests, which would confirm whether the desired quality is present and dominant in the subsequent generations. This would take lot of time from the field-testing to be released as a new variety.

With the introduction of molecular biology techniques in the plant breeding programs, the time taken for the development of varieties has been shortened. In other words, while in conventional plant breeding programs, the development of a variety would have taken at least ten to twelve years. Using the molecular techniques in the breeding program, the time taken for the development of new variety would be shortened to four to five years.

Moreover, the molecular techniques would enable the plant breeder to incorporate genes of interest from any living organism either in the plant or animal kingdom. This process involves a shift in the way the plant breeder looks at the object of research i.e., the rice plant. But the changes that were to be incorporated would be at the molecular level i.e., at the level of the DNA. This would employ completely different set of strategies of intervention and imply a change in the associated practices to be followed by the plant breeders in the plant-breeding program. Mendelian genetics will play significant role in evaluating a variety in successive generations. The choice of a particular strategy of intervention would be based on a series of selections. The factors that influence the selections and ultimate choice of a particular strategy of intervention by the community of plant breeders are significant sociological questions.

The present exploratory study aims to make a sociological analysis of the nature of changes at the level of cognition, the level of intervention and also at the level of organization of the profession that are likely to occur in the conventional plant breeding practices when faced with the new form of knowledge i.e., the techniques of molecular biology. It is interesting to note that at present most of plant breeders seem to be learning/acquiring the techniques of molecular biology in order to carry out their work independently without having to depend upon the molecular biologists.

The fieldwork for the project was carried out in the institutions where scientists receiving financial support from the Rockefeller Foundation were located. These scientists were drawn from organizations located both in the public and private sectors. The data collected for the project were also utilized to provide the background for the present study. Apart from the data collected as part of the project, separate questionnaire and interview schedule were prepared for the purpose of the data collection for this doctoral study. In addition to the data collected through questionnaire and the interview schedule, the biodata/C. V and lists of publications of the scientists were collected. The lists of publications were important to indicate the patterns of collaboration of scientists within the organization and also with the scientists employed in different organizations. However in-depth analysis of the patterns of collaboration on the basis of publications was not undertaken, as all the scientists have not provided their complete lists of publications. The data for the present study was collected from scientists located in the public sector institutions. The organizations visited for the conducting the fieldwork for the doctoral study were University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bangalore, Central Rice Research Institute (CRRI), Cuttack and Directorate of Rice Research (DRR), Hyderabad.

Plant breeding involves research that plays an important part in the agricultural crop improvement. It is through crop improvement research programs carried out by the plant breeders that new crop varieties are developed. The parameters that guide plant breeding programs are: a. yield potential; b. biotic stresses; c. abiotic stresses and d. agronomic factors. In other words scientists engaged in plant breeding should have to make a series of inter connected selections on the basis of tradeoffs among the parameters. In other words the plant breeders have to deploy practical reasoning and socially situated reasoning in their research.

The plant breeding programs prior to the advent of the molecular techniques into plant breeding programs were governed by Mendelian genetics. The plant breeders depended on the conventional breeding techniques like hybridization to develop the varieties with the desired traits. For instance if the plant breeder has to develop a variety, which is resistant against a pest/insect, he/she would first select the variety, which is high yielding. After having selecting the high yielding variety, the plant breeder would select a variety within the species, which would confer resistance to that particular pest/insect. Then the plant breeder would cross these two plant varieties. Having crossed the two varieties, the plant breeder brings about homogeneity in the variety by crossing it through the next seven generations (i.e., from F1 to F7 generations). Conventional plant breeding involves a series of interconnected selections as mentioned above.

After the plant breeder develops the variety it would be tested by the organization, which is entrusted with the responsibility of multi-location trials across the various agro-climatic zones of the country. The aim of the multi-location trials is to assess the performance of that particular variety in these various zones. In the case of rice the organization, which is entrusted with this responsibility, is Directorate of Rice Research (DRR), Hyderabad.

In conventional plant breeding research, plants were understood at the level of the phenotype i.e., more holistic and grosser external appearance of the plant. The plant breeder employs the strategies of intervention at the phenotypic level. The other important point to be noted is that in conventional plant breeding, most of the activities of the plant breeder are field-based. The field is the area of operation for the plant breeder and the testing arena. He/she carries out the various activities like the selection of the plants based on the plant breeders' assessment (on the basis of one's experience and other technical criteria) of the phenotypic appearance of the plants, crossing and the related activities. Thus plant breeding was both an art and science. The laboratory has a limited role to play in the conventional plant breeding programs. The laboratory activity involves routine tasks such as taking measurements like the panicle weight, thousand-grain weight among other things. The laboratory is also used to store the equipment that is used in the conventional breeding programs.

However in attempts to introduce the molecular techniques into plant breeding, the cognitive orientation of the plant breeder undergoes a shift with the emphasis shifting based on the understanding of plants at molecular level or at the level of the DNA. The emphasis changes from the phenotype to the genotype. Instead of looking at the phenotypic characteristics of the plant the breeder will look at the level of the genes responsible for various traits like yield potential, tolerance against biotic and abiotic stresses and select appropriate parental lines for the development of new varieties. In other words, the molecular biology techniques are surgical tools to enhance the precision of selection of appropriate parental lines with the genes of interest.

More over with the introduction of the molecular techniques into the conventional plant breeding programs would bring about changes, which influence the strategies of intervention selected by the plant breeder. Hybridization has been the principal strategy of intervention prior to attempts to introduce molecular techniques. But once the molecular techniques are selected, the strategies of intervention would be either Marker Assisted Selection (MAS) and/or recombinant DNA technology also referred to as genetic engineering. The community of plant breeders evaluates the relative efficacy of the strategies and selects one of them for a given plant-breeding program. The significant difference one needs to bear in mind is that in case of marker-assisted selection, the gene of interest would be from the same species. But in case of genetic engineering, the gene of interest could be from any living organism from the plant or the animal kingdom. This raises certain ethical issues regarding the acceptance of the products developed through this method. In this situation plant breeders seem to approve of selecting MAS, which is not as controversial as the genetic engineering. The selection is based on both practical reasoning and socially situated reasoning.

In the sphere of the associated practices of the plant breeder a major change is visualized with the introduction of molecular biology techniques in plant breeding. First of all as mentioned above, there is a change in the way the plant as an object of manipulation/intervention is seen. It changes from the plant as a whole to the genes of interest i.e. the genome level. Then the plant breeder will have to use both laboratory and the field as his/her sites of research. The laboratory is no longer relegated to a secondary position in the plant-breeding program, as it was the case in conventional breeding. The laboratory activities, equipped with the necessary equipment to observe plant at molecular level and manipulate it at molecular level assumes significance in the plant breeding programs. The scientists can be more precise in the selection of the parent plants to develop new varieties as they can identify the genes responsible for various traits and manipulate them at the level of the individual plants. With the equipment and techniques to find out whether a plant contains the desired gene or not, the job of the plant breeder becomes much more precise. Introduction of molecular techniques into plant breeding program would also subject research to more proprietary controls as the gene constructs, the chemicals and plasmids used in biotechnology research are usually patented elsewhere.

As mentioned earlier, the community of plant breeders evaluates the efficacy of the molecular biology techniques in the plant breeding programs. The older generation plant breeders have a sense of resistance towards the molecular techniques. These breeders who are at the fag end of their career, or have been using conventional plant breeding techniques for a long time, are not receptive to these new techniques.

The reasons for this kind of resistance towards these techniques are varied. Apprehensions arise due to lack of knowledge about the utility of the molecular techniques in the plant breeding program and the scale of operation involved in molecular techniques. The molecular biologist deals with small number of plants when compared to the plant breeders who deals with large populations and this seems to be one of the reasons for apprehension among the plant breeders towards molecular techniques. However the study suggests that the molecular biology techniques are evaluated

The introduction of molecular component into plant breeding would increase the cost of research as well as the cost of the product/variety developed through these techniques. In the context of the research becoming more proprietary, the plant breeder would need organizational support in terms of more physical resources, trained human resources and more importantly financial resources to incorporate molecular biology and techniques in teaching and research.

Limitations of the present study:

The present study attempted to understand the changes that have occurred and/or likely to occur in the profession of plant breeding after the introduction of molecular biology techniques. The research questions are sociologically significant questions to understand social change in the profession. The study has included scientists working in the public sector institutions. This is one of the limitations of the present study, as it does not include the perceptions of the scientists from the private sector organizations. There is a need to carry **out** more empirical research to fully grasp the implications of molecular biology for plant breeding at cognitive level and at the level of the community of scientists engaged in plant breeding to understand the patterns of communication among plant breeders and other applied scientists on one hand and between applied scientists and basic scientists on the other.

Annexure-I

UNIVERSITY OF HYDERABAD

DEPARTMENT OF SOCIOLOGY

The present study aims to understand the changes that have occurred in plant breeding profession with the introduction of molecular biology techniques. The present questionnaire is part of data collection for my doctoral work. Kindly fill up this questionnaire. Please furnish your biodata and list of publications. Your cooperation will be highly appreciated. The information provided will be used for research purposes only. Strict confidentiality will be maintained.
T. Laxmi.

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01. Name

02. Gender: Male/Female

03. Age as on last birthday

04. Organizational Affiliation

05. Your present position/rank in the organization

06. What was your position/rank when you first joined the organization?

07. Duration of employment in the present organization

08. Educational qualification

    a. Highest degree acquired till date

    b. Age at the time of obtaining the highest degree

    c. Awarding institution

09. What was your area of specialization at the level of doctoral degree?

10. Post-doctoral research experience before and after getting a regular job

Before		**After**	
Institution	**No. of years**	**Institution**	**No. of years**

11. Did you work at any other organizations before joining the present organization? Yes/No

If yes, please give the details.

S.No.	Organization	Position/Rank	No. of Years

\2. Areas of initial research interest

13. Areas of current research interest

H.Number of research students guided at different levels till **date**

Degree	No. of men	No. of women
Ph. D degree		
M.Phil Degree		
Projects		
Any other (pl. specify)		

15.How many of your research students at present **are** supported by the following sources?

S.No.	Nature of Fellowship	No. of men	No. of women
1.	CSIR/UGC Scholarship		
2.	ICAR Scholarship		
3.	Projects		
4.	University/Institutional		
5.	Any other (pl. specify)		

16. Did you undergo any training in molecular biology techniques? Yes/No

If yes, give the details

Name of the organization

Duration of training

At what stage of you career:

1. During Ph.D.
2. During post-doctoral degree/work
3. After joining the regular job

17. Have you undertaken any projects after joining in your regular/permanent job? (Please furnish a list of projects if the space provided is not adequate)

a. Details of completed projects

Project Title	Year of commencement	Year of completion	Funding agency	Collaborators, if any	No. of publications	Patents, if any

b. Details of ongoing projects

Project title	Year of commencement	Funding agency	Collaborators, if any	Publications, if any	Patents, if any

Annexure-II

INTERVIEW GUIDE

01. What are the basic steps involved in plant breeding and varietal development?

02. What are the various methodologies that a professional plant breeder uses in conventional plant breeding?

03. What are the major strategies that are employed in conventional plant breeding?

04. What is the daily routine of the plant breeding activities like?

05. Are there any changes in the daily routine of the plant breeder after the introduction of molecular biology tools into plant breeding?

06. What are the various skills and training required to become a competent plant breeder?

07. Which of these activities you value the most, as a professional plant breeder?

A. development of variety
B. publication of papers
C. both
D. any other

08. Do you think that molecular biology tools will help in plant breeding?

Yes/No

If yes, in what ways and what stages
If no, elaborate

09. You have been involved in using molecular biology techniques in plant breeding. How do you look at plant breeding having armed yourself with the molecular biology techniques?

10. What are the skills and training required in molecular biology for one to become a competent plant breeder using molecular biology techniques?

11. Do you think that the lab has become an important component in plant breeding with the introduction of molecular biology tools? What is the role that the laboratory plays now at different stages of plant breeding?

12. Do you think that the field related activities have become less significant with the addition of the molecular biology lab?

13. What are the new/additional tasks/roles, which you as a plant breeder will have to take up at different stages of work with the introduction of molecular biology techniques into plant breeding?

14. What are the different categories of field staff and their roles along with their activities in conventional plant breeding?

15. Are there any additions of new categories of field staff with the introduction of molecular biology tools? What will be their roles and additional tasks, which they take up?

16. Have the activities of the field staff undergone any change in the content of their work with the introduction of molecular biology techniques into plant breeding?

17. With the introduction of molecular biology techniques, what will be the nature of help/expertise you need/expect from other applied scientists like pathologists, entomologists, and geneticists in your research?

18. With the involvement of the private biotechnology companies in development of varieties and the seed industry, do you think that the scientists from the public sector institutions will move over to the private sector? What will happen to the research in the public sector institutions?

19. Given the possibility/reality of the molecular biology techniques being introduced into plant breeding, what are the constraints you are likely to face in your organization regarding

    a. Funds
    b. Human resources
    c. Norms related to collaboration
    d. Autonomy

20. What do you think should be the nature of the organizational support appropriate to the new situation in terms of

    1. Rules of project formulation, implementation and collaboration;
    2. Infrastructure in terms of water, space and electricity etc;
    3. Funds;
    4. Human resources and
    5. Any other

21. What are the various parameters that are tested in multi-location trials? Will these parameters change with the introduction of molecular biology techniques?

22. Introduction of molecular biology techniques into plant breeding requires collaboration between molecular biologists and plant breeders. Do you think it is taking place? Yes/No

    If no, elaborate

23. Do you think there is resistance among plant breeders against molecular biology tools? Yes/No

If yes, kindly elaborate

Glossary

Glossary

Agrobacterium mediated transformation is one of the vector mediated transformation wherein the gene of interest is introduced through the soil bacteria (*agrobacterium tumefaciens*)

Biolistic Gun is one of the means of direct transformation where in the gene of interest is introduced into a plant. In this either gold or tungsten particles coated with the DNA of interested are accelerated to a very high initial velocity.

Deoxyribonucleic Acid abbreviated, as DNA comprises of the genetic material of the organisms.

Diploid indicates an organism with two copies of a single genome i.e., with chromosome number of 2x.

Electrophoresis is a laboratory technique used to separate mixtures of molecules, such as proteins and nucleic acids in a suspension, by their charge-to-mass ratio.

Gene is the fundamental unit of inheritance and function in a cell. In classical genetics involving plant and animal breeding the gene is regarded as the unit of heredity.

Genetic engineering implies the technology that enables DNA fragments from different sources to be combined to make recombinant DNA and inserted into cells thereby altering the function of the recipient transgenic cells.

Genotype indicates the genetic constitution of an organism

Haploid implies a individual with a gamatic (either male or female) chromosome number

Heterogeneous indicates a mixture of different types usually different genotypes.

Homogeneous indicates consisting of the individuals of the same genotype or phenotype

Marker refers to a gene, which is used to identify a particular fragment of DNA during transgenic work or genetic engineering. The marker gene confers a ready method of identification such as the production of a color on suitable treatment.

Phenotype indicates external appearance of an individual with reference to a single character or a number of characters.

polyploidy indicates an increase in the number of chromosomes, most commonly in plants. It usually involves the replication of a complete set of chromosomes and the resultant plant has double the number of chromosomes (4n) than the parent plant (2n).

Polymer Chain Reaction (PCR) is a technique, which enables multiple copies to be made of specific sections of DNA molecules. It allows isolation and amplification (increase by volume) of such sections from large heterogeneous mixtures of DNA and has many diagnostic applications.

Random Amplified Polymorphic DNA (RAPD) involves the use of random primers giving random amplified polymorphic DNA. This technique is considered simpler and offers several advantages over more commonly used technique known as RFLP. RAPDs have actually been used for a study of polymorphism and chromosome mapping. They are used to make comparisons between the parental line and hybrid. RAPDs are used to detect recombinant inbreeds or back cross segregating populations (F2 populations) or doubled haploids derived from haploids can be used to detect linkage and recombination techniques. recombinant inbreeds or back cross segregating populations (F2 populations) or doubled haploids derived from haploids can be used to detect linkage and recombination techniques.

Restricted Fragment Length Polymorphism (RFLP) can be studied in a set of related species using a random or a specific probe. The similarities and differences can be used to make comparisons between the parental line and the hybrid.

Transgenics indicate plants in which a gene (or genes) from another organism has been introduced through genetic engineering and has become integrated in its genome.

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