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Research Papers

Forecasting technological needs and prioritizing factors in agriculture from a plant breeding and genetics domain perspective: A review

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ABSTRACT

Future technologies in the domain of Indian agriculture are expected to be different from what these are now. The subject of Technology Forecasting (TF) can be resorted to identify the needs to fill the gaps in the present technological trends. As a TF exercise, Brainstorming and Questionnaire approaches were employed to envision future technological needs for one of the subdomains of agriculture, i e Plant Breeding and Genetics (PB&G). Information obtained from experts was subjected to linear combination weighted scoring method for prioritizing key factors leading to future technological needs and were analyzed using multi-dimensional scaling for identifying key agricultural dimensions.

Key words: Brainstorming, Multidimensional scaling, Plant Breeding and Genetics, Questionnaire approach, Scoring method, Technology forecasting.

Indian agriculture in future is likely to be much different from what it is now. New upcoming technologies are expected to be different from what these are now. The future of Indian agriculture is bound to be affected by the emerging scenario of population explosion, shifts in dietary pattern, shrinking land availability and urbanisation. Besides urbanisation and concomitant land demand for non-agricultural uses, globalisation, privatisation and corporatisation of agricultural research may have a bearing on future agriculture. It is therefore imperative to articulate technological needs of different segments of agriculture and contemplate how developments in science can help address these needs. Rapid developments in scientific fields like nanotechnology, Information and Communication Technology (ICT), plant genomics, biotechnology and remote sensing undoubtedly are having profound applications in agricultural sciences and technologies. The present agricultural technology scenario is not without problems. Some problem areas ailing the technology front in our country's agricultural scenario are productivity stagnation, genetic erosion, low technology application, biotic and abiotic stresses, slow pace of diversification, poor water/energy management, intensive input use requirement and/or poor input-use efficiency, adverse effects of plant protection measures, plateau in adoption of HYV seeds, low public investment and low value addition. These issues call for forecasting technological needs to fill the gaps in the present technological trends using tools from the well established field of Technology Forecasting.

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Technology Forecasting (TF) in agriculture

Technology Forecasting (TF) can be defined as the qualitative and/or quantitative prediction at stated level of confidence of feasible and/or desirable characteristics of performance parameters of future technologies such as machines, procedures or techniques with a specific time frame and specified level of support such as policy, capital, human resource and infrastructural needs (by combining definitions/inputs from Jones and Twiss 1978, Rohatgi *et al*. 1979, Martino 1983). TF is required for better planning and future preparedness, enlarging the choice of opportunities and setting priorities, assessing impact and chances, focusing selectively on economic, technological and social areas for further research and it may also give strategic advantage and global competitiveness in research and development. The most commonly used TF techniques range from qualitative and/or quasi-quantitative intuitive methods (e.g. Delphi, brainstorming, scenario building and cross impact analysis) to statistical/ quantitative methods (e.g. trend extrapolation, substitution models and Analytical Hierarchy Process) to normative methods (e.g. morphological analysis and relevance trees) to monitoring methods (e.g. bibliometric/ scientometric/ patent analyses). A good account on these methods is available in many books, to cite a few, refer Saaty (1988), Georghiou *et al*. (2008) and Roper *et al*. (2011).

Several studies have been conducted for TF in the domain of agriculture in India. Rohatgi *et al*. (1979) have forecasted the technological needs and trends in different sectors such as education, energy resources, health services etc. including food and agriculture using Delphi, trend extrapolation, substitution techniques and relevance tree approaches. Rao and Kiresur (1994) utilized the most popular Delphi technique for forecasting Sorghum scenario by 2000 with respect to various parameters like area, production, yield, percentage area under HYVs and number of years for sorghum to become attractive for alternative uses. Rao *et al*. (2000) have conducted studies in TF on nine oilseed crops for entities such as area, yield, consumption, competing crops, research breakthroughs and processing improvement by using Delphi, Brainstorming, trend extrapolation and growth rates. Porter *et al*. (2004) have classified Brainstorming (which has been used in the present study) as one of the methods that compile information which require creativity, and is mainly a 'soft' approach (qualitative: judgment based, reflecting tacit knowledge) that can be used as both normative (beginning the process with a perceived future need) and exploratory (beginning with extrapolation of current technological capabilities) in the ambit of what they call 'technology futures analysis'. Rajalahti *et al*. (2006) illustrated the utility of scenario planning methodology in supporting strategic planning and long-term agricultural research and development investments, and thereby supporting organizational development by application of the methodology in the design of National Agricultural Innovation Project (NAIP) to ensure that India's agricultural technology system is well prepared for the future. Sastry *et al*. (2010) have assessed the implications of current trends in nanotechnology for the agri-food sector in India and prioritized research needs across the agricultural value chain also assessing the environmental and societal implications of this emerging technology. Garg *et al*. (2011) have applied scientometrics to envision emerging subdomains of research in PB&G for selected countries with special reference to India. Bhatia *et al*. (2012) have done TF in agriculture for commodity Rice and for the domains, viz. PB&G, Rainfed Agriculture and Fisheries and forecasted relevant technological trends and/ or needs by applying TF tools, viz. Analytical Hierarchy Process (AHP), Brainstorming, Scientometrics and Multi-Dimensional Scaling (MDS). In addition, they have done impact studies of frontier fields of science, viz. Information and Communication Technology (ICT) and Remote Sensing (RS) on the domain of agriculture. Moreover, application of cross-impact analysis technique in Indian Cotton with respect to production, export, import and supply phenomena and substitution models like Gompertz and Pearl in the context of Bt cotton over traditional cotton were also done. Jeeva *et al*. (2013) have forecasted technological needs and prioritized factors in post-harvest sector of Indian Fisheries using TF tools.

TF in Plant Breeding and Genetics (PB&G) domain

Plant Breeding and Genetics (PB&G) in agriculture has continued to evolve with a much broader scope and potential than in the past, more so with incorporation of new technologies and new knowledge from other fields of science. The PB&G programmes will reduce the time frame for evolving new technologies through emerging fields like biotechnology and nanotechnology. Nevertheless, the classical methods of PB&G will continue to flourish as the new sciences will be useful only when they are built upon such established and time tested technologies. Improved understanding of plant metabolic pathways can pay enormous dividends in terms of ultimate economic yield in crops. Agriculture has just scratched the genetic surface of plants. Research into plant genomics can help boost crop yields with much less exposure to biotic and abiotic stresses by harnessing the untapped genetic diversity in addition to reducing the environmental impact on agriculture. Concerted efforts are hence needed to perform TF and also technology assessment in PB&G domain.

Techniques used

In this study, two TF tools, viz. Brainstorming and Questionnaire approaches have been used for forecasting technological needs and prioritizing factors in agriculture from a PB&G domain perspective. The collected data were also analyzed using multi-dimensional scaling for identifying key dimensions in agriculture.

As a TF exercise, a one day Brainstorming session was organized at Division of Genetics, Indian Agricultural Research Institute (IARI), New Delhi by providing a platform to experts which included plant breeders and geneticists in scripting the future technological needs of agriculture pertaining to the PB&G domain for envisioning conversion of crop varieties/commodities into viable products for productivity improvement and effective utilization of modern tools for value addition and genetic enhancement. It is reasonable to expect experts to visualize and assess the future in their areas of specialization. Since most discoveries and innovations are deliberately engineered by sustained inputs of funds and manpower for R&D activities, it is felt that probing the minds of the experts involved in these developments can give an idea of likely future events. Moreover, the experts chosen are well-informed individuals who can use their insights and experience and are better equipped to predict the future than theoretical approaches or extrapolation of trends. In addition, in situations where evaluation of unconventional 'alternatives' is needed, Brainstorming is resorted to as a frank and free search technique, which when properly conducted, minimises the effects of influence of dominant individuals and bandwagon (Martino 1983, Roper *et al*. 2011). It is exploratory in nature as it starts from today's assured basis of knowledge and is oriented towards the future and thus extending the present into the future.

Also by questionnaire approach, information from experts was obtained for identification of specific technologies with greater utility in the years to come and for prioritizing factors affecting various aspects such as agricultural productivity, yield gap and new varietal development. The questionnaire has been designed in consultation with the experts, each question made self explanatory. Each question focussed on one event only. Some questions were open-ended while some were having a list of possible options on a five point linguistic scale ranging from 'extremely important' (EI) to 'least important' (LI), the intermediate scales being 'very important' (VI), 'moderately important' (MI) and 'somewhat important' (SI), with a few additional rows left blank for the experts to fill in factors left out, if any, in the list provided.

The collected data were subjected to Multi-Dimensional Scaling (MDS) technique to identify key dimensions of the factors of agriculture. MDS is an exploratory data analysis which helps the analyst to identify key unrecognized dimensions underlying respondents' evaluations of objects and facts (hereinafter collectively referred to as factors). MDS can also determine how the factors are related perceptually. The strength of such a perceptual mapping is its ability to infer dimensions without the need for defined attributes. In a simple analogy, it is like providing the dependent variable (similarity among factors) and figuring out what the independent variables (perceptual dimensions) must be. Hence the purpose of MDS is to transform respondents' judgments of preferences/ similarities of factors into distances represented in multidimensional space (two-dimensional, to be comprehensible, in this work) for effective comparison and to show the relative positioning of all factors. Assumptions of MDS such as comparability of factors, representativeness of respondents (experts) and stability of solutions have been adhered to in the given data. There were common objective or perceived characteristics the respondents used for evaluation of factors hence they were comparable. Even though all experts belonged to the same domain, they need not attach the same level of importance to a dimension, even if all of them perceive this dimension. Hence the experts constituted a representative sample. For stable multidimensional solutions, one should have more than four times as many factors as dimensions desired and in this work, ten important factors were taken for constructing two dimensional maps. Having developed the maps, labelling of the two dimensions have been determined by subjective evaluation as is usually done in practice. Detailed discussion regarding various MDS techniques can be found in many books, to cite a few, Hair *et al.* (1995) and Izenman (2008). Here, MDS has been done with similarity data. That is, the expert's opinions have been converted to values in trying to determine which factors are the most similar to each other and which are the most dissimilar. For this, instead of asking the expert to rank or rate the similarity of all pairs of factors ("all-pairs design"), these rankings have been derived from the scales given by employing a method discussed subsequently.

Methodological steps and results

Brainstorming: In the Brainstorming session conducted, the group of experts were first sensitized about the need and approach of TF and the objectives of the initiative undertaken. Thereafter, every expert was given opportunity

Table 1 Technology to evolve crop varieties for specific end uses

Crop	Type of end use	Technology	Timeline (in years) to action
Chickpea	Functional food	Extraction process	10
Soybean	Functional food	*Lecithin* extraction	2
	Quality of oil & cake	Breeding	10-12
	Low beany flavour	Breeding	5-10
	Food uses	Free from beany flavour, trypsin inhibitors	8-10
Pearl millet	Direct consumption by humans	Biofortification, hybrids, MAS	5
Maize	Sweet corn - Direct consumption by humans	Hybrid + Quality	2-3
	Baby corn - Direct consumption by humans	Hybrid + Quality	1-2
	Pop corn - Direct consumption by humans	Hybrid + Quality	3-4
	Sweet corn/QPM maize	Single cross hybrid	7-8
	Specialty corn	Hybrids	5-7
	Nutritional quality	Hybrids	7-10
	Biofortified	GM maize	8
Pigeonpea	Development of dwarf determinate hybrid suitable for combine harvesting	Hybrid	10
Mustard	Zero erucic/glucosinalate and long keeping quality	Varietal development	8-10
	Canola type varieties with 0% erucic acid and < 30 micronic glucosinale	Molecular tools	3-5
Wheat	Bread	Bread specific varieties	5
	Biscuit	Biscuit specific varieties	5
	Biofortified	Biofortification using MAS breeding	5-10
Rice	Biofortified	GM rice	2-8

to air his/ her views. The information obtained from Brainstorming were utilised to envision future technological needs in the PB&G domain. On synthesizing the opinions floated, the following future technological needs in PB&G domain emerged out:

- Exploitation of heterosis for developing hybrids based on Cytoplasmic Male Sterility (CMS) system
- Biotechnological interventions like gene pyramiding, Marker Assisted Selection (MAS), transgenics, structural and functional genomics, association mapping and QTL mapping
- Automated high throughput genotyping to achieve desired breeding workflows coupled with next generation decision support tools
- Development of crops with multi-purpose uses (analogous to multi-purpose trees), e.g. breeding for fodder as well
- Development of varieties tolerant to abiotic stresses, e.g. in wheat, varieties tolerant to heat throughout the growing season and not just for terminal heat stress, and, also for fog stress tolerance
- Development of product specific varieties, viz. increasing protein content in pulses, sedimentation value and grain hardness for wheat
- Proactive crop research for resistance to minor pests which may become major eventually
- Technology for circumventing the time lag in backcross method to arrive at homozygosity for wheat
- Doubled haploids in hybrid maize breeding for significantly reducing total duration of crop

The experts were sought to indicate the technological characteristics that can contribute in the coming years to achieve agricultural enhancement on a 5, 10 and 15 years horizon. While the enabling technologies reported were Conventional, Hybrid, MAS, Molecular Breeding and GMO, the characteristics for agricultural enhancement in the coming years are high yield potential, broad adaptation, good stability, resistance to biotic and abiotic stresses, acceptable industrial quality, early maturity (short duration), relatively photo-period and/ or thermo-insensitive traits and better responsiveness to inputs.

The information provided by the experts with regard to the technologies that can evolve crop varieties for specific end uses along with time frame is given in Table 1. Table 2

Table 2 Plant Breeding and Genetics technologies related for specific crops, countries and ecosystems

Technology	Crop/ Commodity	Countries where used (other than India)	Suitable ecosystem (mention also states) in India	Constraints/remarks/ modifications
Varietal development	All crops	Most of the countries	All India	Low SRR, varieties not reaching farmers
Heterosis Breeding	Most of crops Pollinated crops	China, USA	All India	Maintenance breeding
MAS	All crops	Australia, US, Israel	All India	Research not making headway
	Cereals, pulses and oilseeds	European countries, Oilseeds	Existing regions in these crops	Few trained scientists and well equipped laboratories in MAS techniques
Single cross hybrid seed production	Maize	USA, China	Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Uttar Pradesh, West Bengal	
GM	Maize	USA	*Kharif* and *rabi*	
	Rice, soybean		All ecologies	Regulation limitation, economies of seed cost and trade
Hybrids	Mustard	Canada, US, China	All mustard growing areas	CMS systems with lesser cytoplasmic penalty
	Soybean	China	Soybean growing belt	Non availability of CMS
	Rice, pigeonpea	USA, Mexico	All crop growing regions	Suitable production technologies, Mechanising seed production
Water saving technologies	All crops mainly *rabi* season	Israel	All India except NEH region where sufficient rainfall is there	Cheap technology with govt. subsidy
Transgenics	Mustard	Canada, US	All mustard growing areas	Shortening the duration and acclimatization, Biotic and abiotic stress resistances
Bio-fortification	Rice, maize, wheat	Iran, USA, Canada, S. America	All regions central/NE plains	Non availability of suitable hybrids and varieties

gives the emerging technologies as per the opinion given by experts during the Brainstorming session related to Genetics and Plant Breeding for specific crops, countries where they are/ can be used, suitable ecosystem along with constraints.

Questionnaire approach: Information from 33 completely filled-in questionnaires obtained from experts was analyzed for prioritizing factors leading to envisioning future technological needs in PB&G using linear combination scoring method. It is noted here that while around 80 experts participated in the Brainstorming session, only 33 of them returned the filled-in questionnaires. Hence the usually popular Delphi technique which requires several rounds of eliciting information through questionnaire was not resorted to and the present practical way of inviting experts at one place was done.

Scoring method: Each factor has been scored by experts individually on a comparable linguistic scale: "extremely important" (EI) through "least important" (LI), as was discussed in the preceding section and frequency was computed. Thereafter a weighted total score (weights being 1, 0.75, 0.50, 0.25, 0 for EI through LI respectively) is defined as a linear combination of these individual counts against factors. Table 3 pertains to prioritizing major factors that may enhance agricultural productivity. The score of the first factor "Quality seed availability' has been obtained by simply adding the weighted counts, i e $\{(25\times1.00) + (6\times0.75) + (2\times0.50) + (0\times0.25) + (0\times0)\} = 30.5$ and likewise for other factors. The factors have been furnished in the descending order of the scores obtained for prioritization.

In general, while mathematically elegant and computationally simple, the linear combination scoring approach has certain shortcomings. A change in linguistic

Table 3 Major factors for enhancing agricultural productivity: Scoring method

Factors	EI (1.00)	VI (0.75)	MI (0.50)	SI (0.25)	LI (0.00)	Score
Quality seed availability	25	6	2	0	0	30.5
Better varieties	22	8	3	0	0	29.5
Proper research infrastructure	16	11	4	2	0	26.8
Better agronomic practices	11	15	7	0	0	25.8
Adaptation to climatic change	12	12	7	2	0	25.0
Development of location specific technologies	9	13	8	3	0	23.5
GM crops	3	18	10	2	0	22.0
Technology to fill nutrient depletion-supply to soil gap	3	18	10	2	0	22.0
Nutrient management	5	15	10	3	0	22.0
Use of ICT	4	13	14	2	0	21.3
Post harvest management	3	15	11	4	0	20.8
Domestic/International trade	5	11	13	4	0	20.8
Farm mechanization	5	9	15	4	0	20.3

Table 4 Similarity matrix obtained from scoring of first ten major factors for developing new crop varieties for constructing MDS map in Fig 1

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1.00	.	.	.	.	.	.	.	.	.
F2	0.69	1.00	.	.	.	.	.	.	.	.
F3	0.77	0.90	1.00	.	.	.	.	.	.	.
F4	0.87	0.81	0.84	1.00	.	.	.	.	.	.
F5	0.89	0.79	0.83	0.96	1.00	.	.	.	.	.
F6	0.73	0.85	0.83	0.77	0.78	1.00	.	.	.	.
F7	0.69	0.84	0.81	0.77	0.76	0.83	1.00	.	.	.
F8	0.64	0.83	0.80	0.71	0.72	0.81	0.82	1.00	.	.
F9	0.68	0.85	0.82	0.76	0.77	0.85	0.80	0.93	1.00	.
F10	0.77	0.84	0.88	0.81	0.80	0.85	0.81	0.79	0.82	1.00

F1-High yield potential; F2-Broad adaptation; F3 - Good stability; F4 - Resistance to biotic stresses; F5 - Resistance to abiotic stresses; F6 - Acceptable industrial quality; F7 - Early maturity (short duration); F8 - Relatively photo-period insensitive conditions; F9 - Relatively thermo- insensitive conditions; F10 - Better responsiveness to inputs

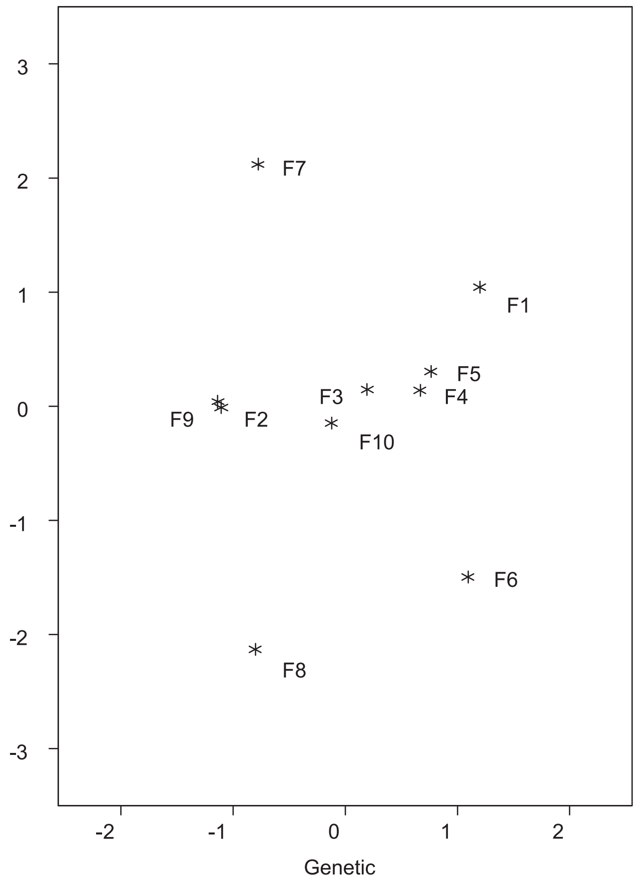

Fig 1 MDS map – Prioritizing factors for developing new crop varieties (for description of F1 through F10, refer footnote of Table 4)

scale (observed variable) from scale MI to scale EI, for instance, may be a highly significant change in 'importance of the factor' (latent variable), while a change from scale LI to scale MI may mean that the same is insignificant. Hence the multivariate approach, viz. MDS, which has sound statistical basis has been employed in order to handle such ordinal data and is discussed in the next section.

Multi-Dimensional Scaling (MDS)

MDS approach has been employed for determining the key dimensions emerging out from the factors responsible for prioritizing factors for developing new crop varieties. In order to study the experts' perceptions, the first ten important factors were considered for further analysis. The factors (which may differ in their levels of importance as viewed by the experts) were considered two at a time ("all-pairs design"). Thus the responses (on a five point score from EI to LI with scores 4 to 0 respectively) of experts for the possible ${}_{10}C^2$ = 45 pairs of factors were collated to form a table of 33 respondents by 45 factor pairs by deriving the similarity rating as (4 – |score1 – score2|) where score1 and score2 are the scores given by the same expert for the two different factors in the pair in question. The ratings thus obtained for each pair of factors was averaged over all respondents and the result divided by four to bring the similarity ratings in the interval (0, 1), by doing so the weights became 1, 0.75, 0.5, 0.25 and 0 as were given in the scoring method. These mean similarity values were then collected into the 45 corresponding pairwise positions of the lower triangle in a (10 × 10) matrix form given in Table 4, which can then be treated as a correlation-like matrix leading to MDS map of two dimensions for the top ten factors using principal coordinate approach (Kruskal and Wish 1978). The MDS map thus obtained is given in Fig 1. The factors seem to cluster together into two groups as genetic and environmental factors. Thus if one of the factors in a group is targeted for finding a solution, then other related factors in the group can mostly be taken care of by marginal additional efforts itself.

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