Climate change and seed quality: an alarming issue in crop husbandry

Aniruddha Maity and Pragati Pramanik

With every sunrise, the world is being challenged to produce adequate food for its ever-growing population. Besides some inherent bottlenecks in agriculture, a basket of emerging problems has narrowed down the smooth pursuance of enhanced productivity. Among these, the burning issue of climate change and its possible consequences on agricultural production has received importance late, but the problem is very real. If nothing is done to seize or adapt to climate change, the situation will be harsh for us in the coming years. Agricultural productivity is a function of better inputs, among which quality seed holds utmost importance. Use of only 20–25% quality seeds, i.e. purchased new every year of total quality seed demand by Indian farmers[1], makes it possible to produce about 260 mt foodgrains annually[2]. So we can think of the production potential of high-quality seeds. But, a steady temporal fluctuation in climatic variables has put seed quality under threat.

Climate change

The fundamentals of climate change have long been well understood because they encompass the basic physics that keeps the earth habitable. Heat-trapping greenhouse gases (GHGs) in the atmosphere (like water vapour and carbon dioxide) act like a blanket and keep the surface and lower atmosphere about 33°C warmer than it would be without GHGs. Since, the beginning of the Industrial Revolution, burning of fossil fuels and deforestation are increasing the concentration of CO_2 and other GHGs in the atmosphere, and thickening the GHG blanket[3]. The Inter-governmental Panel on Climate Change (IPCC) in its fourth assessment report has projected that temperature increase by the end of the 21st century is expected to be in the range 1.8–4.0°C (ref. 4). It is more likely that future tropical cyclones will become more intense with greater peak wind speed and heavier precipitation. Increase in the amount of precipitation is likely in high altitudes; while decrease is expected in the subtropical regions. Himalayan glaciers and snow covers are projected to contract. The projected sea-level rise by the end of the 21st century is likely to be 0.18–0.59 m. For the Indian region, the rise in the aforesaid factors is not an exception[4].

India is confronted with the real issue of sustaining rapid economic growth and food security amidst the increasing global threat of climate change. According to the UN Human Development Report[5], most of the poorest people live in rural India and almost completely rely on natural resources for their livelihood. In India, around 60% of the people are engaged in agriculture and allied sectors, while many others earn their living in coastal areas through tourism or fishing. Evidence has shown that climate change will affect the distribution and quality of Indian's natural resources like monsoon rainfall pattern[6], which will ultimately threaten the livelihood security of most poor and marginal sectors of the population who are closely tied to India's natural resource base, i.e. agriculture.

Climate change and seed quality

Seed is the basic and most vital input of agriculture. Without high quality seed, other inputs and better technologies remain worthless. At adverse field conditions, good quality seeds along with recommended doses of other inputs provide uniform and rapid germination, healthy crop establishment and subsequently good crop harvest. Seed quality comprises of several parameters, viz. physical and genetic purity of seeds, seed germination, viability, vigour, seed health and appearance like size, shape, weight and colour. Each of these parameters depends on climatic variables prevailing during the entire crop growth period and subsequent seed processing. If the climatic factors are adverse during crop growth period, the resultant poor quality seeds fetch lower market value and ultimately the economy of farmer comes in a verge of loss.

To obtain high-quality seeds, they have to pass through several well-defined sequential steps starting from timely sowing with required inputs in the field to good and uniform germination and growth, timely flowering; complete development of flower primordial, pollen and egg; pollination followed by double fertilization, embryo formation and endosperm development; seed maturation and timely harvest; and seed processing, transportation, storage and handling until next sowing. Every stage of this long chain is vulnerable to biotic and abiotic stresses[7–10]. Alarming reports are being generated and disseminated frequently by various scientific groups, and non-governmental organizations in every aspect of plant growth[11–13].

It has been revealed that climate warming may result in a shift in germination from spring to autumn[14]. Seed dormancy has been naturally modified by changing environment and promotes germination at an undesirable time. Study shows that temperature affects both phenology and pollen sterility in wheat crop. Less temperature during crop growth period enhances crop duration, while higher temperature hastens anthesis and maturity of crop. Low temperature during anthesis increases pollen sterility, thereby decreasing germination of pollen grains rendering good seed set[15].

In many tropical and subtropical regions, potential seed yields are expected to decrease for most projected increase in temperature. Various studies have reported that direct impacts of climate changes would be small on 'kharif' crops, but overall 'kharif' agriculture will become vulnerable due to increased incidence of weather extremes like delayed or early onset of monsoon, intensity and frequency of droughts and floods, diurnal asymmetry in temperature, change in humidity and pest incidence and virulence[16]. Production of 'rabi' crop is relatively more risky due to shortened crop growth periods and increased terminal heat and water stress[17].

Among the climatic variables, high temperature and moisture stress not only affect seed yield but also seed quality and performance of the resultant crops[18]. Climate change poses a threat for the existing crop species by altering phenology and crop growth periods, promoting prevalence of new seed-borne diseases, affecting the behaviour of pollinators[19], shifting crop suitability areas, reducing seed yields, storability and longevity of seeds. Weather stress during seed production lowers the duration of stigma receptivity, which ultimately leads to reduction of seed set and size. Decrease in seed size may also cause problems during seed processing. However, every adverse effect reflects on the whole seed quality characteristics, which is directly related to lower market value and poor farm economy.

Even if acceptable quantity of seed is produced, possible change in chemical composition of seed by adverse weather condition during crop growth lowers its quality. Polyphenolics and fatty acid composition of seed oil have significant effect on viability, germination, dormancy, seed-coat permeability and storability. Accumulation of different lipids and soluble sugars changes the resistance to peroxidative damage caused to the seeds during storage. Oleic to linoleic acid ratio or unsaturated to saturated fatty acid ratio plays the main role. Linolenic acid has been reported to be associated with higher rate of germination. It is particularly required for the synthesis of glycolipids, which are the major components of cell membranes. But the fatty acid profile and ratio in crop plants are vulnerable to environmental stress. Oil-producing plants growing in warmer climates are higher in saturates and mono unsaturates and lower in poly unsaturates, than the plants growing in cooler climates[20].

Climate change is reported to have adverse effects on the biochemical composition of seeds with far-reaching consequences on seed quality. Recent proteomics work has provided invaluable insights into the molecular processes in germinating seeds of many crops under different treatments, including metal ions (e.g. copper and cadmium), heat stress, drought, low temperature, hormones and chemicals (gibberellic acid, abscisic acid, salicylic acid, and α-amanitin), as well as to artificial disease infection by several pathogens. Till now over 600 environmental factor-responsive proteins have been identified with various expression patterns in germinating seeds[21]. Activity of some important enzymes like callase (β-1,3 D-glucanase), sucrose and starch synthatase, hydrogenase, α- and β-amylase, invertase, protease, lipase, mannase, peroxidase and plant growth regulators (PGRs) like abscisic acid, gibberellins, ethylene, brassinosteroids, auxin and cytokinins is indispensible for development and maturation of high-quality seeds. These enzymes and PGRs regulate the interconnected molecular processes that control seed development, maturity, dormancy release and germination. Amino acids like proline which confers stress tolerance in plants as well as seeds and the enzymes of its synthesis pathway like pyrroline-5-carboxylate synthetase, ornithine aminotransferase, and proline dehydrogenase are also modified by environmental stress[22]. Various researchers highlight diverse regulatory and metabolic mechanisms upon seed germination, including induction of environmental factor-responsive signalling pathways, seed storage reserve mobilization and utilization, enhancement of DNA repair and modification, regulation of gene expression and protein synthesis, modulation of cell structure, and cell defence. Quality messenger RNAs stored during embryo maturation in the mother plant, proteostasis and DNA integrity, sulphur amino acid metabolism pathway regulating cell metabolism and its close relationships with hormone signalling pathways play a major role in control of germination process[23]. Temperature irregularity at any crop growth stage may hamper the normal functioning of these essential components resulting in physiological abnormalities which ultimately worsen seed quality.

Mitigation strategies

To survive in this changing environment, C_3/C_4 balance is changing with time in several ecosystems worldwide[24], like the way once C_4 evolved from C_3 by means of genetic, anatomical and physiological changes[25] for better utilization of enhanced temperature and CO_2 (ref. 26). Using modern research strategies like C_4 engineering, a C_3 plant may be converted into C_4 plant[27] to utilize increased level of atmospheric CO_2. Identifying and transforming the genes necessary to install C_4 photosynthesis is the key step for C_4 engineering. The functional C_4 cycle also requires down-regulation of part of the Calvin–Benson cycle in mesophyll cells. Another aspect of C_4 engineering is addition of the transporters required to support fluxes of metabolites between subcellular compartments of the C_4 cycle.

Beside these research advances, there is a need to shift crop-growing areas towards suitable growing locations and accordingly, we may shift seed-production areas. Studies have shown the steady effect of changing temperature regime on productivity of wheat, mustard, chickpea and barley, and have recommended shifting the sowing time as an adaptation strategy[28]. Wheat yield reduced with maximum decrease in Haryana (4.29 q/ha) followed by Rajasthan (2.49 q/ha) per degree rise in seasonal temperature. There are some temporal changes in seed-production areas of India like in the south, erratic rainfall patterns are causing the coffee crops to fruit twice and sometimes thrice in a year resulting in inferior beans. Similarly, in the Kuttanad region of Kerala (the state's rice bowl), heavy rains delay normal October sowing, pushing it up to December[29]. Because of late sowing, crop growth period coincides with the occurrence of insect-pests and diseases. The additional cost of pest control increases the price of seeds. So, a combination of shifting the location and sowing time is needed to avoid these problems.

Improvement in microclimate around seeds may eliminate or curtail the risk of damage due to possible climatic calamities in field conditions. Seed coating with thermostable polymer[30] augmented with pesticides and growth supplements (e.g. PGRs, etc.) is a promising option in high-value crops to cope with harsh field conditions. In this technique, seeds are allowed to germinate in the field only within a suitable range of temperatures instead of sudden unfavourable conditions. Retaining high amount of moisture in the soil for easy germination of seeds is an alternative to cope with changing soil–moisture pattern. To withstand low soil–moisture condition in the field, seed hardening, i.e. alternate wetting and drying of seeds under artificial condition is to be practised for sensitive crops. Amending soil with superabsorbent hydrogels that can retain soil moisture several times higher even in dry soil, thus improving seed germination and seedling emergence, can also be an alternative technique[31,32].

In the changing climate era, to combat major regional or global catastrophe, the Svalbard Global Seed Vault has been established on the Norwegian island of Spitsbergen in 2006. An Indian seed bank in the Himalayas in Chang La has also been planned.

Beside the above strategies, evaluation, screening, conservation and seed multiplication of local landraces for their inherent resilience to climate change can supplement the endeavour[33]. Novel breeding approaches for high germinable varieties and hybrids displaying photo- and thermo-insensitive nature, with high concentration of advantageous chemical components (sugars, protein, lipids and others) and enzymes will further widen the way to combat against climate change. But human efforts above cannot help overcome the natural consequences of the ever-increasing undesirable activities of man on this Earth. Until and unless the causes of climate change are minimized to the maximum possible limit, the sufferings are going to increase manifold.

1. http://seednet.gov.in/. http://seednet.gov.in/Material/SRR-13.pdf
2. Fourth advance estimates of production of oilseeds and other commercial crops for 2012–13; http://agricoop.nic.in/ (accessed on 22 July 2013).
3. AMS, Climate change – an information statement of the American Meteorological Society (adopted by AMS Council, 20 August 2012), 2012.
4. IPCC, Climate Change 2007. The Physical Science Basis. Summary for Policymakers, Intergovernmental Panel on Climate Change, 2007.
5. UNDP, Fighting climate change: human solidarity in a divided world. United Nations Human Development Report, 2007–08.
6. Lal, M. *et al.*, *Curr. Sci.*, 2001, **9**, 1196–1207.
7. Maity, A., Chakrabarty, S. K. and Yadav, J. B., *Indian J. Agric. Sci.*, 2012, **82**(9), 753–758.
8. Ellis, R. H., *Seed Sci. Res.*, 2011, **21**, 95–101.
9. Khanduri, V. P., *Am.-Eur. J. Agric. Environ. Sci.*, 2011, **11**(6), 834–839.
10. Dadlani, M., Chakrabarty, S. K. and Basu, S., *Indian J. Genet. Plant Breed.*, 2009, **69**(4), 325–330.
11. Kumar, P. R., Yadav, S. K., Sharma, S. R., Lal, S. K. and Jha, D. N., *World J. Agric. Sci.*, 2009, **5**(1), 18–26.
12. http://www.slideshare.net/daltond/plant-phenological-responses-to-climate-change-presentation; http://www.ucl.ac.uk/Geol-Sci/micropal/spore.html
13. http://www.usanpn.org/
14. www.phys.org/news/2013-03-germination-alpines-climate-shift-seed.html
15. Chakrabarti, B., Singh, S. D., Nagarajan, S. and Aggarwal, P. K., *Aust. J. Crop Sci.*, 2011, **5**, 1039–1043.
16. Krishnan, P., Ramakrishnan, B., Rao, K. S. and Dash, R. N., In *Climate Change and Crops* (ed. Singh, S. N.), Environmental Science and Engineering, Springer-Verlag, Berlin, Heidelberg, 2009, pp. 39–61.
17. Mall, R. K., Singh, R., Gupta, A., Srinivasan, G. and Rathore, L. S., *Climatic Change*, 2006, **78**, 445–478.
18. Alqudah, A. M., Samarah, N. H. and Mullen, R. E., In *Alternative Farming Systems, Biotechnology, Drought Stress and Ecological Fertilisation, Sustainable Agriculture Reviews 6* (ed. Lichtfouse, E.), 2011, pp. 193–213.
19. Hegland, S. J., Nielsen, A., Lázaro, A., Bjerknes, A. and Totland, O., *Ecol. Lett.*, 2009, **12**, 184–195.
20. McVetty, P. B. E., In Green Crop Network Workshop, 16 and 17 July 2009.
21. Tan, L., Chen, S., Wang, T. and Dai, S., *Proteomics*, 2013, **13**(12–13), 1850–1870.
22. Song, S. Q., Lei, Y. B. and Tian, X. R., *Russ. J. Plant Physiol.*, 2005, **52**, 793–800.
23. Rajjou, L., Duval, M., Gallardo, K., Catusse, J., Bally, J., Job, C. and Job, D., *Annu. Rev. Plant Biol.*, 2012, **63**, 507.
24. Lattanzi, F. A., In Proceedings of 23rd General Meeting of European Grassland Federation (eds Schnyder, H. *et al.*), Kiel, Germany, 29 August–2 September 2010, Grassland in a Changing World, 2010, vol. 15, p. 3.
25. Leegood, R. C., *J. Plant Physiol.*, 2013, **170**, 378–388.
26. Kalra, N. *et al.*, *Curr. Sci.*, 2008, **94**, 82–88.
27. http://articles.timesofindia.indiatimes.com/2011-01-30/special-report/28.
28. Kalra, N. *et al.*, *Curr. Sci.*, 2008, **94**, 82–88.
29. http://www.upi.com/Business_News/Energy-Resources/2011/02/01/Indias-crops-affected-by-erratic-climate/UPI-58761296595012/
30. http://www.ccimarketing.com/CCINews/Landec/landec2.asp
31. http://pusahydrogel.com/
32. http://www.horticulturalalliance.com/index.php?route=product/category&path=66_136
33. Chakrabarty, S. K., Joshi, M. A., Singh, Y., Maity, A., Vashisht, V. and Dadlani, M., *Indian J. Genet. Plant Breed.*, 2012, **72**(2), 136–142.

Aniruddha Maity is in the Seed Technology Division, Indian Grassland and Fodder Research Institute, Jhansi 284 003, India; Pragati Pramanik is in the Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi 110 012, India.*
**e-mail: maityam@gmail.com*