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Breeding for organic agriculture

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Abstract
Organic agriculture is the type of agriculture system that converges to the state that relies on ecosystem-based management rather than external agriculture inputs. It is system that considers the impact of all inputs that are used in the farming not only on the plant as food but also as a one of the living entity and more importantly it considers environment, ecosystem and biodiversity effects on priority bases than other and this system is based on sustainability. Synthetic chemicals used in conventional agriculture have many undesirable effects on environment as well as the human health so to reduce that residual effect of chemicals, only use of organic inputs in organic agriculture. Thus there is requirement for development of cultivars that will be abiding all these rules and also the having on par yield and other agronomically superior traits in them so that would be help organic farmers for better yield and even encourage the conventional farmers to go for organic farming as these will yield on par with conventional cultivars, adding to this there is acute need even for the development of new breeding techniques for organic cultivar development that would pace the development of cultivars for organic condition, so considering both food as well as nutritional security development of cultivars for organic condition should be done because without either of one above, sustainability of not only organic farming even whole agriculture will be under question that is this review paper brief about possibilities of achieving organic farming with current and advanced plant breeding.

Keywords: Conventional agriculture, ecosystem, biodiversity, environment, organic agriculture, organic farming, organic plant breeding techniques, organic plant breeding, residual effect, sustainability, synthetic chemicals

Introduction
Organic farming is an age-old agricultural system used and practiced to raise animals and grow plants. Currently consumption of expensive organic food is increasing due to rising awareness of toxic chemicals used in modern agriculture and long-term hazardous effects on human health and environment. Anna Wigmore one of the finest holistic health practitioner, naturopath and raw food advocate quotes "Food We Eat Can Either Be Safest Form of Medicine or Slowest Form of Poision" thus indicating the importance of healthy food which is grown as naturally as possible. Food we eat contains many nutrients, minerals and many other healthy components in it, along with that depending on the way the food is derived i.e., food production process or growing conditions, the plants or crops tend to accumulate many other things in the due course of growing period which may or may not be essential to plants but harmful to human consumption and animal consumption besides having environmental side effects.

The present scenario of our modern agriculture is that it is mostly dependent on synthetic chemicals and fertilizers. Majority of the crops are cultivated by application of these chemicals most of them which have hazardous effect on the environment and human health. This can be tackled by opting for the farming system without using unnecessary synthetic element in cultivation of plants by following natural way of crop cultivation as principled in organic farming.

Organic farming uses agricultural production systems reliant on biological pest control, green manure or compost and crop rotation to produce crops, poultry and livestock. Organic farming forbids the use of chemical like fertilizers, pesticides, antibiotics and growth hormones in crops, meat and other food production. The primary aspects of organic farming are, to use green manure or compost, animal manure, crop rotation to improve soil fertility, restoration of soils biological activity, interrupting pest's habitation and diseases. (Verhoog *et al.*, 2003) [14]

Organic farming is an agricultural system that aims to mimic processes in natural ecosystems for the provision of nutrients and pest control, instead of relying on inorganic chemical inputs. Organic agriculture is a broader term and organic farming is a part of organic agriculture and basically organic agriculture is based on the underlying principles of health, fairness, ecology and care. It is based on the concept of working 'with nature'. Very well-known characteristic of organic farming is that it produces food without the use of any synthetic fertilizer or pesticide, and neither with the use of genetically modified organisms (GMO). (IFOAM, 2015) [4]

Organic farming is a strategy used in agricultural sector to avoid the overuse of chemical fertiliser, pesticide, insecticides and herbicide so as to reduce public health issues and environmental risks. Use of chemical fertilizer destroys natural habitat of wasps, beetles, bugs, flies, birds or frogs. Use of organic manures instead of chemical/conventional fertilizers and adaptation to crop rotation practice preserve soil health and provide the necessary nutrients for crop growth and development. Many agricultural products like meat, dairy products and eggs are produced in a natural and organic way of feeding and maintaining animals. Every agricultural system has pros and cons including organic farming. (Lammerts *et al*., 2002) [8]

Organic agriculture as defined by IFOAM (International Federation of Organic Agriculture Movements):

"Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved".

Green revolution technologies like; High yielding varieties, chemical fertilizers, synthetic pesticides, mechanization, irrigation lead to the improvement in High production along with overcoming food crisis, self-sufficiency in food grain, and maintaining buffer stock of food grain of our own. But at the same time, it made our agriculture a non-sustainable venture because of stagnation or fall in productivity, decline in soil fertility, salinity problem, lowering of water table, environmental pollution. Modern agriculture often makes wasteful use of water, destroying soils and increasing threats to biodiversity and ecosystems. As each year, salinization leads to about 1 million hectares of agricultural land going out of production due to unscientific and excess use of water resources. Many parts of the world are experiencing a decline in yields despite the increased use of chemical inputs. Pesticides are a major health hazard for farmers and farm workers, particularly in developing countries, as well as to wildlife. Genetically modified crops, rather than reduce pesticide inputs, are causing them to skyrocket in amount and toxicity.

On the other side, Organic agriculture supports and enhances ecologically sound systems of food production and it also helps in combating:

Desertification through decreasing erosion, improving water uptake and retention, providing diversified, healthy and nutritious food for farming families and communities with stabilized yields, particularly in marginal lands; Improved Water Holding Capacity (WHC); Increased soil organic matter; Maintaining and improving environmental services

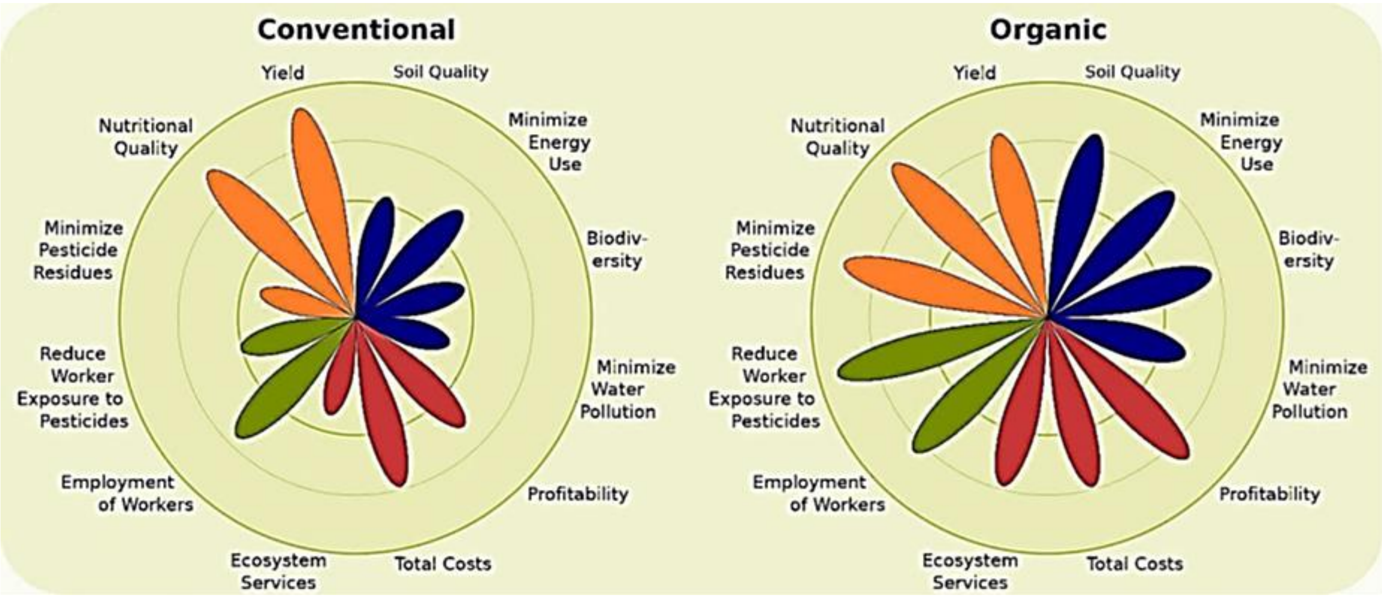

Fig 1: Comparison of conventional and organic farming systems (Reganold *et al*., 2016) [10]

This picture depicts the balancing nature of organic system and imbalance created by conventional system. Here, conventional farming concentrates only on yield, quality, costs and employment and neglects all other aspects but organic farming concentrates on all most all aspects like yield, nutritional quality, soil quality, biodiversity, minimising pollution, reduction of residues, costs and employment. With all these aspects it balances our nature and future and even more profitable when adopted over a long period of time (Reganold *et al.,* 2016) [10].

Research has shown that OF can contribute to reduce soil carbon losses, mainly due to the application of organic fertilizers such as compost or stacked manure which should derive from the integration of crop production and livestock. Research comparing the dynamics of soil organic carbon between Organic Farming and Conventional Farming shows that the former can significantly increase the concentration, stock and sequestration rates of organic carbon in the soil (Gattinger *et al.,* 2012) [2].

Global and Indian share in organic farming

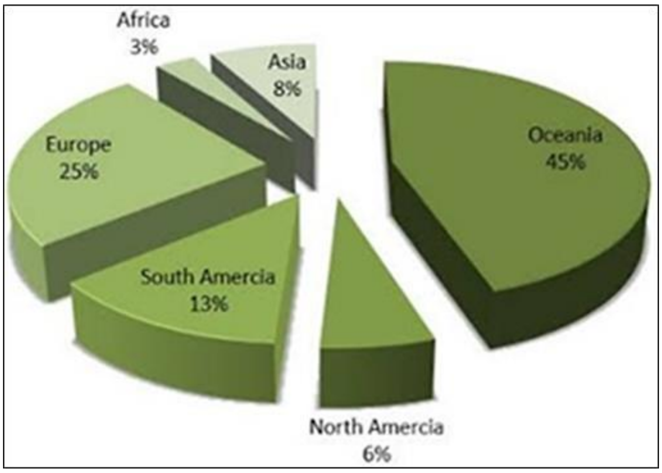

Fig 2: Global share of organic farming

Globally organic area is covered mostly in Ocenia (Australia) with 45%, Europe (25%), South America (13%), Asia (8%), North America (6%) and Africa (3%). A total of 72.3 million hectares were organic at the end of 2019, representing a growth of 1.1 million hectares (1.6%) compared to 2018. Australia has the largest organic agricultural area (35.7 million hectares). In financial year 2020, over two percent of the net area in India was under organic farming, a major increase from last year (4.3 million Ha). In general, the area under organic farming has increased continuously, signifying more demand for organic food. The registred organic producers are 3.1 million with the highest number of producers in India (13,66,000) followed by Uganda (2,10,000) and Ethiopia (2,04,000).

Organic plant breeding

Plant Breeding impacts people and societies because it determines the course of our agricultural future, without appropriate varieties that are relevant for their particular farming systems, farmers cannot be successful and consumers suffer from either price increases or lack of food availability or both. So, plant breeding plays a major role in success of any farming system by breeding cultivars specific for particular farming system.

Organic plant breeding not only cares for limitations of natural crossing barrier but also enhances genetic diversity. Hence, IFOAM defined organic breeding with following principles. (IFOAM., 2017) [5].

- Organic plant breeding is sustainable, enhances genetic diversity and works according to the ecosystem
- Organic breeding is always creative, cooperative and open for science, intuition, and new findings.
- Organic plant breeding is a holistic approach that will concentrate not only on the final product of crop but also the complete procedure of the plant growth and development.
- Organic plant breeding is based on viable plants.

Organic varieties are obtained by an organic plant breeding program.

Requirements for organic plant breeding

- Plant breeders shall select their varieties under organic conditions that comply with the requirements of this standard. All multiplication practices except meristem culture all shall be under certified organic management
- Organic plant breeders should not use genetic engineering as use any genetically modified organisms is completely prohibited in organic agriculture, so use of genetic engineering in development cultivars in organic plant breeding is prohibited.
- Organic plant breeders shall disclose the applied breeding techniques. This will allow farmers to select the varieties based on the techniques and tools used in plant breeding programme.
- Organic farming looks at the breeding of new varieties in a holistic way. In holistic view the organic sector embraces the partner attitude towards nature which includes that not only humans and animals but all living entities, including plants, are considered ethically relevant out of respect for the integrity of life, referring not only to an extrinsic value (usefulness for mankind) but also to a perceived intrinsic value of living organisms (worth as a living entity as such based-on respect for their "otherness", dignity, wholeness and autonomy).
- The genome is respected as an impartible entity, so technical interventions into genome like genome editing are completely prohibited.
- The cell is respected as an impartible entity. Technical interventions like cell fusion, protoplast fusion etc are not allowed.
- The natural reproductive ability of a plant variety is respected. NO terminator technologies where further germination of seeds are restricted which will not have provision for farmers to save seeds in next season.
- Organic plant breeders may obtain plant variety protection, but organic varieties shall not be patented.
- Annuals at least for one generation under organic conditions, biannual plants and perennials have to be grown for at least two generations under organic conditions and for land conversion land should be under conversion into organic for two years.

Basic principles endorsed by IFOAM

The principle of health

The Principle of Health in organic agriculture is about serving the wholeness and integrity of living systems (including society) at various levels (immunity, resilience, regeneration, sustainability). The implication for breeding is that useful organisms need to be robust, dynamic, and resilient, able to benefit from interactions with the surrounding biome in which they grow, and to reproduce themselves and to produce high quality, nutritious food.

The principle of ecology

The Principle of Ecology in organic agriculture is about contributing to optimally functioning of a diversity of site-specific ecological production systems. This means that breeding needs to develop multilevel approaches, such as decentralized breeding for regional adaptability and enhancing genetic diversity and adapt organism to the environment instead of the environment to the organism.

The principle of fairness

The Principle of Fairness in organic agriculture is about serving equity, respect, justice and stewardship of the shared world. It implies the need to develop new socio-economic structures in breeding to ensure free access to genetic resources, no patents of life, breeding approaches that involve all value chain actors, equal benefit sharing among chain partners and maintenance and accessibility of diversity for future generations.

The principle of care

The Principle of Care in organic agriculture is about enhancing efficiency and productivity in a precautionary and responsible manner. It means that organic breeding refrains from breeding techniques that interfere directly at DNA level, including cell fusion and mutation breeding, and stimulates transparent and participatory/collaborative processes.

Present plant breeding scenario

Over the past several decades, plant breeding has become increasingly formalized and centralized. Which was once done in farmers field now have become centralized and only done in big MNC, SAU, and Research institutes, and most breeders working for large seed companies, as well as most public breeders, focus their attention primarily on the largest markets for seed and for a particular farming system.

The three largest companies Monsanto, DuPont and Syngenta control 53% of the global proprietary seed market. Where they only concentrate on large seed market in few farming systems that are mostly for high input (chemical inputs) conditions, thus making no cultivars specific for organic conditions.

This large focus on certain farming system and crops also needs to be towards organic and low input conditions that will give organic farmers with better cultivars specific suited for organic conditions. That will enhance the organic production.

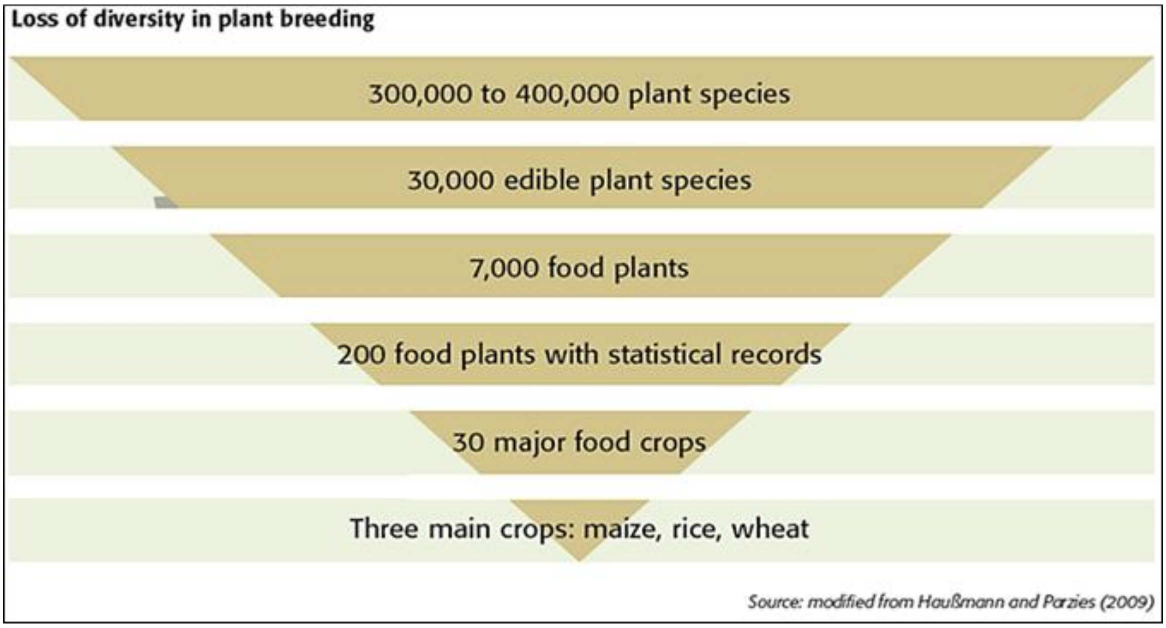

Fig 3: Loss of diversity in plant breeding

The more and more evolved and intense cropping system puts pressure on natural resources and reduces the biological genetic diversity. The concentrated breeding efforts only with three major food crops (Mize, rice and wheat) globally has neglected other 7000 food plants. This will not only reduce the crop diversity even for the framing system, so that no cultivars specific for other system of farming are actually breed, making no choice for farmers to go with either farming system of their interest with unsuited cultivars in it or choosing the farming system according to the cultivar available to them, former one will obviously reduce the productivity because as the cultivar is not suited to that system or condition and later one is the reason for no diversity and no choice for other farming systems.

As per Sharma *et al.*, (2018) [20] the breeding objectives for organic condition involve around sustainable use of natural resource including genetic diversity within the crop species:

- **Optimal adaptation to local climate and nutrient dynamics:** As we provide the crop only with organic supplements crop should be breed in such a way that it should be well adapted to local nutrient and climate conditions, as there is always interaction between genotype with existing environment each genotype interacts differently in different environment so there is need for development of cultivars that are optimally adapted to micro environment of the crop grown where it is very important in case of organic farming.
- **Nutrient efficiency:** In organic farming we are using manures and organic fertilizers which are actually less concentrated so the crops should be breed such that they are nutrient efficient and highly responsive to the natural nutrients supplied to them, as we will supply nutrients through manures and other organic supplements which are very bulky in nature, to meet the crop requirements huge amount is required thus there is absolute need for development of cultivars for organic conditions which are highly nutrient efficient and responsive.
- **Tolerance to mechanical weed control:** The only way to control weed is through hand weeding in organic farming so breeding crops for early vigour, more canopy area of plant, high competency for nutrient with other crops etc. are desirable so that it out competes the weed growth and cope with the mechanical hand weeding and yields on par, so if the cultivar tolerates or cope with the mechanical weed control then yield will not be affected.
- **Durable resistance and tolerance against pests and diseases:** Breeding for horizontal resistance should be main objective (breeding for broad and durable resistance). As growing resistance genotypes is the most

effective and appropriate method of controlling the disease and pest. Because use of synthetic chemicals is completely prohibited in organic agriculture.
- Improving legume symbiotic effectiveness, so that the plants will be more vigorous and healthier. If it is very effective then plants will be vigorous and they will effectively use natural resource that reduces the fertilizer again which needs to be applied organically i.e., organic fertilizers which are bulky in nature so legume symbiotic efficient ones should be objective.
- Rhizosphere competence for disease suppression, more competitiveness of plants for nutrients and other supplements in rhizosphere compared to pathogens.
- **Yield stability:** Yield should be stable and on par with conventional varieties, as the first thing that will be considered by farmer will be yield comparison with the conventional ones. Yield is main trait that is considered so that needs stable yield as well as on par with conventional ones.
- Storability, shelf life of the cultivars should be longer.
- Human nutritional, sensorial quality and some secondary metabolites may be valuable in resistance to human diseases.
- Organic plant breeding aims should be defined on a crop-by-crop bases involving farmers, breeders, traders and consumers, integrated approach of plant breeding programme.
- Focus should be more towards domesticating the other plant species for food, fuel and shelter

According to FiBL., 2015 [9] selected crop improvement techniques suited for organic farming objectives can be selected for development of new varieties for organic condition:

1. Inter-specific hybrids

Critical issues from the perspective of organic farming

Crossing barriers between species are not clearly defined boundaries, but become stronger with increasing differentiation of the species, i.e., the chance of successful fertilization and seed formation decreases correspondingly. Technical interventions, such as *in vitro* fertilization of the egg cell and pollen or *in vitro* cultivation of the embryo shortly after fertilization is not allowed it should be completely natural without any aid for fertilization and these naturally obtained ones can be further used in plant breeding programme.

2. Embryo rescue in plants

Critical issues from the perspective of organic farming

In order to improve frequency of progeny of wide crosses, the embryo is transferred to artificial media in rare cases. So, in organic plant breeding the embryo must be derived from natural fusion of egg and pollen cell, so embryo obtained should be natural and completely free from any artificial hormones, and for that rare embryo, Embryo rescue can be followed to obtain elite combination or to further use of that in crop improvement for organic conditions.

3. Bridge crossing

Critical issues from the perspective of organic farming: None

When two species are not cross compatible, we can go with bridge crossing to cross compatible species so that be useful traits can be transferred.

4. Shuttle breeding

Critical issues from the perspective of organic farming: None

We can have cultivars that are suitable for two different locations simultaneously thus making breeding effective and speeding up the process of breeding, this will reduce the time and also cultivar development at two different locations.

5. Proteomics/Metabolomics

Critical issues from the perspective of organic farming: None unless chemical or genetically engineered plants are not involved in cultivar development.

Mere selection of the best cultivars based on the results of the genomics, transcriptomics, proteomics, metabolomics and phenomics will benefit for early and efficient selection of cultivars, so no issues unless we are just using it for identification of best one in organic conditions.

6. Clonal varieties

Critical issues from the perspective of organic farming: None

Application of synthetic rooting hormones for increasing the rooting, effective roots and use of pesticides are completely prohibited in organic plant breeding, without use of synthetic chemicals for clonal production or rooting.

7. Apomixis

Critical issues from the perspective of organic farming: None

Apomixis can be used in plant breeding programme for improvement in organic conditions but the apomixis should be natural and it can't be induced through any chemicals, natural apomixis can be exploited for development of cultivars in organic condition.

8. Synthetic varieties

Critical issues from the perspective of organic farming: None

While open pollination care should be taken to prevent out crossing with conventional grown varieties and GMO, so by maintaining the proper isolation with GMO's and conventional varieties we can even use Synthetic varieties in organic conditions.

9. Polyploidisation

Critical issues from the perspective of organic farming: None

If natural colchicine and if applied on intact seed or plants then NO issues. Tetraploid plants occur in nature but can also be induced by anti-mitotic drugs. Polyploid plant often show higher vigour. The antimitotic drug can be obtained from plants e. g. colchicine or oryzalin must be used if one wants to develop cultivars for organic conditions. Application must be on the whole seed or on seedlings. No *in vitro* step is allowed.

10. Marker-assisted selection

Critical issues from the perspective of organic farming: None

Plants are evaluated merely based on their DNA Sequence no interventions into cell or genome so markers can be used in organic breeding programme, as this will drastically reduce the time for development of cultivars, in organic condition as we will not apply any of the chemicals to control disease and pest for crop, the cultivars will become susceptible easily so there is need for development of cultivars for organic conditions more frequently as cultivating the resistant cultivars is the best and most efficient way for organic agriculture so reduced time for development cultivar especially in organic condition is very significant, so Marker assisted selection plays a major role. (Lammerts *et al.,* 2010) [8]

We can go with early generation marker-assisted selection and marker-assisted Backcrossing.

11. Marker assisted gene pyramiding (MAGP)

Pyramiding is a breeding strategy for taking genes from different parents and stacking them in one progeny. As genetic resistance-based crop protection is the most effective strategy for disease management, So MAGP is one of the effective methods for accumulating multiple resistance genes in a single genotype, it is one of the most important applications of molecular markers to organic plant breeding as it reduces time, more efficiency and multiple resistant genes in single genotype.

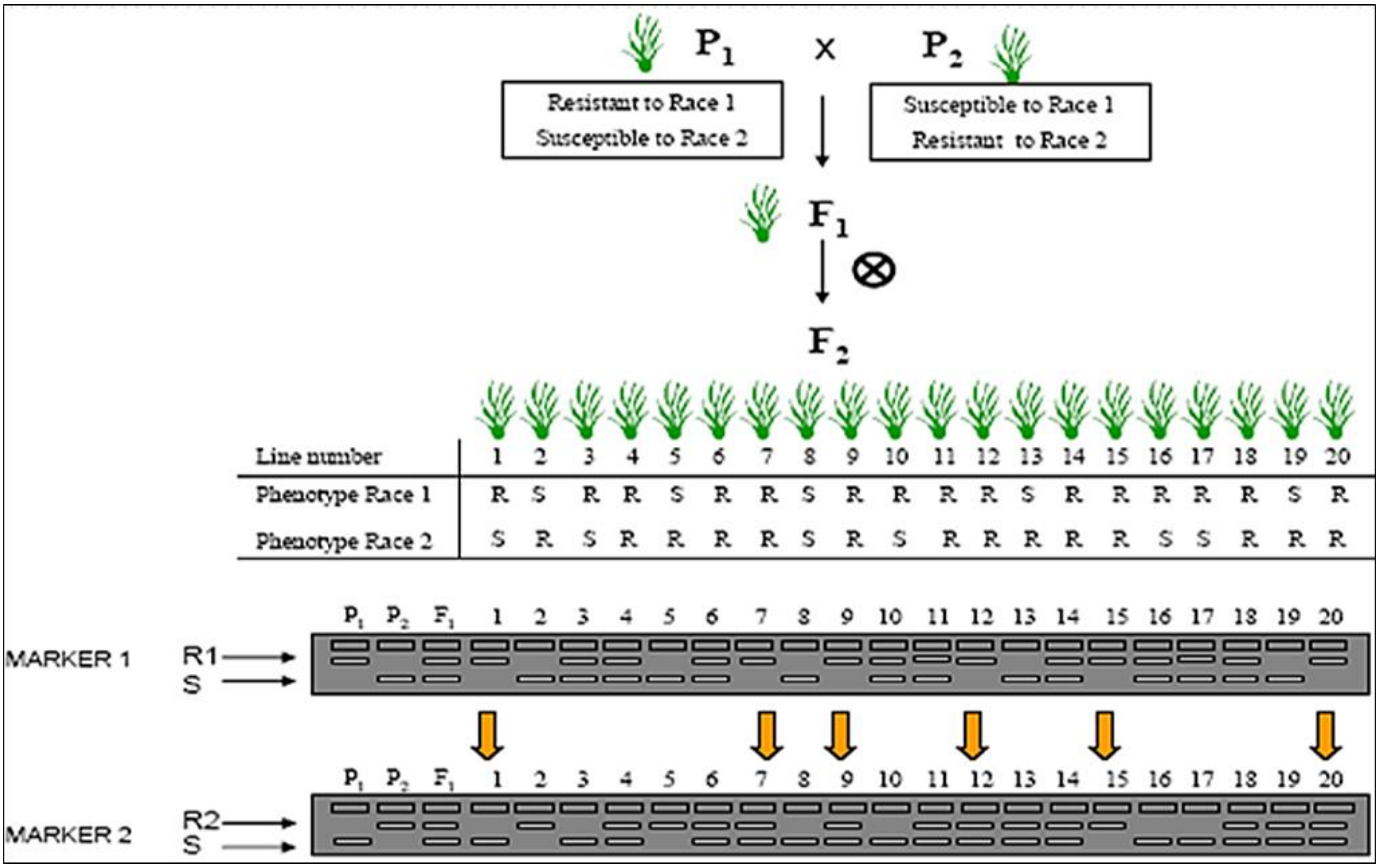

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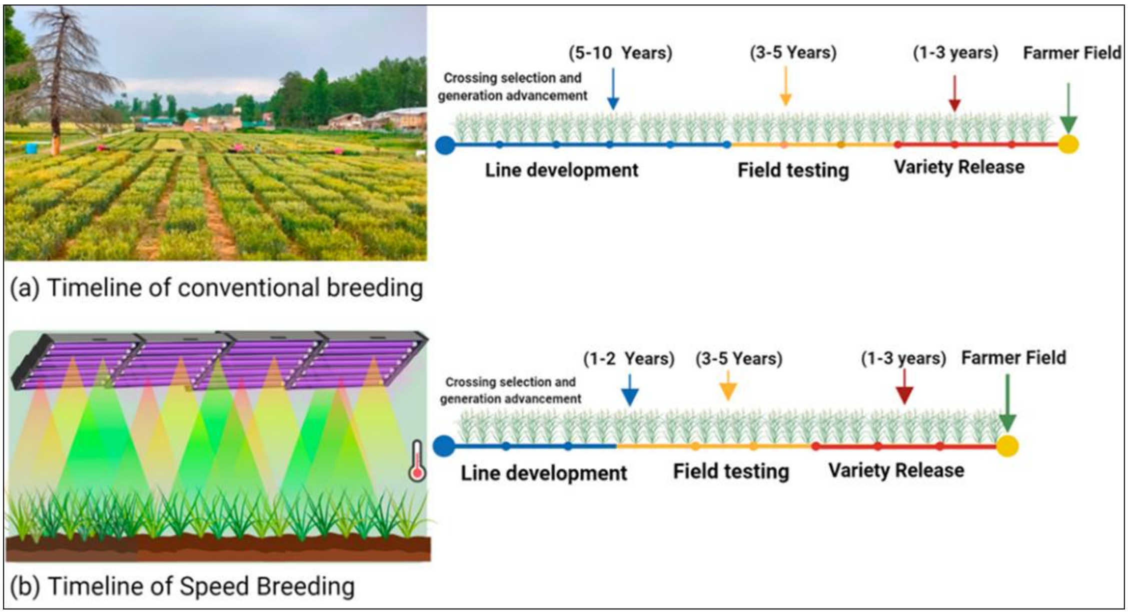
Fig 4: Overview of Markesr assisted selection for selection of genotypes

12. Participatory organic plant breeding

Participatory plant breeding is the ideal method of plant breeding programme as it multi-disciplinary and integrated approach, where everyone that are part of process of food production i.e. farmers, breeders, stake holders, consumers etc will be involved in selection of varieties or hybrids which they think it is best in their own perspective because farmer has his own perspective towards crop, scientist will see crop in different way, industries will have their own way of looking at crop etc as everyone expects different outcome from crop as some want quality and some want quantity, it again depends on their objective, so the final variety which will be obtained is the one selected not only by scientist but by all involved in the breeding programme. This method is best suitable for organic plant breeding as this considers all the aspects for crop production and even "organic farming is also a holistic approach of agriculture". In participatory organic plant breeding, development of new cultivars in collaboration with all that will very effective especially for organic conditions as the one who grows in field, they will select the best for them and adoption rate will also be high.

13. Speed breeding

As it is discussed earlier in this paper there is need for development of new and durable cultivars frequently so this method of breeding can be one among them that drastically reduces time for development of cultivars specific for organic condition, the principle behind speed breeding is to use optimum light intensity, temperature, and daytime length. Speed breeding had been reported to shorten generation time by extending photoperiods, while certain crop species, such as radish (*Raphanus sativus*), pepper (*Capsicum annum*), and leafy vegetables such as Amaranth (*Amaranthus* spp.) and sunflower (*Helianthus annuus*) responded positively to increased day length, by knowing the behaviour of plants accordingly we can handle plants naturally and speed up the breeding process. But it is not allowed to use phytohormones as it will be injected artificially so without of that we can go for speed breeding.



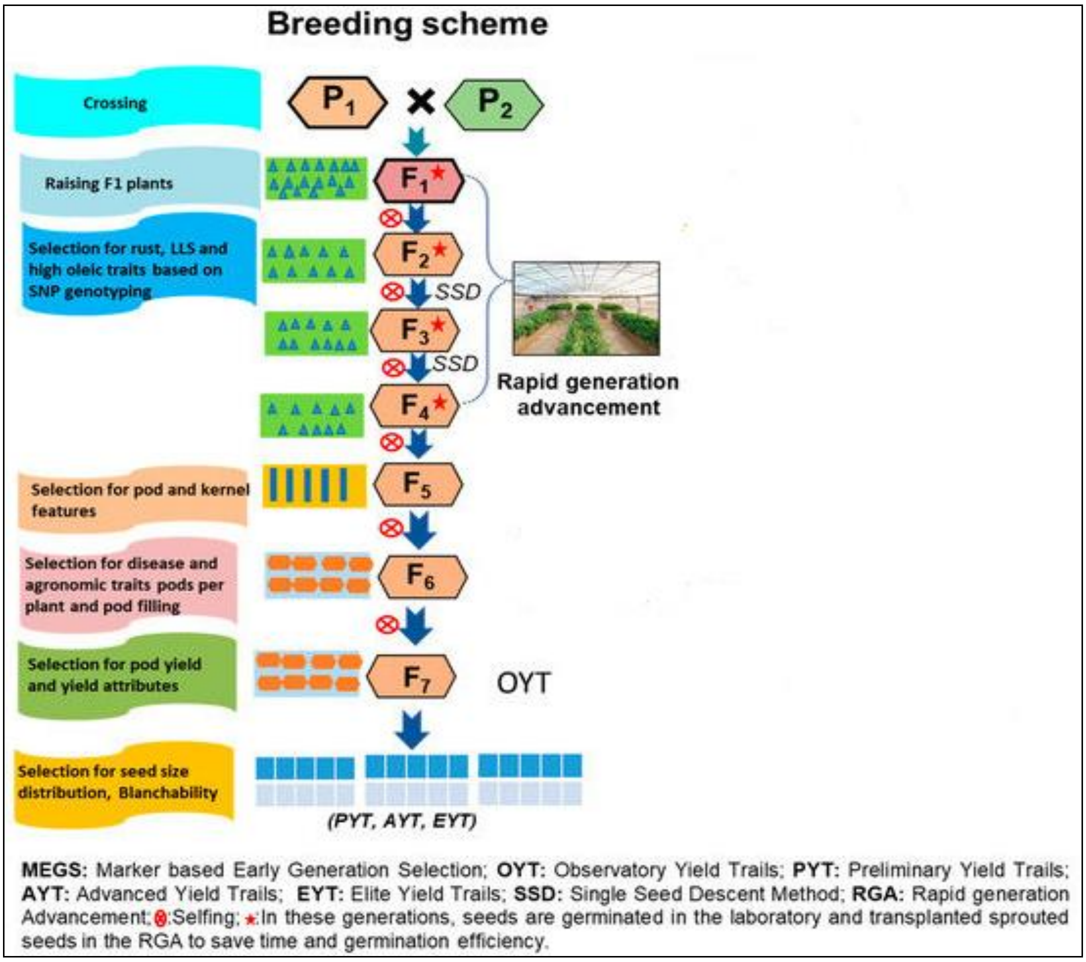
Kajal *et al*., 2022

Fig 5: Comparison between conventional and speed breeding methods

In the image we can see that reduced time for the life cycle so that we can reduce the generation time by almost significant time, here in single year we have 4 generations, this will gradually reduce the time for variety release. Importantly in organic conditions more frequently we require cultivars against prevailing diseases, pest and nutrient conditions in field. So, we require this kind of methods where we can breed more cultivars in less time for organic conditions.

14. Fast track breeding by single seed descent

In order to speed up the breeding process causing fast onset seeds allowing several generations per year, e.g., wheat, ground nut.



Aejal *et al*., 2021

Fig 6: Fast track breeding coupled with the SSD to enhance the breeding cycle

To enhance the speed of breeding, increase seed quantity and increase selection efficiency this method can be used that results elite cultivars with more quantity of seed and in less time.

15. Double Haploids obtained by pollination with inductor line and spontaneous duplication (*in vivo*) SHGD (Spontaneous Haploid Genome Duplication)

Generally, production of double haploids involves use of chemicals and *in vitro* culturing of plants but this method will not involve those steps and we can obtain the double haploids that can be utilized in the organic agriculture as this is within the boundary of organic farming. Egg cells can be induced by cross pollination with inductor line to develop haploid embryos without fusion of the egg cell and pollen and, thus, no recombination of genes. The haploid embryo can spontaneously double their chromosomes to become homozygous double haploid plants. This was a standard practice in maize breeding.

16. ECO-TILLING = Targeting Induced Local Lesions in Genomes and DEco-tilling

In general TILLING the mutants are used and inducing the mutations and then variability is analysed. But in ECO TILLING analysis of natural available genetic diversity by reverse genetics. A system to detect SNPs that is DEco-TILLING. The DEco-TILLING method facilitates the development of useful genotyping assays rapidly and inexpensively and can reduce bias, which is essential in organic plant breeding.

17. Transposons

Transposons are jumping genes that occur in nature and are responsible for mutations naturally. Transposon activity can be modified in order to increase mutation rate. This can be done by chemicals or by physical stress like drought or heat. In organic plant breeding we are not supposed to use the synthetic chemicals so we will use physical stress to induce mutations (Note: Not through mutagenic agents) and variation is created and that will be exploited for crop improvement

Examples of genes that have been introduced into domesticated crop varieties rendering them less dependent on chemicals (Hengyou *et al.*, 2017) [3]

These are the examples for the some of genes that have been transferred from wild relatives and other related ones that will actually reduce the reliance of that cultivar on the fungicides, pesticides and other synthetic chemicals.

Table 1: Examples of the application of CWRs for the improvement of biotic/abiotic stress resistance/tolerance/yields in major crops

Taxa		Traits[a]		
Crops	**Wild relatives**	**Abiotic stress resistance**	**Biotic stress resistance**	**Agronomic traits**
Rice	*Oryza minuta*; *Oryza rufipogon*; *Oryza australiensis*; *Porteresia coarctata*; *Oryza meridionalis*; O. *australiensis*	Salt tolerance (Majee et al., 2004[G]; Sengupta & Majumder, 2010[R]; Rohini et al., 2014[O]); heat and cold tolerance (Baruah et al., 2009[R]; Scafaro, Haynes, & Atwell, 2010[R]; Baruah et al., 2011[R]); flooding tolerance (Niroula et al., 2012[G])	Blast resistance (Liu, Lu, Zeng, & Wang, 2002[Q]; Huang, Hwang, Chiang, & Lin, 2008[G]; Yoshida & Miyashita, 2009[G]; Rahman, Khanam, Roh, & Koh, 2011[QI]; Lv et al., 2013[G]); planthopper resistance (Renganayaki et al., 2002[Q]; Jena, Jeung, Lee, Choi, & Brar, 2006[Q]; Du et al., 2009[QG]); bacterial leaf streak resistance (He et al., 2012[Q]); bacterial blight resistance (Huang, He, Shu, Li, & Zhang, 2001[Q]; Zhou et al., 2009[GI]; Zhou et al., 2011[GRI]; Hutin, Sabot, Ghesquiere, Koebnik, & Szurek, 2015[GR]); fungal diseases resistance (Jeon et al., 2008[G]; Eizenga, Agrama, Lee, & Jia, 2009[QR])	Yield (Xie et al., 2008[Q]; Fu et al., 2010[Q]; Luo et al., 2011[Q]; Li et al., 2012[Q]; Zhu, Ellstrand, & Lu, 2012[GR]); heading date (Dai et al., 2012[Q]); fragrance (Prathepha, 2009[GR]); lipid components (Przybylski, Klensporf-Pawlik, Anwar, & Rudzinska, 2009[RM]); grain quality (Han, Zhang, Qin, & Zhai, 2013[R]); multiple traits (McCouch et al., 2007[R]; Luo, Tian, Fu, Yang, & Sun, 2009[Q]; Ali, Sanchez, Yu, Lorieux, & Eizenga, 2010[QI]; Ammiraju et al., 2010[RO]; Das, Nayak, Patra, Ramakrishnan, & Krishnan, 2010[R])
Barley	*Hordeum spontaneum*; *Hordeum* chilense	Drought tolerance (Nevo, Beiles, Gutterman, Storch, & Kaplan, 1984a, 1984b[Q]; Diab et al., 2004[Q]; Suprunova et al., 2004[G]; Suprunova et al., 2007[G]; Chen et al., 2009[Q]; Chen et al., 2010[Q]; Nevo & Chen, 2010[QGR]; Zhao, Sun, Dai, Zhang, & Wu, 2010[R]; Chen et al., 2011[QG]; Honsdorf et al., 2014[Q]; Naz et al., 2014[QI]); salt tolerance (Nevo et al., 1984a, 1984b[R]; Yan, Chen, Cheng, Nevo, & Gutterman, 2008[R]; Nevo & Chen, 2010[QGR]; Shavrukov et al., 2010[G]; Qiu et al., 2011[G]; Wu et al., 2011[GR]; Wu, Shen, et al., 2014[O]; Bahieldin et al., 2015[O])	Fusarium crown rot resistance (Chen et al., 2013[Q]); scald resistance (Pickering et al., 2006[QG]); powdery mildew/leaf rust resistance (Schmalenbach et al., 2008[QI]); blotch-related disease/powdery mildew/ leaf scald resistance (Yun et al., 2005[Q]; Yun et al., 2006[Q]); late blight resistance (Danan, Veyrieras, & Lefebvre, 2011[Q])	Maturity (Danan et al., 2011[QM]); linkage map (Rodriguez-Suarez et al., 2012[Q])
Wheat	*Triticum dicoccoides*; *Triticum aegilops*; *Triticum tauschii*; *Triticum monococcum*; *Triticum urartu*, *Agropyron elongatum*; Aegilops species; *Haynaldia villosa*; *Leymus mollis*	Drought tolerance (Nevo et al., 1984a, 1984b[R]; Reynolds, Calderini, Condon, & Rajaram, 2001[QR]; Rampino, Pataleo, Gerardi, Mita, & Perrotta, 2006[R]; Peleg et al., 2009[Q]; Krugman et al., 2010[O]; Nevo & Chen, 2010[Q]; Di Bianco et al., 2011[GR]; Lucas, Durmaz, Akpinar, & Budak, 2011[G]; Placido et al., 2013[QI]); salt tolerance (Munns, Hare, James, & Rebetzke, 2000[Q]; Munns, Rebetzke, Husain, James, & Hare, 2003[Q]; James et al., 2006[I]; Mguis et al., 2008[R]; Munns & Tester, 2008[QG]; Nevo & Chen, 2010[QR]; Shavrukov et al., 2010[G]; Habora, Eltayeb, Tsujimoto, & Tanaka, 2012[G]; James et al., 2012[G]; Munns et al., 2012[QG]); O_3 tolerance (Biswas et al., 2008[R])	Powdery mildew fungus resistance (Blanco et al., 2008[Q]; Ji et al., 2008[Q]; Schneider, Molnar, & Molnar-Lang, 2008[R]; Hua et al., 2009[Q]; Li et al., 2009[Q]; Yahiaoui, Kaur, & Keller, 2009[G]; Ben-David et al., 2010[Q]; Cao et al., 2011[QG]; Xie et al., 2012[Q]; Xue, Ji, Wang, Zhang, & Yang, 2012[Q]); stem rust resistance (Leonova et al., 2007[Q]; Marais, McCallum, & Marais, 2008[Q]; Liu et al., 2011[QI]; Rouse & Jin, 2011[R]; Periyannan et al., 2013[QG]; Saintenac et al., 2013[QG]); leaf rust resistance (Marais et al., 2008[Q]; Murphy et al., 2009[Q])	Grain quality traits (Rawat et al., 2009[R]; Tiwari et al., 2009[Q])

Soybean	*Glycine soja; Glycine tomentella*	Salt tolerance (Ji et al., 2010[G]; Tuyen, Lal, & Xu, 2010[Q]; Ha et al., 2013[Q]; Sun et al., 2013[G]; Tang et al., 2013[G]; Qi et al., 2014[QGO]; Sun et al., 2014[G]; Wu, Zhou, et al., 2014[R]; Xue, Zhao, Gao, & Sun, 2014[R]); drought tolerance (Ji et al., 2010[G]; Luo et al., 2013[G]; Tang et al., 2013[G]); aluminum stress tolerance (Zeng et al., 2012[GO])	Nematode resistance (Winter, Shelp, Anderson, Welacky, & Rajcan, 2007[Q]; Kim, Hyten, Niblack, & Diers, 2011[Q]); aphid resistance (Hesler, 2013[R])	Multiple traits (Lam et al., 2010[QGO]; Wang et al., 2013[QI]; Li et al., 2014[QGO]; Singh & Nelson, 2015[R]; Zhou et al., 2015[QGO])
Tomato	*Solanum pimpinellifolium; Solanum chilense; Solanum habrochaites; Solanum hirsutum; Solanum parviflorum; Solanum* lycopersicon	Antioxidant activity (Melendez-Martinez, Fraser, & Bramley, 2010[M]); salt tolerance (Rao et al., 2015[G]); drought tolerance (Arms, Bloom, & St Clair, 2015[Q])	Powdery mildew resistance (Bai et al., 2003[Q]); fungal pathogen resistance (Jones, Thomas, Hammondkosack, Balintkurti, & Jones, 1994[G]; Thomas et al., 1997[G]); insect pest resistance (Frelichowski & Juvik, 2001[M]; Mirnezhad et al., 2010[M]); spider mite resistance (Salinas et al., 2013[Q]; Antonious & Snyder, 2015[M]); late blight resistance (Chen et al., 2014[Q]; Haggard & St Clair, 2015[Q]); begomovirus resistance (Menda et al., 2014[QI]); white fly/spider mite resistance (Sallaud et al., 2009[M]; Bleeker et al., 2011[QM]; Bleeker et al., 2012[M]); *Tomato yellow leaf curl virus* resistance (de Castro, Blanca, Diez, & Vinals, 2007[M])	Yield-related traits (Kamenetzky et al., 2010[OM]; Wu et al., 2015[QM]); leaf traits (Muir, Pease, & Moyle, 2014[Q]); grain quality traits (Haque, Kjaer, Rosenqvist, & Ottosen, 2015[M]; Ning et al., 2015[M])
Potato	*Solanum paucijugum, Solanum brevicaule, Solanum commersonii; Solanum ruiz-ceballosii; Solanum* bulbocastanum; *Solanum* microdontum	Cold sweetening resistance (Hamernik, Hanneman, & Jansky, 2009[RI])	Potato beetle resistance (Jansky, Simon, & Spooner, 2009[R]; Spooner, Jansky, & Simon, 2009[R]); soft rot resistance (Chung, Holmquist, Spooner, & Jansky, 2011[R]); potato virus resistance (Cai, Spooner, & Jansky, 2011[R]; Duan, Richael, & Rommens, 2012[G]); potato late blight resistance (Sliwka et al., 2007[Q]; Bhaskar et al., 2008[G]; Hein et al., 2009[Q]; Sliwka et al., 2012[Q]; Khiutti, Spooner, Jansky, & Halterman, 2015[R]; Tiwari et al., 2015[G]); nematode resistance (Brown, Zhang, & Mojtahedi, 2014[QR]); pathogen resistance (Zuluaga et al., 2015[O]); tuber moth resistance (Horgan, Quiring, Lagnaoui, & Pelletier, 2007[R]); other pests resistance (Le Roux et al., 2008[R])	Multiple traits (Jansky, 2011[R])
Peanut	Arachis stenosperma; Arachis duranensis: Arachis ipaënsis	Drought and fungal resistance (Guimaraes et al., 2012[O])	Nematode resistance(Chu, Holbrook, Timper, & Ozias-Akins, 2007[Q]; Guimarães et al., 2010[O])	Multiple traits (Fonceka et al., 2012[QI])

Examples of few wild crop relatives for transfer of favourable traits

Success stories:

On-farm apple breeding by non-profit organization Poma Culta (Rey *et al.*, 2020)

Biodynamic fruit farmer, Niklaus Bolliger was looking for new possibilities to create high performing varieties, which did not require high inputs for pest control. In other words, he was selecting and crossbreeding for cultivars which could meet the high-quality standards of the market, while also being robust and healthy. He does all the breeding practices in his farm and selects the best lines that are suitable for organic condition as well as for his own farm environment, this made his organic farming as well as his organic plant breeding very much successful, he doesn't use any of the chemical pesticides and fertilizers make use natural things and mainly breeding best cultivars from his farm for management of disease and pest.

Area: 15 ha organic vegetable and fruit farm with livestock (of this 1 ha is reserved for breeding and 0.5 ha for fruit production).

Turnover: € 400 k (3.35 crores).

Since: 2004.

Location: Switzerland.

Sikkim the best example for success of planed implementation of policies for making it a 100% organic state:

From including organic farming in the school curriculum to providing farmers with the right information they needed to complete the transition, the state facilitated everything. The entire state's farming practices have been certified organic by agencies accredited by Agriculture and Processed Food Products Export Development Authority. A total cultivatable land of 58,168 hectares in Sikkim is now producing nearly 800,000 tons of chemical free, organic, and healthy food It took Sikkim 15 years, relentless pursuit, and collective commitment to its success and they proved to whole world and living proof of the fact that going "organic in no way means reduced productivity". (www.24mantra.com)

Agriculture crisis in Sri Lanka caused due to shifting of agriculture to organic farming without proper pre-planning:

In April 2021, President Gotabaya Rajapaksa announced that Sri Lanka will only allow organic farming totally banning inorganic fertilizers and agrochemicals-based fertilizers. The drop-in tea production as a result of the fertilizer ban alone resulted in economic losses of around $425 million and created a 20% drop in rice production within the first six months alone reversing previously achieved self-sufficiency in rice production and the country was forced to import rice at a cost of $450 million. The situation in the tea industry was described as critical, with farming under the organic program being described as "ten times more expensive" and "producing half of the yield" by the farmers. The banning of the trade of chemical fertilizers and pesticides produced a severe economic crisis, since the population expects to remain without income and without food. In November 2021, Sri Lanka abandoned its plan to become the world's first organic farming nation following rising food prices and weeks of protests against the plan. (2019-present_Sri_Lankan_economic_crisis. (https://en.wikipedia.org)

Scope and Future of organic plant breeding

In light of ever-increasing global population and food demand, also the raising concern over quality of food that is consumed there lies more scope for organic farming, for that to be effective and feasible in future, the first thing is to have specific cultivars for organic system, so more durable and high yielding so that it can meet the growing food demand, thus cultivar development for organic conditions with specific objectives should be the main objective in future.

Natural resource limitation is the another concern where the population is increasing and the land and other natural resources are remaining constant, so aim should be increasing productivity that could meet the demands of the whole world because just having the organic production (quality of food) without its production (quantity) that would not meet the food demand all over the world, it would fail miserably as there would be no sufficient food for all and food security would be under question, so considering the natural resource as important factor for development of cultivars according to that needs to be done.

Human health is the priority among all the things, so as we can observe one thing in common from IFOAM rules is that organic agriculture cares about the environment and human health on priority basis, so through this system of agriculture we can achieve the nutritional security and also human health is enhanced.

Conclusion

Organic farming is not only the farming system but it is the ideal way that agriculture should be practiced as it is followed considering all the aspects as it was clearly described in four Basic principles endorsed by IFOAM for organic plant breeding where it respects the environment, ecosystem, biodiversity, other organisms life etc. so it is being not only holistic approach that values integrity of plant, ecosystem and biodiversity along with it also produces the food in safest form and healthy food that is devoid of unnecessary residual effects from the harmful synthetic chemicals. Because of this there is increased concern for the organic products, so there is need for the increased production in organic sector thus meeting the demand created for this the area under the organic must be increased. This is possible only when there are varieties or hybrids specifically breed for organic conditions, making cultivars available for farmers in organic conditions and which will obviously increase the production, productivity and area as well, this will not only help in meeting demand for organic products but also creating nutritional security through organic products. Mere selection of best cultivars among conventional one is not enough as they are bread accordingly, so more focus needs to be towards development of new cultivars specific for organic condition this will even encourage other farmers to take up organic farming in the country. Not only the cultivars specific for organic condition but also the there is need for development of new breeding techniques and tools that are specially designed for organic conditions, which will make breeding easy for organic conditions, this will increase the number of cultivars for organic conditions and again encourage the farmers to take up the same as they have more choices with them and it also increases the crop diversity in organic farming.

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