A Review of Rapid Generation Advancement (RGA) in crop improvement

Abstract:

The use of the speed breeding method is widely considered to be the wave of the future in plant breeding. The term "speed breeding" is used to describe a rapid generational advancement technique that is used to minimise the time it takes from seed to seed, therefore reducing the length of a crop plant's typical life cycle. Plants that are not sensitive to light may have as many as six generations in a single year using this method, whereas other plants can only expect two or three generations every year. With this technique, the photoperiodic and temperature needs of crops produced in controlled-poly homes may be altered. This methodology, when combined with other cutting-edge tools like genome editing and high-throughput genotyping systems, may help breed new kinds of crops at a much quicker pace. Spacefaring food producers: NASA first conceived of this notion. Breeder's equation may be used to determine whether speed breeding is applicable to a certain crop. Light, photoperiodic regime, temperature, and humidity modification make up the backbone of the fast-breeding formula. Accelerated breeding, expedited genomic selection, improved transgenic and CRISPR-Cas9 pipelines, and the investigation of critically important agricultural plant physiological properties are just some of the numerous uses for this approach.

Keywords: Generation advancement, photoperiodic conditions, photo insensitive, speed breeding

1. Introduction:

To develop candidate cultivars that may satisfy market expectations, traditional crop breeding begins with selecting parental genotypes that are complementary in terms of desirable features, then proceeds to crosses and a series of selections and advancements of better progenies [1]. Enhanced resistance to biotic and abiotic stressors, as well as increased yield potential, are common breeding aims in crop cultivar improvement programmes [2,3]. Following this logic, the following steps can be distinguished in any crop improvement program's breeding procedures: (a) selecting desirable parents with complementary traits to be combined; (b) crossing the selected parents and developing progenies; (c) selecting and genetically advancing the best progenies based on target traits; and (d) selecting the best progenies for screening in multiple target production environments to identify the best performer [1]. Most programmes to enhance crop cultivars employ the standard breeding techniques described here. Conventional breeding methods, on the other hand, might take up to ten years or more to produce and release a new and better species [4,5]. The third and fourth stages of the breeding process are where most of the effort, money, and space are allocated for variety design initiatives. The length of time required at these steps is a major bottleneck to the development and marketing of new cultivars. The standard breeding method takes a whole growing season, and the sluggish pace of development between generations is due to the cyclical nature of crops. The average grain and legume crop has a three- to six-month generational and annual cycle. In contrast, one breeding generation in cassava takes between 15 and 18 months to finish. Because of factors like severe temperatures, unpredictable and poor rainfall distribution, day duration etc. [6] Certain agroecologist are limited to a single crop cycle annually. It's possible to have two full generations every year in the tropics with the right circumstances for crop production [7]. When creating homozygous or genetically stable breeding populations, evaluating yield and economic traits first necessitates the use of continuous field selection and early rapid generation advancement, which in turn necessitates the use of phenotyping expertise and production resources to manage a large number of segregating populations. Technologies like doubled haploid breeding [8] and speed breeding may shorten the time it takes to produce a new crop [9]. Speed breeding is a collection of methods for rapidly progressing to the next generation of breeding stock by manipulating the environmental circumstances in which crop genotypes are developed. By rapidly progressing through generations, the approach saves both time and money in the breeding process. Speed breeding may reduce the breeding cycle and maximise resource efficiency by combining several selection approaches such as single seed descent (SSD), single pod descent (SPD), single plant selection (SPS), clonal selection (CS), and marker-assisted selection (MAS) [10, 11, 12]. When compared to the one or two generations per year that can be reached using traditional selection methods, the three to nine generations per year that can be accomplished by speed breeding are striking [13, 14]. Therefore, speed breeding allows for the quick creation of homozygous and stable genotypes and facilitates the rapid advancement of generations, which speeds up the process of developing and releasing new cultivars [12]. Additionally, MAS and high-throughput phenotyping methods for multiple trait selection mesh well with speed breeding technology.

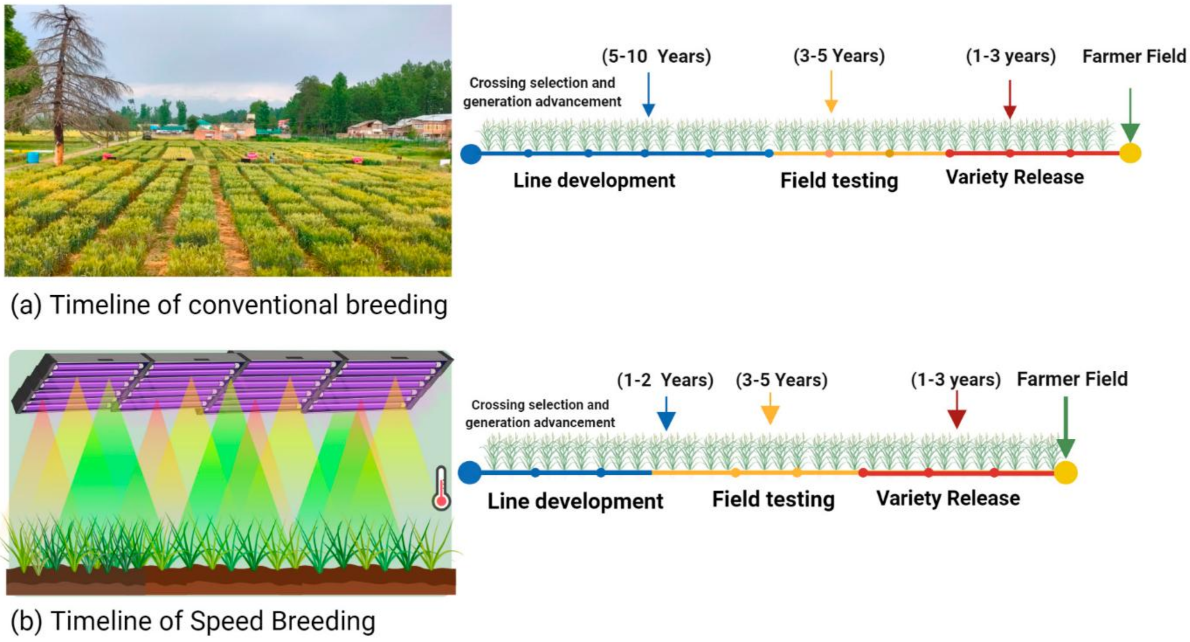

Fig 1; Comparison of traditional breeding and speed breeding [15]

2. Speed breeding set up

1. Light: for rapid plant reproduction, you may use any kind of lighting that provides a spectrum that focuses on the blue, red, and far-red ranges of the Photosynthetic Active (PAR) zone (400-700 nm).
2. Photoperiod: It has been shown that a photoperiod of 22 hours of sunshine followed by 2 hours of darkness is optimal for rapid breeding.
3. Temperature: It has been shown that using daytime temperatures of 22 degrees Celsius and night-time temperatures of 17 degrees Celsius is optimal for fast breeding.
4. Humidity: While carrying out the speed breeding programme, a humidity of 60–70% has been kept [13,12]
(Fig. 2)

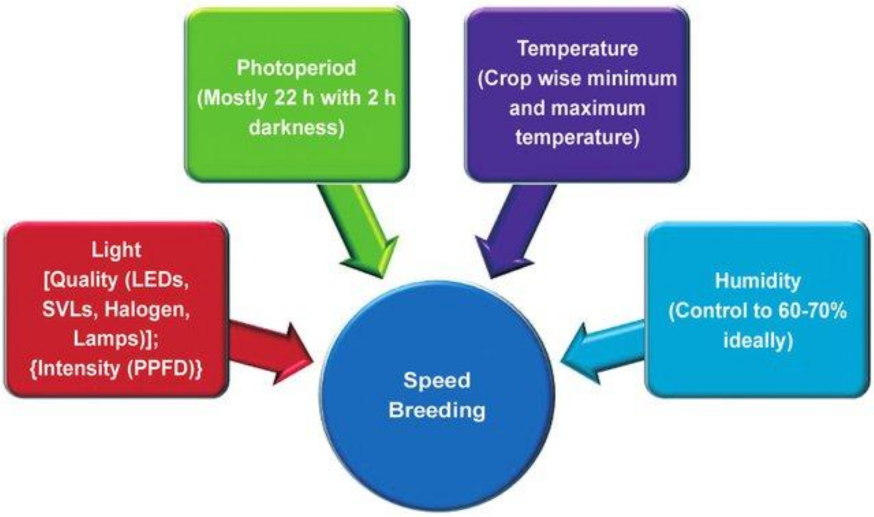

Fig 2; Facilities requirement for RGA [16]

3. Procedure of Speed Breeding

A general procedure for low cost speed breeding in a homemade growth room design is as follows:

1. Substituting a room with insulated sandwich panelling, seven LED light boxes (one light box every 0.65 m2), and a 1.5 horsepower inverter split system household air conditioner for the standard Conviron BDW chamber is possible. The following is a basic procedure for rapid breeding at minimal cost in a home growing room.
2. At bench height, you want a PAR value of 210–260, and at 50 cm above the pot, you want a value of 340–590. The ideal location for the lights is 140 cm above the bench top. 20 cm pots should fit in the space.
3. When utilising an Irrigation Controller, one solenoid per room and one spike dripper per 20.3 cm pot are required to perform automatic watering.
4. The humidity conditions should be ambient.
5. More blue, red, and far-red light should be used. For four weeks, have it set at 12 hours of light and 12 hours of dark, and then gradually raise it to 18 hours of light and 6 hours of dark.
6. The temperature may be controlled using an air conditioner, which can be adjusted to 21 degrees Celsius during the day and 8 degrees Celsius at night.

For cereal crops in particular, the single seed descent method is ideal for implementing the speed breeding approach. Accelerating the cycle of many lines producing healthy plants and viable seed requires raising the seeding density, which is done through speed breeding.

The plants grown under speed breeding reached anthesis in approximately half time as compared to those grown in same conditions under glasshouse conditions. The above-described procedure has been used for speed breeding of wheat, barley, oat and triticale.

Fig 3; Speed breeding under controlled conditions

4. Harvesting of Immature Spikes

Grain has to be stored for at least 15 days following harvest in order to naturally mature and reduce moisture content. In rapid breeding, plants are often harvested barely two weeks after anthesis, while the spikes or pods are still green. They are then matured artificially by placing them in a hot air oven/dehydrator at 35 degrees Celsius for three days. Except for a little reduction in weight, seeds dried in this manner function just as well as those dried in the conventional manner. By artificially hastening the ripening process, we may save valuable time and have a quicker seed-to-seed cycle, which is, at its heart, the most important factor in the success of our endeavours.

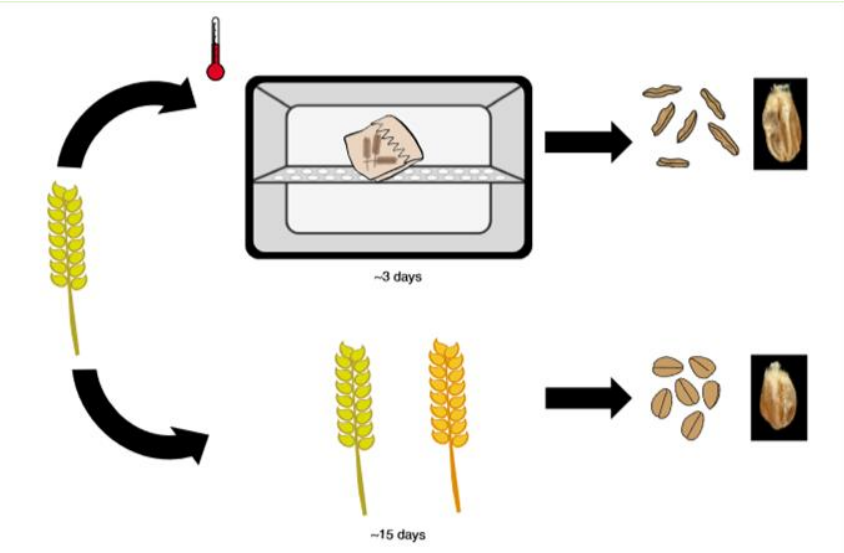

Fig: 4- . Comparison between normal seed ripening process (takes about 15 days) and harvesting immature spikes and their subsequent drying in dehydrator (takes about 3 days) [12].

5. Opportunities of speed breeding techniques:

5.1 Rapid development of homozygous lines for accelerated breeding

Several crops have made use of speed breeding methods to rapidly create homozygous lines following an initial cross with supportive features. The method requires careful control of photoperiod, light intensity, temperature, soil moisture, soil nutrition, and dense planting. In order to speed up the breeding process, several techniques have been utilised to hasten blooming and seed set before their natural periods (Table 1). In a year, anything from three to nine breeding generations may be produced using this procedure. This works well for rapid breeding and population assessment in all of the targeted production contexts using several types of selection approaches, such as SSD, SPD, and SPS [17].

5.2 Amenability with selection methods

Generational progress is often accelerated using speed breeding with minimal phenotypic selection. However, cutting-edge technology (such as high-throughput genotyping approaches, marker-assisted selection, etc.) may be effectively included for selecting desirable features. In settings that limit plant development, the preservation of a strong breeding population and genetic diversity, as well as the generation of optimal yields, should be possible with the help of speedy breeding and efficient selection procedures [18]. Selecting high-yielding genotypes by traditional approaches like bulk, mass, recurrent, pedigree, and pure line require a genetically stable plant population. As a result of the lengthy inbreeding and selection cycles they need, these approaches are not optimal for fast breeding. Single seed descent (SSD), single pod descent (SPD), and single plant selection (SPS) are the most applicable selection approaches compatible with speed breeding.

Crop	**Techniques**	**Days to flowering**	**Number of generations per year**	**Selection method**	**Reference(s)**
Amaranth	Photoperiod and temperature	28	6	SSD	[19]
Arabidopsis thaliana	Plant hormones, immature seed germination and photoperiod	20–26	10	—	[20]

Barley	Photoperiod, temperature, soil fertility, immature seed germination and embryo rescue	24 – 36	9	SSD	[21]
Canola	Photoperiod, light intensity, temperature, immature seed germination and soil moisture	73	4	SSD	[12]
Chickpea	Photoperiod and immature seed germination	33	7	SPD	[11]
Faba bean	Plant hormones, photoperiod, light intensity and immature seed	29–32	7	SPD	[7]
Groundnut	Photoperiod and temperature	25–27	3	SPD	[22]
Lentil	Plant hormones, photoperiod, light intensity and immature seed	31–33	8	SPD	[7]
Pea	Plant hormones, photoperiod and immature seed germination	33	5	—	[23]
Pigeon pea	Photoperiod, temperature, immature seedgermination	50–56	4	SPD	[24]
Rice	Photoperiod, temperature and high-density planting	75–85	4	SSD	[25]
Sorghum	Photoperiod, temperature and immature seedgermination	40–50	6	SSD	[26]
Soybean	Photoperiod, temperature and immature seedgermination	23	5	SSD	[27]
Wheat	Photoperiod, temperature, soil fertility, immature seed germination and embryo rescue	28–41	7.6	SSD	[21]

Abbreviations: SPD, single pod descent; SSD, single seed descent; SPS, single plant selection; —, not available.

Table 1; Different techniques for Rapid Generation Advancement in various crops [28]

6. Challenges of speed breeding

It is possible to speed up the pace of traditional breeding programmes by using speed breeding methods. However, the technology needs people with the right skills, access to efficient and complementary plant phenomics facilities, the right kind of infrastructure, and consistent funding for R&D [1]. Conventional plant breeding, marker-assisted selection, and genetic engineering all benefit from rapid breeding techniques, but their availability depends on the widespread acceptance of the importance of these methods. In addition, the integrated suite of instruments calls for knowledge of plant breeding and biotechnology, access to long-term funding, and official backing from policymakers. The majority of public plant breeding operations in Sub-Saharan Africa (SSA), for instance, use conventional plant breeding methods. There are technological, economic, and institutional barriers that prevent the public sector from making full use of current breeding technologies [29]. The introduction of new conventional and GM agricultural cultivars in SSA might be sped up with the use of speed breeding techniques. To implement fast breeding, however, you'll often require (a) access to suitable facilities, (b) people educated in the protocol, (c) implementing considerable modifications to the design and management of your breeding programme, and (d) long-term finance. It is possible to speed up the pace of traditional breeding programmes by using speed breeding methods. However, the technology needs people with the right skills, access to efficient and complementary plant phenomics facilities, the right kind of infrastructure, and consistent funding for R&D [1]. Conventional plant breeding, marker-assisted selection, and genetic engineering all benefit from rapid breeding techniques, but their availability depends on the widespread acceptance of the importance of these methods. In addition, the integrated suite of instruments calls for knowledge of plant breeding and biotechnology, access to long-term funding, and official backing from policymakers. The majority of public plant breeding operations in Sub-Saharan Africa (SSA), for instance, use conventional plant breeding methods. There are technological, economic, and institutional barriers that prevent the public sector from making full use of current breeding technologies [29]. The introduction of new conventional and GM agricultural cultivars in SSA might be sped up with the use of speed breeding techniques. To implement fast breeding, however, you'll often require (a) access to suitable facilities, (b) people educated in the protocol, (c) implementing considerable modifications to the design and management of your breeding programme, and (d) long-term finance.

7. Conclusion:

The traditional way of breeding in agriculture takes more time, but the resulting crop is of a high-yielding kind. They typically have a reproductive cycle of eight to ten years. Because of the world's ever-increasing population, it will be challenging to solve the problem of food shortages in the coming decades. Accelerated generational output will aid in breeding's pursuit of genetic improvement. It is possible to increase crop yields through the use of a protocol known as "speed breeding," which involves modifying environmental factors such as light duration, intensity, and temperature; developing disease-resistant crop varieties; and reducing the sensitivity of certain crops to salt, most notably rice. Improved photosynthesis brought forth by speed breeding allows for a quick expansion of the crop. When compared to the conventional method of breeding, this method yields many more generations of the same crop in a shorter amount of time. From what we can tell from the available literature, this technique does not provide enough light on the many areas that have not yet been thoroughly investigated. Since speed breeding is such a novel field in the modern world, there is a lot of room for discovery. There is a need to close the research gap. It has the potential to do wonders for our offspring, ensuring that they grow up without experiencing hunger or malnutrition. Therefore, we can back up the claim made in the study's title that rapid breeding has great promise for the future of humanity in terms of food security, which is a major issue on the minds of people all over the globe.

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