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Review Article

Resistance Sources for Powdery Mildew and Breeding Strategies for Improvement in Fenugreek

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Fenugreek is a multiuse and very valuable commercial spice crop farmed around the world, notably in Ethiopia, where it is valued for its seeds, tender shoots, and fresh leaves as well as its significant economic contribution. The yield of fenugreek crops adversely impacted by powdery mildew is the most damaging disease that exerts a substantial impact on the entire plant components and loss of its output. Appropriate breeding strategies such as resistance breeding, collection of germplasm, evaluation and conservation, mutation breeding, tissue culture techniques, and marker-assisted selection are therefore worthy sources of resistance to fenugreek powdery mildew disease as well as need to be implemented and applied immediately to minimize yield losses due to the incidence of complex crop pathogen. For culture, ovule culture, micropropagation, in vitro selection, and somaclonal variations, for example, are biotechnological methods that can be used in fenugreek breeding programmes to get varieties free from powdery mildew disease. New tools to open up new research avenues to create new genotypes with unlimited potential for the treatment of powdery mildew disease are also being used to improve and supplement conventional programmes for fenugreek enhancement. The application of resistance breeding, collection of germplasm, evaluation and conservation, mutation breeding, tissue culture techniques, and marker-assisted selection have an immense role in the production of fenugreek crops by reducing yield limiting factors in the crop, primarily for powdery mildew disease.

1. Introduction

Fenugreek (*Trigonella foenum-graecum* L.) is a multipurpose (herb, spice, and vegetable) annual, dry land-adapted, forage and legume crop cultivated with extreme potential for introduction under appropriate agroclimatic zones in different parts of the world. The plant is extensively grown in Argentina, Egypt, Morocco, Algeria, Ethiopia, and Lebanon in addition to India, where it is said to have originated from South-East Europe or South-West Asia. In accordance with materials cited by several academics, the fenugreek's genome has been identified using the somatic chromosome numbers of *Trigonella* taxa, which are $2n = 14$, 16, 30, and 46, as well as its chromosomes [1, 2], and its genome size is around 685 Mbp [1, 3].

Fenugreek crop is now widely cultivated in most parts of the world, and more than 260 species of *Trigonella* are diffused in the world [4], but cultivation is mainly covered in India [5]. The Indian states of Rajasthan, Gujarat, Madhya Pradesh, and Uttar Pradesh are where fenugreek is primarily grown. More than 80% of Rajasthan's land is used for fenugreek cultivation, making it the state with the largest production center. Fenugreek's green leaves also contain carotene and ascorbate, and its seed is frequently used for medical, pharmacological, and nutraceutical applications [6], fiber, iron, calcium, and zinc even more than the regular food items [7]. It is also effective in the handling or treatment of diabetes, hyperglycaemia, and hypercholesterolemia cases.

In Ethiopia, the crop is grown either for use as a spice, food, or for other special purposes, such as for nursing mothers and infants as a breakfast beverage, used in crop rotation for the purpose of enhancing soil fertility, generating income, and a flavoring for traditional bread that preserves the soft texture of "teff injera." The main dish named "la fiso," which is produced from either maize or sorghum "injera" and served as baked in a mixture of fenugreek flour boiling either with meat or alone, is made with fenugreek by almost all farmers in Hararghe [8].

Due to the combined effects of numerous biotic and abiotic factors, fenugreek has a low yield. The major decisive disease causes for fenugreek productivity are *Cercospora* leaf spot (*Cercospora traversiana*), charcoal rot (*Macrophomina phaseolina*), powdery mildew (*Erysiphe polygoni* and *Leveillula taurica*), downy mildew (*Peronospora trigonellae*), rust (*Uromyces trigonellae*), root rot (*Rhizoctonia solani* and *Sclerotium rolfsii*), damping off (*Pythium aphanidermatum*), *Fusarium* wilt (*Fusarium oxysporum*), and yellow mosaic disease (bean yellow mosaic virus). The most detrimental fenugreek disease, powdery mildew, has a significant negative influence on all plant portions that are above ground [9] and causes loss in its productivity which is characterized by the appearance of white floury patches on both the surface of leaves and other aerial parts of plants. The later stage of the fenugreek crop becomes serious when pod formation takes place [10].

It is known that fenugreek powdery mildew can persist through cleistothecia found in plant debris in the field or when planting seed contaminated with infected plant debris. However, secondary transmission of the disease, which occurs through conidia and may germinate in a wide range of temperatures from 5°C to 350°C, is what causes the most spread and harm [11]. The powdery mildew disease in fenugreek often appears in February and spreads throughout the field until the crop is fully mature. In order to increase the production of the fenugreek crop, this review study focused on identifying sources of resistance to the powdery mildew disease. It also discussed breeding techniques for these improvements.

2. Different Breeding Strategies for Sources of Disease Resistance

Fenugreek is a drought-resistant plant, characterized as plastic to growing conditions [12], even though biotic and abiotic factors are more limiting of the productivity of fenugreek crop farming. Fenugreek breeding results in a significant improvement in the yield of seeds, green vegetables, and fodder. Fenugreek in India can have a 20–70% yield loss as a result of the complicated disease pathogens [13]. Implementing breeding programs for resistance to the powdery mildew disease in fenugreek is urgently important in order to reduce output losses brought on by a complex of pathogens in the crop. Fenugreek seeds already have low yield levels, which are made worse by the powdery mildew disease. To maintain consistent fenugreek cultivar seed production and quality as well as to develop high-yielding, disease-resistant varieties suitable for different agroclimatic conditions, genetic improvement work on this crop is urgently needed [14]. As a result, this review places particular attention on sources of resistance to the powdery mildew disease and breeding techniques for fenugreek crop development, which are listed under the following areas.

3. Resistance Breeding

The powdery mildew is one of the many diseases that affect the fenugreek crop, which is a common problem because it reduces productivity and quality. To identify the root causes of breeding resistance, it is preferable to use screening procedures primarily for generations. Diseases were less of an issue in the early years of fenugreek production, but with the introduction of crops in new places, various diseases and pests have now established severe concerns, necessitating development in resistance breeding. Testing for breeding resistance is often conducted in the field, with laboratory or glasshouse approaches being used solely as a backup. As a result, the screening procedure should be straightforward, useful, and effective in order to create cultivars that are resistant to the powdery mildew disease.

Moreover, unfavorable weather conditions in the form of drought, heat, salinity, and other stresses ultimately diminish the seed yield of crops additionally to the disease. The stresses have a major influence on morphological, physiological, and biochemical processes. Genetic variability for various characters contributing to resistance for stresses has been observed and exploited. Even though fenugreek is sensitive to salinity problems in the area of cultivation, but tolerant cultivars suitable to the area can be developed through effective breeding procedures. Resistance breeding is also straight forward to quality production as it avoids the necessity of application of pesticides which often leaves undesirable residues [15], and fenugreek crops can also prevent powdery mildew emerging through the resistance breeding technique similarly as developing for salt tolerant varieties. In another case to achieve resistance breeding, high genotype × environment interactions recognized and recommended for the crops that breeding programmes may be targeted for specific environment and developed suitable varieties for each condition.

According to [16], amongst 44 lines screened against powdery mildew, GC-39 and UM-32 were found free from fungal infection, whereas GC-7, GC-20, and UM-34 were categorized as resistant varieties. Another report showed that Hisar Madhavi, RMt-305, and RMt-303 were found resistant varieties towards powdery mildew disease. Overall, the Department of Agriculture, Ministry of Agriculture and Farmers' Welfare, Government of India has identified RMT-1, RMT-143, and RMT-305 as fenugreek cultivars that are resistant to the powdery mildew disease. Thus, RMT-305 is documented as a sustainable resistant variety towards powdery mildew disease.

4. Enhancing Germplasm Collection and Conservation

Breeders have developed the high-yielding and desirable genotypes of fenugreek through appropriate selection techniques from the indigenous or exotic material collections. Moreover, the methodological collection and maintenance of indigenous germplasm, exotic material principally from primary centers of origin and secondary centers of origin variability should essentially be introduced. Fenugreek is a highly self-pollinated crop and commonly involved pure line or single plant selection, and mass selection procedures have been reported to be practiced largely for improvement programme. Germplasm screening technologies and sources of disease resistance are important and effective methods than others such as pest-resistant genes [13]. The seed spice (fenugreek) improvements for attributing genetic potential through collection and characterization of germplasm enhance the variability and ultimately lead to the development of superior varieties.

Traditional crops are mostly conserved on a farm, which maintains crop genetic diversity along with traditional knowledge, often on small covers of land and in home gardens [17]. The collection of indigenous germplasm of the fenugreek seed with time-bound goals by means of a well-set programme must be immediately started because of the indigenous germplasm that exists in the form of traditional varieties, which are expected to possess valuable genes for resistance to biotic and abiotic stresses. The 989 accessions of fenugreek seeds are collected, evaluated, maintained, and conserved at various centers of All India Coordinated Research Projects [18]. On the other hand, if collection and conservation of the gene are not ensured immediately, adoption of improved varieties may result in irretrievable loss of valuable genes. Indigenous and exotic strains being maintained and studied for variation in all morphophysiological characters yield per plant as well as resistance for diseases and also the effect of environmental interaction on germplasm must be evaluated over different environments to identify promising material for advanced exploitation [8]. Germplasm collection and amount of variability collected could be esteemed for economically important characters related to the crop improvement programme.

5. Mutation Breeding

Mutation breeding has become increasingly popular in recent times as an effective tool for crop improvement for different crops. As indicated, the report showed successful crop improvement through mutation breeding of fenugreek [19]. Crop improvement through mutation breeding can distinguish the normal plant type that could be controlled by a single dominant gene and giant mutant plant type by a recessive allele. The generation of variability and selection for desirable traits resulted in identification of some mutants with important agronomic characteristics that can be used as germplasm for improvement of fenugreek crop. Seed treatment with chemical mutagens for instance ethyl methane sulfonate (EMS) has the potential to cause chromosome damage, resulting in individual mutations along with addition or loss of chromosomes from cells [20].

Mutation breeding techniques can generate genetic variation and increase the desired characters significantly in plants of new cultivars [21] because it helps in greater magnitude of variability in various plant traits in a relatively shorter time to get resistance against powdery mildew disease. The application of mutagenesis in agriculture for improving the crop plants presented a new departure from the conventional breeding methods. Fenugreek crop has been more important economically, agronomically, and environmentally with a relatively broad adaptation in different regions. Using mutation breeding can be used to generate new genetic variation in an existing gene pool for fenugreek traits and used for a large number of alleles at the same time to correct a particular trait of interest [22].

Mutagenesis is an important tool in crop improvement and free of the regulatory restrictions compulsory on genetically modified organisms. Conventional breeding programmes can be exploited by the forward genetic approach that enables the identification of improved or novel phenotypes. Influential reverse genetic approaches that allow the detection of induced point mutations in individuals of the mutagenized populations can address the major challenge of linking sequence information to the biological function of genes and can also identify novel variation for plant breeding. The Food and Agriculture Organization officially issued and registered 3,248 mutant varieties with crop improvement findings [23]. Yet, compared to cereals (49.50%), flowers (21.9%), and legumes (15.0%), the uses of mutant breeding for medicinal and aromatic crops are quite low [24]. Therefore, fenugreek seeds can also be treated with either gamma rays (25–15 kR) or ethyl methanesulphonate (0.1–0.5%, 2 hrs) or ethylene imine (0.01–0.1%, 2 hrs). For the application of mutagen, the best treatment at 0.4% of EMS dose stimulates plant growth [21]. Fenugreek crop improvement in a quantitative trait such as seed yield is reported through chemical mutagenesis [25].

Finally, developed varieties through mutation increase biodiversity and deliver breeding material for conventional plant breeding; therefore, it has direct contribution to conservation and plant genetic resource uses [26]. Since fenugreek is self-pollinated and the determinate trait is governed by recessive genes, mutation breeding can be used to generate mutant plants with a determinate growth habit without losing beneficial adaptations and other agronomic traits in the base population to get resistant variety even for powdery mildew disease.

6. Tissue Culture Technique

Since the resistance to disease and improvement in quality has a special significance in seed spices such as fenugreek crop, a multidisciplinary collaborative approach is pledged to achieve the objective of developing high-yielding and disease resistant varieties with better quality. Powdery mildew in fenugreek has so far been avoided with effective control measures. The tissue culture technique can be used to create variation [15]. The frequency of somaclonal variation can be enhanced if coupled with in vitro mutagenesis and screening of population at a large scale for resistance to biotic and abiotic stresses, and the regeneration is also a little difficult and reproducibility is poor [13]. Identification of pathogen causing the diseases needs developing techniques to create uniform and artificial disease epiphytotics. The use of tissue culture helps to accelerate the resistance screening programme on which research work needs to be initiated to make the resistance breeding effectively. Nevertheless, resistance breeding is also directly related to quality of the produce as it obviates the necessity of application of pesticides which often leaves undesirable residue [9].

Conventional breeding programmes are costly and take long time to achieve results; therefore, under such situations, double haploid breeding holds its promise and particularly offers better scope for improvement in productivity and diosgenin and galactomannan content in fenugreek. The first tissue culture on fenugreek crop was documented [27], and we checked the effects of diniconazole on cell suspension cultures on the crop. Advanced and successful work on micropropagation, callus regeneration, and somatic embryogenesis with fenugreek crop on an MS medium containing thidiazuron (TDZ) was conducted [28].

7. Marker-Assisted Selection Breeding

Conventional breeding predominantly performing depends on the phenotypic selection of superior genotypes. Thus, phenotypic selection has its inherent weakness. Very little effort has been made to estimate the genetic variability among fenugreek genotypes in contemporary years regardless of the advancement in the sequencing technologies. Several investigations have been investigated about fenugreek genetic diversity using various traditional genetic markers [29] such as consuming 14 ISSR and 22 RAPD markers. Seventeen accessions were estimated [30], and additional research investigated 90 genotypes using 13 SSR and 49 RAPD markers [31]. Recently eight landraces were studied using six SRAP primers combination [32]. At the moment, marker-assisted selection is widely used to select plants carrying genomic regions that are involved in the expression on traits of interest, through DNA markers. Plant genetic characters through marker-assisted selection could be increased in importance and precise transfer of genes of interest and to speeding up the recovery of the recurrent parent genome such as fenugreek. The main factors that determine the success of mass assisted selection in crops improvement techniques are the number of target genes to be transferred, the distance between the flanking marker, the candidate gene, and population size in breeding for disease resistant varieties [33].

8. Conclusion

Fenugreek production is an important cash crop of India and other countries in the world meeting domestic needs as well as earning substantial foreign exchange. Its cultivation involves multiple factors that cause biotic and abiotic stresses, adversely affecting the productivity of the crop. From those elements that affect yields of fenugreek crop, powdery mildew is the most destructive disease which causes a major impact to the all the plant parts. Thus, appropriate breeding programmes such as resistance breeding, germplasm collection, evaluation and conservation, mutation breeding, tissue culture techniques, and marker-assisted selection for resistance to powdery mildew disease in fenugreek need to be immediately introduced and applied to decrease yield losses due to the pathogen in the crop.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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