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A review of Iranian big data to advance sustainable production of legume across global farming systems

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ABSTRACT

Sustainable production in legume farming systems needs an advanced understanding of the main biotic and abiotic stresses lower yield, in particular under climate change. This framework must minimize applications of agro-chemicals which harm not only consumers but also agro-ecosystems, and to reduce costs. To accomplish this, a highly diverse array of experimental findings has been reviewed in terms of agricultural, environmental and pathogenic descriptors influential on legume productivity in Iran. We reviewed the documents reporting significant associations of legume production with agro-ecosystem in particular with the rhizosphere. Hence, this Iranian collection involves most influential factors which can play a notable role in improving the sustainability of legumes productivity worldwide. Complicated and joint interactions of legume yield with proper sowing time and dept, best crops to be rotated with legumes, avoid agro-chemicals use, treating seeds with bio-fungicides before sowing, optimized irrigation methods, enhanced rhizobial nodulation via using manure and crop residue to improve soil organic matter were reviewed comprehensively. This novel systematic insight to integrated legume management programs leads global efforts to apply the best farming practices in order to maximize the sustainable productivity via minimizing climate change and agro-chemicals' threats.

1. Introduction

Legumes have been ranked in the world as the second main food source after cereals. Hence, efficient tools for food safety purposes are necessary to secure the legume consumers' (human and livestock) and environmental health. Furthermore, cultivation of legume plants results in numerous benefits for their next crops (Naseri, 2023). In fact, legumes improve soil fertility that benefits them during their growing season and then, also crops in next seasons (Naseri, 2019). In particular, the nodulation of legumes roots provides a rhizobial symbiosis which not only restricts the plant damage due to biotic and abiotic stresses but also improves productivity (Kalantari et al., 2018). These lab and greenhouse observations were also verified at plot and regional scales across commercial fields (Naseri and Tabandeh 2017). Regarding biotic stresses, the most prevalent root rot pathogens in bean crops cultivated in Zanjan province, the third main bean producer in Iran, *Fusarium solani*, *Rhizoctonia solani*, *Macrophomina phaseolina* and *F. oxysporum* have been restricted by rhizobial nodulation on roots (Naseri, 2007, 2008a, 2008b, 2012, 2008a). In Lorestan province, the second bean producer of Iran, lab and molecular studies confirmed the highest prevalence of *F. solani* as root rot pathogen followed by *F. oxysporum*, *M. phaseolina*, and *R. solani* (Dehghani et al., 2016). Morphological, molecular and pathogenic examinations were performed on *Fusarium oxysporum* associated with chickpea wilt in Kermanshah province, the first chickpea producer of Iran (Younesi et al., 2021a). For alfalfa, *Rhizoctonia crocorum* caused violet root rot as the most destructive root disease in multi-year fields in Zanjan (Naseri, 2002).

Although interactions of root diseases with rhizosphere have been well known, it is desired to seek possible associations between aerial plant diseases with the root system and subsequently rhizosphere events. For instance, this is evident for Fusarium wilt in legumes that infect xylem and phloem tissues, however, it is associated with root rots as mentioned above. For another example of indirect biotic stresses on legumes' roots, the productivity of sainfoin as a forage crop is threatened by powdery mildew caused by *Leveillula taurica* across main sainfoin growing regions in Iran, Zanjan province (Naseri and Alizadeh, 2017).

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Although this prevalent disease is caused by an air-borne spores, it can restrict plant growth probably resulting in a lower root system development (Naseri and Alizadeh, 2017). Therefore, such a pathogenic attack to aerial parts of this leguminous plant can also influence root functions which are supposed to restrict not only rhizobial symbiosis but also microbial activities in the rhizosphere. Similarly on alfalfa, *Colletotrichum truncatum*, *Leptotrochila medicaginis*, and *Phoma medicaginis* infect leaves in Zanjan, as one of major forage producer in Iran. However, these destructive diseases decrease plant growth and presumably root expansion linked to rhizosphere imbalances (Naseri and Marefat, 2008). These prevalent pathogens cause brown leaf spot and black leaf blotch epidemics under appropriate agro-ecological conditions. For instance, weekly rainfalls and temperate climate stimulate these diseases. Furthermore, chickpea Ascochyta blight epidemics in Kermanshah are predictable according to the best disease progress predictors fitted to weather variables (Naseri and Mahmoudi, 2024). It is still interesting to unravel interactions of such air-borne diseases with the root and rhizosphere characteristics.

This review focuses on recent Iranian findings to maximize the sustainability in legume yield build-up with the help of proper crop and rhizosphere management strategies. It is highly desired to explore complex interactions among abiotic stresses, climate, diseases, farmers' practices, host plant, pests, soil, weeds and yield for stable productivity purposes. For instance, yield losses to legume pathogens can be alleviated by a highly beneficial interaction of legumes and soil microbiota in particular with rhizobial bacteria (Faraji et al., 2015). On the other hands, these beneficial bacteria as potential legume symbionts are notably associated with agro-ecological variables (Naseri and Tabande, 2017). Therefore, a highly diverse range of regional, plot, greenhouse and laboratory findings on key agro-ecological descriptors of major legume stresses and yield losses has been reviewed according to an Iranian framework.

2. Abiotic stresses

The water, soil conditions, agro-chemicals and temperature stresses are noticed as major abiotic stresses in the current article reviewing 25 years epidemiological studies on legumes' productivity. Hence, sustainable crop management strategies have been found promising, based on Iranian big datasets to protect and produce legume crops stably under major abiotic stresses, are discussed in this section. In contrast to detrimental impacts of drought stress, a traditional practice as proposing bean seedlings to an initial drought period (no irrigation for 2-6 weeks after sowing) commonly used by Zanjanian farmers restricted not only weeds, but also Fusarium and Rhizoctonia root rots (Naseri and Tabandeh, 2014). Although charcoal root rot and Fusarium wilt were slightly intensified, this ancient practice improved bean productivity (Naseri and Veisi, 2019). It also saved 2-6 irrigations for bean growers and water resources that appeared particularly beneficial in arid and semi-arid regions threatened by the global warming and climate change.

Moreover, using gibberellins, zinc sulfate, salicylic acid and seaweed reduced not only root rots as biotic stresses but also the abiotic stress of water deficiency, and thus, increased bean productivity (Naseri et al. 2025a, 2025b). Seaweed fertilizer was sprayed on bean plants at 0, 50, 100 and 150 g/ha concentrations. Therefore, this Iranian practice could be considered in future efforts to develop more sustainably productive crop management programs worldwide. Furthermore, the application of such environmental-friendly inducers of plant resistance can benefit from biocomposts involving rice residues, chicken manure and olive waste (Sharafi et al., 2023) to promote stress resistance and plant growth, possibly by inducers like silicate potassium. Providing field-scale confirmation, this biocompost can be used in fields under the above-mentioned traditional drought practice presumably even longer drought periods can be practiced to control weeds more efficiently, enhance plant resistance to diverse abiotic and biotic stresses, and improve productivity. This would increase sustainability of legumes production while saving further fertilizations and irrigations. It may be also helpful in improving yield of rainfed beans and other legumes which needs further investigation. Thus, investigations are needed to explore the efficiency of combining an ancient practice with novel methods for sustainable crop production in beans as well as other legumes and even cereals.

2.1. Weather & climate

Climatic change in terms of dry and hot summers in Lorestan and Zanjan can lead to a greater susceptibility in legumes to root rot pathogens in particular to charcoal root rot disease (Siahpoush and Dehghani, 2024; Dehghani et al., 2018;Dehghani and Siahpoush, 2024). Root rots were also intensified by early sowing of beans in cool weather in mid-spring in Zanjan, suggesting that these climatic stresses increased the susceptibility of bean seedlings to soil-borne root rot pathogens. Weather variables have been also used to predict severe epidemics of Ascochyta blight in chickpea crops in Kermanshah (Naseri and Mahmoudi, 2024). For sainfoin crops, forage productivity corresponded with not only epidemics of powdery mildew (*Leveillula taurica*), but also six weather indicators involving rainfall, air temperature and relative humidity (Naseri and Alizadeh, 2017). Moreover, these weather indicators provided greater associations with the disease and yield than the genetic resistance at field scale. This reminds us why the stability and adaptability of high-yielding lines and genotypes of legumes are to be examined across different geographical regions and environments (Alizadeh et al., 2021; Shobeiri et al., 2024b). In fact, climate change and global warming can reduce the resistance of plants to drought, temperature and diseases stresses which are to be considered in future breeding programs (Shobeiri et al., 2024a).

2.2. Abiotic & biotic stresses interplay

Regional findings demonstrated improvements of bean nodulation following sowing white beans, avoiding fungicide and urea use, restricting root rots, late sowing in late spring, shallow seeding, applying initial drought, improving soil organic matter in particular by either animal manure or recycled wastes, hand-weeding, following weekly irrigations, and growing bean after cereals (Tabande and Naseri, 2020). Although these agro-ecological characteristics have been previously reported, this new insight into accumulated and ranked impacts of joint interactions between yield and these highly influential parameters is noticed for the first time. Rankings of effective parameters can simplify interpretations of complicated interrelationships driving agro-ecosystems. Such novel information advances our understanding of legumes in a highly complex interaction with abiotic and biotic stresses for sustainable crop protection and production. For instance, deeper and earlier plantings in midspring had more severe root rots with roots rotted by soilborne pathogens not only failed to develop rhizobial nodules efficiently, but also were attacked by larger populations of pathogens when seeds germinate during a longer pre-emergence period (Naseri et al., 2021). As another example, the fungicidal treatment of bean seeds and field soils intensified root rots by restricting rhizobial nodulation and increasing populations of pathogens possibly due to reduced biocontrol agents in the rhizosphere (Naseri, 2013a, 2013b).

According to our data analysis, planting date provided the strongest linkage with bean root nodulation, followed by soil texture and Fusarium root rot index. Therefore, rhizobial nodulation is mainly improved by a highly effective combination of late spring plantings in warm soil, heavier soil textures with greater silt and clay contents maintaining further wetness and minerals, and lower root rot infections as reported by Naseri and Veisi (2019). In other words, temperature, water and pathogenic stresses are reduced by optimizing these three most influential factors on the symbiosis capability of bean plants. Although herbicide applications improved rhizobial nodulation and bean productivity due to reductions in weeds as potential competitors of light, water and minerals, the traditional practice of tempering seedlings with drought restricted weeds more effectively than synthetic herbicides (Naseri, 2016). Therefore, the abiotic stress of water and nutritional deficiency following biotic stresses of root rots and dense weeds is remarkably restricted by an optimized organic agriculture allowing natural events to be occurred in the rhizosphere.

2.3. *Legume genotypic stability*

Bean crops are classified to different classes according to the type of plant growth, seed color and size. The significant association of bean class as a genetic and botanical indicator of the plant in interaction with diverse agro-ecosystems could be used to highlight a pivotal role for yield improvements. Comparisons of legume crops for stability and adaptability in seed production and yield levels also provide valuable information on genetic diversity among sainfoin, lentil and chickpea genotypes evaluated across different environments ((Shobeiri et al., 2024a; 2024b;Pezeshkpour et al., 2025; Alizadeh et al., 2021). Such a systematic insight into the advanced yield improvement in legumes according to the remarkable interaction of plant genome with agro-ecosystems leads to higher and longer resistance levels against abiotic and biotic stresses by using optimized agro-ecological factors as stabilizers. Moreover, soil microbes that can be considered biofungicides (Naseri and Younesi 2021b), bioherbicides (Kakhki et al., 2017) and biofertilizers (Sarafi et al., 2023) are also useful as plant growth and resistance inducers interacting with the plant genome for yield improvement purposes.

Furthermore, bean class affected the complex interaction of the root system with the rhizobial symbiosis linked to inhibitory impacts of using agro-chemicals including herbicides, fungicides, urea and fertilizers. Whereas, these restricted nodulation and yield levels as consequences of above inorganic methods were improved by proper rotations of bean with cereals, enhancing soil organic matter content by applying animal manure, irrigating at 7-9 days intervals to avoid soil over-wetting and low oxygen stresses, and the practice of tempering seedlings with drought which lowered weed density significantly (Naseri, 2014a).

2.4. *Biotic stresses, physical conditions & planting time*

Careful surveys of 87 commercial fields during growing seasons correlated bean yield to soil moisture (Naseri, 2010). Yield decreases following the occurrence of root rots epidemics were observed in bean fields seeded mechanically, early seeding in midspring, monocropping, urea use and dense weed. Subsoil pressure following mechanical seeding in conjunction with seed germination in cold soils which also suppressed root nodulation particularly following urea usage, weak competition for water and nutrients absorbed by dense weeds, and root rotted more severely due to bean mono-cropping can partially justify the above-mentioned observations (Naseri and Hemmati, 2017). Lower root rots, weed and fly damage occurred in shallow sowings of late spring at both scales of experimental plots (Naseri and Mousavi, 2013) and regionally (Naseri and Marefat, 2011) resulting in increased bean yield. Model accuracy of bean yield estimates was improved when seed bed type, previous crop before bean, and root nodulation were also included in the model (Naseri, 2012, 2013c, (2013d)). Root rots were intensified by soil texture with 35-65% sand, pH above 7.5, in larger fields, early sowing in mid-spring in the cold soil, deep sowing at 5-15 cm depths, and denser weeds (Naseri, 2014b, 2014c). We remark that a later planting of beans in late spring restricted root rots and improved the productivity when joined to lower fly damage and higher efficiency of herbicides (Naseri and Kakhki, 2022; Kakhki et al., 2022a, 2022b, 2022c, 2022d, 2023). Likewise, a well-timed sowing of chickpeas to avoid low temperature stresses reduced Ascochyta blight, wilt and root rots, and improved the productivity without any additive synthetic fertilization and fungicides, and labor expenses. Lower Fusarium wilt and greater chickpea productivity at plot scale were detected in late sowings in November and shallow seeding, compared to early sowings in March and deep seeding (Younesi et al., 2020). It is believed that optimal sowing dates increased the durability of genetic resistance in legumes irrespective of the level of susceptibility to stresses (Naseri and Fareghi, 2024). Hence, this influential agronomic practice can add a remarkable value to plant breeders' efforts to find highly resistant cultivars to different stresses. Such advantageous, cheap and easy crop management strategies help us for more economic and stable protection and production of legume crops (Naseri et al., 2018).

3. Pathogen genotype

The genetic diversity among pathogen populations distributed across diverse regions are insufficiently understood to evaluate the virulence level for each major pathogen. Because highly diverse populations of the pathogen results in the breakdown of genetic resistance to that disease that reduce the host plant productivity (Naseri and Emami, 2013a;2013b). A high genetic diversity in *F. solani* f.sp. *phaseoli* populations infecting bean roots was observed in Zanjan. This pathogen was also virulent on red, white and chiti bean classes, chickpea, lentil, sainfoin, alfalfa, faba bean and wheat. Molecular and vegetative compatibility groups studies also confirmed such high genetic diversities in pathogen populations (Khodagholi et al., 2013; Safarlou, 2011). Another influential pathogenic factors on legume yield is the survival of pathogens in the plant residue, seed and soil. Soil populations of *F. solani* in commercial bean fields increased by the end of season. Moreover, the ability of the pathogen to survive in soil and plant tissues varied by the pathogen and region. For instance, *F. solani* and *R. solani* infected roots more frequently, while *F. oxysporum* infected seeds and soils more often (Naseri and Emami 2013a,b). As a result, bean yield was significantly linked to populations of *M. phaseolina* and *R. solani* in roots, and *F. oxysporum* in soil. Root infections also corresponded more strongly to the frequency of *F. oxysporum* isolated from roots, and *M. phaseolina* and *F. solani* isolated from seeds (Naseri and Mousavi, 2015;Naseri and Moradi, 2007). Populations of *M. phaseolina* over the season were more frequently isolated from soils with a lower silt or higher EC. Moreover, populations of these prevalent pathogens were decreased by growing red beans in larger fields, using P-fertilizer, clay-silty soils, monocropping, herbicide and urea (Naseri and Ansari Hamadani, 2017; Naseri et al., 2021). Thus, sustainable legume production programs can be optimized by priorities made according to such regional findings.

In Lorestan, an optimized irrigation program resulting in a suitable level of soil moisture restricted bean root rots (Dehghani, 2012). Mechanical sowing of beans intensified Fusarium root rot and reduced yield that was probably due to a poor maintenance and over-use of planters by farmers (Naseri et al., 2016). Moreover, dense weeds, frequent irrigations at 2-4 days intervals, over-using urea ranging from 50 to 500 kg/ha, rotations as shorten as 1-3 years, dense sowings within the range of 4-17 plant/m^2 intensified root rots on a regional basis (Naseri and Ansari Hamadani, 2014; Naseri and Moradi, 2015). Rotating beans with corn and potato restricted Fusarium and Rhizoctonia root rots, respectively. Such advantageous and easy to implement crop management strategies help us achieve sustainable legume yields with reduced pathogen infections at lower costs than using agrochemicals (Naseri et al., 2018).

4. Rhizosphere biology

In Lorestan, treating bean seeds with local isolates of *Rhizobium etli* b. v. *phaseoli* and seed-bed treatments with *Rhizophagus irregularis* and *Rhizophagus mosseae* reduced root rots and increased productivity (Faraji et al., 2012). These biocontrol agents were more impactful than the fungicide in reducing root rots. In Zanjan, treatments of bean seeds and field soils with local isolates of *Rhizobium* sp., *Bacillus* sp. and *Pseudomonas* sp. decreased Fusarium and Rhizoctonia root rots and Fusarium wilt, and also improved yield in the greenhouse (Kalantari et al., 2011).

In Lorestan, *Rhizobium radiobacter* increased bean yield when treated onto seeds before sowing (Dehghani et al., 2025).

A meta-analysis study of 228 worldwide reports on soil antagonists of bean root rot pathogens indicated the best bio-control efficiencies were achieved with *Trichoderma gamsii*, *Gliocladium virens*, *Trichoderma viride*, and *Pseudomonas fluorescence* (Naseri and Younesi, 2021). This study also showed up to 224% yield improvements against different bean pathogens. Local isolates of *Trichoderma longibrachiatum* and *Trichoderma harzianum* reduced chickpea Fusarium wilt by 64-70% and 69-75% in pot soil and seed treatments, respectively (Younesi et al., 2021b).

5. Concluding remarks

Legumes as the second major food sources for human and livestock consumption can conserve organisms' diversity and provide a healthy life for next generations on the earth. The current article reviewed one of the most comprehensive findings aimed a greater agricultural productivity for a better food safety and security. Moreover, numerous factories producing agro-chemicals could be replaced with ordinary workplaces much more easily making environmental friendly products mainly via recycling agricultural and civil wastes considered as dirty gold. This would reduce greenhouse gases causing global warming and climate change.

CRediT authorship contribution statement

Bita Naseri: Conceptualization, Resources, Writing – review & editing. **Seyedeh Soudabeh Shobeiri:** Data curation. **Ali Dehghani:** Data curation. **Sara Siahpoush:** Data curation.

Declaration of competing interest

There is no competing interest to be reported for this article.

Data availability

No data was used for the research described in the article.

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