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Review

Which Agronomic Practices Increase the Yield and Quality of Common Bean (*Phaseolus vulgaris* L.)? A Systematic Review Protocol

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Abstract: The common bean (*Phaseolous vulgaris* L.) is a grain legume functionally characterized by its capacity for symbiotic of biological nitrogen fixation. As such, it does not demand the application of synthetic nitrogenous fertilizer and can offer environmental benefits as part of holistic cropping systems. While common bean commodities are highly nutritious, commercial cultivation of this crop is declining in already-industrialized countries. However, recent interest of consumers towards diets that benefit environmental and personal health has rekindled commercial interest in legumes, including the common bean. The aim of this protocol is to identify agronomic practices that are capable of increasing the yield and quality of the common bean for use as food. To address this research question, published literature will be screened for inclusion on the basis of defined eligibility criteria to ensure data sources are selected in an objective and consistent manner. Consistency checks will be carried out for the title, abstract and full texts of the literature collated. The output is expected to be a summary of the knowledge available to maximize the productivity and quality of the common bean as food. This anticipated synthesis will be of utility for a wide range of value-chain stakeholders from farmers and consumers, to research scientists and policy makers.

Keywords: agronomy; food security; biological nitrogen fixation; legume; nutrition; protein; sustainability

1. Introduction

Legumes, taxonomically classified under the family Fabaceae, account for around 5% of all plant species and 27% of the world's primary crop production [1]. As legume species typically yield high protein grains, their crop types provide 33% of the dietary-protein requirement consumed by humans [2]. Cultivated legume species are used as food (for humans) and as feedstocks for animals and industrial processes [3]. Anthropological studies have revealed that crop legumes were bred and integrated into human society from the earliest farming practices which date to the Neolithic era [4]. According to Hancock [5], legume domestication occurred around 10,000 years ago and occurred simultaneously in different regions of the world. The domestication of the common bean (*Phaseolus vulgaris* L.) occurred in Mesoamerica [6], while that of the faba bean and chickpea originated in Asia [4].

The main characteristic of cropped legumes is their ability to meet their entire nitrogen (N) needs via a natural process termed biological N fixation (or BNF) by "fixing" largely inert atmospheric di-N

(N_2) gas into biologically useful forms. BNF is achieved through a symbiotic relationship between the legume and specific N_2-fixing soil bacteria collectively termed rhizobia [7]. These bacteria infect the roots of compatible species to form unique organs called "legume root nodules" [8]. In these organs the BNF process is performed [9], where the bacterial enzyme nitrogenase catalyzes the reduction of N_2 to ammonia [10], an N form that is available to the plants. The N_2-fixation capacity is dependent on several factors such as plant species and genotype, the associated strains of symbiotic bacteria, and environmental conditions such as the relationship between geophysical, climatic and soil qualities which include mineral content, water holding capacity and organic matter content [11–19]. Moreover, high levels of residual or applied synthetic N fertilizer can inhibit nodulation and BNF in legume crops, including the common bean [3].

Due to their N-fixing activity, legumes can be used to facilitate the production of non-legumes, such a cereals, as part of holistic crop rotation schemes and via agronomic approaches such as intercropping—thereby improving N availability, crop yields and soil quality [14,20]. Reliance upon legumes in agroecological farming practices can be an alternative to inorganic N fertilizer application, since the latter has resulted in the extensive eutrophication of groundwaters with nitrates [21]. Such potential benefits are accrued in addition to others from fossil fuel use, which is avoided from the production and application of fertilizers [22]. Besides improving N availability [23], crop rotation with legumes can also enhance phosphorus and potassium availability in the soil [24,25] and reduce the requirement for phosphorus and potassium fertilizer additions [25], which according to Skowrońska and Filipek [26] and Peoples et al. [27], also results in greenhouse gas (GHG) emission reductions.

The non-reliance of legumes (crops) on synthetic N fertilizer must be considered as a pivotal tool to help adapt to, and mitigate for, the impacts of climate change and realize more environmentally sustainable land-use strategies [28]. Furthermore, the natural N provision by legume residues left in the field after harvest serve as natural and complex "green manure" [29].

However, imperfect management of such high-N legume residues may also lead to eutrophication via leaching of the N into ground waters [30,31]. Therefore, if more-sustainable land use is to be achieved multi-faceted strategies are required to optimize legume crop management—such as via crop rotation schemes over temporal and spatial scales, and a greater uptake of legume-based intercrops including use of legumes in cover crop mixtures [32]. Besides an increase in crop production, such diversified cropping systems can help maintain enhanced and stable yields via low-input means. Such improved natural resource use efficiency via legumes has been shown to enhance the resilience of the production system and down-stream value chains. As such, the production of legumes presents a critical mitigation and adaptation strategy to minimize the impacts of environmentally damaging farming practices. Furthermore, the production of legumes could help to cope with biotic and abiotic stresses which are linked to climate change and ensure greater food security [33].

Grain legume protein cultivation within Europe is low (ca. 1–4% of the arable farmed area), and 80% of the demand on this protein source is covered mainly from soybean for use in animal-feed formulations. Consequently, it is estimated that 75% of farmed area is used for non-legume (i.e., synthetic N fertilizer demanding) crops, and again, mainly for animal feed generation (i.e., meat production), though also alcohol production—with GHG costs and biodiversity losses [34]. Given the demand for more environmentally sensitive consumption [35], and the increase in flexitarian, demitarian, vegetarian and vegan food choices, the popularity of legume grains, such a common beans, for food has become increasingly important.

The most common legume worldwide consumed as food (i.e., consumed by humans) is the common bean [36], and it is cultivated in open fields and in greenhouses as a grain and vegetable crop, respectively [37]. Common bean is considered the most important protein source in the developing world, which also provides an important sources of minerals, including essential minerals such as iron and zinc, as well as vitamins (B-vitamins, folates), fiber, thiamine, antioxidants, polyphenols and phytochemicals with analgesic and neuroprotective properties [37,38]. In addition, the common bean also presents non-nutritional, and other non-nutritional and potentially anti-nutritional factors, such as lectins, phytic acid, saponins, galacto-oligosaccharides and digestive enzyme inhibitors [39]. The most known bacteria populating common bean root nodules and fixing atmospheric N is *Rhizobium leguminosarum* bv. *phaseoli*. However, the common bean is also characterized by its high capacity to nodulate and fix N in response to nodulation by a wide range of rhizobia species. While this ensures BNF is a wide range of environments, the crop-rhizobia symbiosis is commonly often sub-optimal and the common bean demonstrates a low BNF capacity relative to more modern leguminous crops [40]. Therefore, the need to develop varieties with a greater BNF capacity should be the target of breeding programs [41]. Consequently, the application of synthetic N fertilizer to the common bean is widespread, and more effective methods to improve yield and yield qualities could help ensure the crop can meet the rising demand for this crop. Given the importance of the common bean as food source, this review aims to provide an up-to-date overview of the state-of-the-art knowledge of this species' functional potential. This extends to an appraisal of the literature regarding cultivation practices that could improve yield and yield qualities including nutritional provision. The model approach of assessing the common bean as a food crop is timely and of high technical, agronomic, scientific and societal significance: the latter includes "change-makers" such as those who implement and influence governance and policy measures, such as businesses, governments and non-governmental organizations. The increased desire to empower legumes, and especially grain legumes, in sustainable agri-food system planning in Europe and globally, is evident from the plethora of European Union (EU) completed and currently funded projects (Table 1). The results of such projects reporting "grey" (i.e., non-peer reviewed) literature will also be assessed here a part of this systematic synthesis.

Table 1. Websites of projects, specialist organizations and sources for grey literature.

Organisation	Website
EIP-AGRI Agriculture & Innovation	ec.europa.eu/eip/agriculture
EU FP7 LEGUME FUTURES	www.legumefutures.de
EU FP7 EUROLEGUME	eurolegume.utad.pt
EU FP7 LEGATO	www.legato-project.eu
Global Research Partnership	www.cgiar.org; cgspace.cgiar.org
H2020 DIVERSIFY	www.plant-teams.eu
H2020 REMIX	www.remix-intercrops.eu
H2020 DIVERIMPACTS	www.diverimpacts.net
H2020 DIVERFARMING	www.diverfarming.eu
H2020 PROTEIN2FOOD	www.protein2food.eu
H2020 LEGVALUE	www.legvalue.eu
H2020 BRESOV	https://bresov.eu
ERA-CAPS BEAN_ADAPT	http://www.eracaps.org/joint-calls/era-caps-funded-projects/era-caps-second-call-2014/evolution-changing-environment

2. Objectives of this Systematic Review Protocol

In order to study the available information on agronomic practices which aim to increase the yield and quality of the common bean, the following research question was formulated: "Which agronomic practices increase the yield and quality of common bean (*Phaseolus vulgaris* L.)?" This research question has been further analyzed using the population, intervention, comparator and outcome (PICO: Population, Intervention, Comparator, Outcome) elements that are described in Table 2.

Table 2. The elements of the systematic review question.

Population	Intervention	Comparator	Outcome
Common bean: as a model legume crop for food consumption	Specific agronomic approaches affecting yield or quality of common bean	No, or alternative, intervention	Change in yield and/or quality from crops

The aim of this systematic review protocol is, therefore, to collect as much data as possible on all these aspects, and synthesize these to discern the relative reported frequency of the agronomic approaches employed and their utility to influence (positively or negatively) common bean yield and/or quality. It is anticipated that the approach will identify knowledge gaps to help direct future research efforts to enhance the performance of the common bean. The protocol for this systematic review was developed using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines [42] (Table S1).

3. Methods

3.1. Searching for Articles

The aim of applying specific search criteria is to obtain an impartial and comprehensive literature sample relevant to address the research question. Both peer-reviewed and non-peer reviewed data will be captured. A range of database sources will be searched to maximize the amount of information gathered and so address the research question. The establishment of this strategy requires the most appropriate research terms be determined during an initial exploratory literature survey. This approach will help ensure the protocol is sufficiently robust to gather all the necessary information, and to help enable any future repetition of the systematic assessment.

The systematic review will only include studies published in English due to limitations of time [43] and capacities (e.g., knowledge of other foreign languages) within the review team. However, this is not thought to detract from the quality of the systematic review since English is the most used language in scientific literature, and so the main published studies on the topic of study will still be gathered. Combinations of the following searched scientific terms will be applied to the selected databases. A wildcard (*) will also be used to enable the inclusion of multiple word endings. Each term is used to address each PICO element of the research question (Table 2). The terms to be used for searching literature data sources will be as follows:

- ✓ **Population:** common bean or *Phaseolus vulgaris*
- ✓ **Intervention:** (1) breed * or cultivar (or variety) or resistan * or toleran * or landrace *, (2) grafting or rootstock *, (3) biofert * or inocul * or *Rhizobium* * or BNF, (4) seed prim * (5) tillage or rotat * or intercrop * or organic * or cultivat *or soilless culture or hydroponic *, (6) fertiliz * or nutrient * uptake or nitrogen * or phosphor * or potassium or micronutrient *, (7) irrigate * or frequen * or system * or water quality, (8) abiotic stress * or heat stress or water deficit or drought or climate change * or temperature or greenhouse gas * or ozone or salin *, and (9) disease *or pest * or weed * or pesticide * or herbicide * or insecticide * or fungicide *.
- ✓ **Outcome:** yield or quality or grain * or pod * or product * or protein content or protein quality or amino acid * or carbohydrate * or essential mineral * or vitamin* or antioxidant * or carotenoid * or phenolic *.

The scientific terms among the above-mentioned categories will be combined using the simple word "and" (Boolean operator) [44]. When performing the search, the scientific terms and the Boolean operator may be further customized for some databases and websites that do not allow the use of long and complex combinations of scientific terms. In order to test the search terms and/or their combinations that have been used to construct the research strategy, the Web of Science and Scopus databases were used.

The components of recorded data are date on which the search was conducted; name of the database queried; search term(s) applied; number of data entries returned; and any other relevant notes.

The following literature databases will be queried:

- ✓ Web of Science
- ✓ Scopus
- ✓ Science Direct
- ✓ Wiley Online Library
- ✓ Agricola (United States department of Agriculture National Agricultural Library) NAL catalogue
- ✓ Directory of Open Access Journals (DOAJ);

Moreover, additional searches will be performed through the search engine Google Scholar [41,45]. The first 25 data sources identified (.doc or .pdf documents), will be assessed for relevant information.

3.2. Article Screening and Study Eligibility Criteria

3.2.1. Screening Process

Data will be extracted by the members of the review team (reviewer) separately and then a random sample of at least 20% of the studies from each selection will be checked for consistency. This process will assure the accuracy and repeatability of data extraction. In case of disagreement between the results of each reviewer, a third reviewer will be assigned to resolve the issue(s) encountered. Electronic data extraction forms will be used to characterize the data gathered—such as characteristics of the study, the experimental design and protocols used for the analyses and the results. To avoid or reduce duplications of internet searches, a full text of primary literature from databases will be undertaken.

3.2.2. Eligibility Criteria

All studies that investigate the parameters addressed in this systematic review will be considered for inclusion into the systematic review. However, it is anticipated that the search terms will retrieve an extensive number of studies which will not be relevant to the research question which is posed. Therefore, to be included in the review, each study must meet a set of "inclusion criteria". Furthermore, to ensure a reproducible or consistent assessment, and an efficient screening process, exclusion criteria have also been defined. Consequently, the following inclusion and exclusion criteria have been defined for each PICO element.

3.3. Relevant Subject of Study (Population)

This systematic review will only retrieve data from studies focusing on common bean production of fresh and dry beans for use as food. All other types of cropping will be considered as falling outside of the scope of this review. Studies reporting the use of the common bean as animal feed will be excluded. No geographical restriction will be applied to the studies included in this systematic review.

3.4. Relevant Types of Intervention/Exposure/Occurrence

Agronomic practices that increase the yield and quality of the common bean will be the focus of this systematic review. For this reason, this systematic review will include all the relevant information detailing agronomic methods which (as intervention) increase the yield and/or quality of the common bean. This information will include, for example, aspects such as genetic material, sowing, fertilization, irrigation and integrated pest management systems, and the application of bioactive compounds or biological microorganisms, as performance enhancers and will extend to improved harvesting approaches. Common interventions may be holistic (legume-inclusive) rotations, legume-based intercropping and organic cultivation. The agronomic approaches will also extend to soilless culture since even studies carried out provide valuable insights which are little different in highlighting the practical application potential from any other (soilless) ex campo experimental trials. For example, consider the testing of elite rhizobia inoculants: the symbiosis (for the common bean) may be optimized by N application in only the early, and not initial, growth stages (applied to early nodulation and

BNF is inhibited). Thus, information gathered ex campo, is now being applied in campo. Moreover, even production in soilless cultures, which is being used increasingly to realize food security and avoid prevalent abiotic and biotic stresses, must also meet ever-increasing resource use efficient, environmental and food quality standards.

3.5. Relevant Types of Outcomes

This systematic review will discern outcomes which increase the yield and/or quality of the common bean used as food: "yield" being defined as absolute quantity of harvested product as weight, and preferably as dry or fresh weight, and expressed per unit area originally sown. "Yield quality" may relate to numerous other factors including moisture content, thousand grain weight (an indication of individual bean size), size profile (an indication of grain size variability), nutritional values such as contents of protein and/or amino acid complement, (essential) minerals and other secondary metabolites (e.g., polyphenols and lectins). Yield quality would also include an assessment of pest and disease incidence. Environmental sensitivity outcomes will be assessed from relational outcomes such as the extent to which the increased yield and/or yield-parameters were achieved using resources using efficient agroecological practices, such as lower water, synthetic fertilizer or pesticide use. The positive environmental outcomes would not need to be directly evidenced by, for example N levels in soil leachate, GHG measures or pest incidence, but could be inferred from improved resources using efficiency measures such as the avoided use of pesticides and synthetic fertilizers, and/or the extent to which natural or Integrated Pest Management (IPM) practices were employed—and of course what these approaches were specifically, and the environments in which they were effective.

3.6. Relevant Types of Study

The review will consider any primary experimental study that investigates or reports upon agronomic practices aiming to improve the yield and/or quality of the common bean. Studies that provide a detailed research methodology of protocol and experimental conditions will be included. In addition, secondary studies such as reviews and/or meta-analyses that provide data on the different agronomic practices affecting common bean yield and quality will also be considered. These data will be extracted and will be included in the review.

A "three step approach" will be carried out to identify all the relevant information for the review. This process aims to systematically reject studies, or studies that do not contain relevant information or data. First, all publications will be subjected to a screening process based on the title in order to ensure that relevant articles are either selected or rejected. The second step will involve an abstract screening, whereby all publications whose abstracts will be deemed irrelevant will be excluded. To ensure against article quality and for consistent application of criteria between reviewers, at least 10% of articles will be assessed by two different reviewers at the title and abstract stages. Finally, all remaining articles will be reviewed at the full text level. An analogous consistency test will be made among the members of the review team for the full text level.

3.7. Data Extraction Strategy

The articles selected for data extraction will be separated into two groups consisting of an equal number of articles [46]. Each group will be given to a reviewer, while a third reviewer will double check at least 25% of the articles, in order to ensure the necessary consistency among the two reviewers [46]. All reviewers will test and approve the design of the data extraction sheet and how this sheet will be populated.

3.8. Potential Effect Modifiers/Reasons for Heterogeneity

Factors that may potentially cause variation in the measured outcomes include the following:

- ✓ Locality, including biogeophysical and pedoclimatic conditions of the cultivated area,

✓ Physical and/or chemical conditions of rooting medium,
✓ Analytical methods for quality analysis (e.g., analytic approaches for nutritional compounds such as amino acids).

All these factors will be considered and recorded in case they are reported in the primary studies. Moreover, more factors for heterogeneity or search terms might be extracted from the literature during the review procedure.

3.9. Study Validity Assessment

Studies meeting the searching criteria will be subjected to evaluation and categorization based on its quality (low, medium or high susceptibility to bias) [44]. The studies with low quality will be excluded from the review. If any of the following factors are found in the studies, they will be excluded from the review:

✓ Insufficient methodological description
✓ No experimental (year or site) replication
✓ No statistical analysis

3.10. Data availability, Synthesis and Presentation

In the current article data are not available since only trial searches were performed using several scientific terms in the Web of Science and Scopus databases. For the resultant systematic review, which is anticipated, the extracted data records will be made available as supplementary files. The extracted data will be summarized in a table including the study characteristics, the protocols used and the results.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/7/1008/s1, Table S1: PRISMA-P 2015 checklist: recommended items to include in a systematic review protocol.

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