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Biocological features and prospects of Canavalia Ensiformis (jack bean) utilization

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Abstract: This paper presents a comprehensive analysis of the botanical characteristics, agronomic potential, chemical composition, and utilization prospects of Canavalia ensiformis (Jack bean) under arid farming conditions, with particular relevance to Uzbekistan's agricultural regions. Known as sword bean, this crop represents a promising legume species possessing a wide range of agronomic, ecological and biochemical properties. The article synthesizes contemporary scientific research and emphasizes the importance of introducing this crop for industrial applications.

Keywords: Canavalia ensiformis, drought and salt tolerance, legume crop, mycorrhiza, bioplastics, starch, adaptability.

Introduction: The relevance of developing drought-resistant and poor soil crops in the context of increasing climatic stress emphasizes the need to search for alternative sources of protein and carbohydrates. Canavalia ensiformis (Jack bean) has attracted considerable attention in recent decades as a bioresource with high potential for the agricultural sector, processing and biochemical industries [3,4]. According to the Food and Agriculture Organization of the United Nations (FAO), global challenges in the field of food security require the active introduction of sustainable and underutilized agricultural crops. C.ensiformis, with its ability to fix nitrogen, as well as resistance to drought and salts, is a promising plant for integration into the agrosystems of countries with limited resources. For Uzbekistan, where the problems of desertification, soil degradation and lack of protein in the diet are acute, the introduction of this crop can become the most important element of sustainable agriculture. Studies show that Jack bean demonstrates impressive results in marginal conditions and can be adapted to the soil and climatic conditions of Central Asia [15].

METHODOLOGY

To prepare this review article, a systematic search of the scientific literature on Canavalia ensiformis (Jack bean) was carried out using the Scopus, PubMed, Google Scholar, ScienceDirect and AGRIS databases.

The search covered publications for the past 15 years (2009–2024) in English and Russian, with priority given to peer-reviewed sources (journal articles, reviews, FAO and USDA reports).

The review included papers that met the following criteria: focus on agronomic, ecological, physiological and biochemical aspects of Canavalia ensiformis; data on use in arid and marginal regions; experimental or review studies supported by publication in indexed journals. As a result, the review included more than 40 scientific publications reflecting the current state of research and applicability of the crop in the context of sustainable agriculture.

Botanical characteristics. Canavalia ensiformis belongs to the Fabaceae family, Papilionoideae subfamily, and the Canavalia genus, which includes about 50 species, mainly tropical and subtropical plants. This herbaceous, heat-loving plant is cultivated as an annual in a temperate climate and as a perennial in the tropics. The root system is well developed, has a taproot type and penetrates deep into the soil, which ensures drought resistance and efficiency in the absorption of nutrients.

The stem of the plant is erect or climbing, reaching a length of 2.5 to 5 meters, depending on growing conditions. The leaves are trifoliate, with elliptical or ovoid leaflets up to 15 centimeters long. The inflorescence is a raceme containing 10 to 20 pinkish-purple flowers, typical of most members of the legume family.

The fruit is a linear, flattened pod (bean), reaching a length of 30-35 cm and a width of 2.5-3 cm, containing 8 to 20 large seeds. The seeds are oval in shape and smooth in texture, and their color varies from snow-white to cream or light brown. The weight of 1000 seeds ranges from 800-1100 g, depending on the variety and cultivation conditions [3,14].

Physiologically, the plant demonstrates resistance to biotic and abiotic stress. One of the characteristic features of C.ensiformis is the ability to establish symbiotic relationships with rhizobial bacteria, which promotes the biological fixation of atmospheric nitrogen. Moreover, the crop easily forms associations with arbuscular mycorrhizal fungi, which significantly improves the absorption of phosphorus and microelements, especially in depleted or saline soils [13]. The presence of secondary metabolites, such as canavanine and concanavalin A, gives the seeds natural resistance to pests and diseases; however, this requires thermal or enzymatic treatment before use as food. The plant is able to successfully develop in regions with extreme climatic conditions, including the arid territories of Central Asia.

Bioecological features. Canavalia ensiformis demonstrates outstanding ecological adaptability, which makes it suitable for cultivation on a variety of soil types - from acidic and sandy to saline and degraded [15]. Seeds begin to germinate at temperatures above 200C, while the optimal temperature for vegetation is 25-300C. This crop is characterized by a moderate moisture requirement: thanks to its powerful root system, it is able to withstand long periods of drought.

Sowing is carried out after the end of spring frosts, to a depth of 3-5 cm. The recommended seeding rate is 80-100 kg / ha, with a distance between rows of 45-60 cm. Jack bean responds positively to organic fertilizers and phosphorus-potassium fertilizing, while the use of mycorrhizal inoculants helps to increase biomass and increase the protein content in the green mass [13]. Canavalia ensiformis attitude to light. C.ensiformis (sword-shaped canavalia) is a typical light-loving crop. In experiments with a gradient of photosynthetically active radiation (180, 450 and 900 $\mu mol \bullet m^{-2} \bullet s^{-1}$), a significant increase in biomass, photosynthesis and water use was noted with increased illumination [4].

Photoperiod is also important for C.ensiformis. The highest generative activity is observed with a short day (10-12 hours), which is typical of tropical latitudes [11].

Under shaded conditions, C.ensiformis experiences a decrease in the number of inflorescences and seed productivity [4]. This emphasizes the need to provide the crop with sufficient access to light to ensure high yields.

Canavalia ensiformis attitude to water regime. The Jack bean plant demonstrates high adaptability to various humidity conditions. Studies show that even with a moisture deficit of up to -2.3 MPa, photosynthesis decreases by 40-60%, but after replenishing the moisture, the activity of photosynthesis is restored within 24 hours [24]. This confirms the unique ability of the plant to quickly respond to changes in the environment.

Particularly noteworthy is the powerful root system of Jack bean, capable of penetrating to a depth of 1.5 meters. Thanks to this, the plant provides itself with access to moisture from the lower layers of the soil, which is a key advantage in conditions of variable humidity. In addition, the aerenchymatous tissues of the plant allow it to withstand even short-term flooding, providing the necessary aeration of the roots [10].

For regions with a hot climate, such as Uzbekistan, where irrigation of lands is limited, it is recommended to use canavalia as a cover crop on fertile soils or after harvesting the main crop. It is also possible to introduce Jack bean into a drip irrigation system for the efficient use of water resources [6]. These recommendations will allow you to use the plant's potential as efficiently as possible in conditions of limited moisture and high temperatures. Canavalia ensiformis attitude to air temperature. The crop is adapted to tropical and subtropical conditions with an optimum temperature for vegetation of 20-300C [8]. It is important to note that at temperatures below 150C growth slows down, which can lead to a decrease in yield. On the other hand, when 350C is exceeded, stress is observed for plants, which is manifested in leaf fall and a decrease in photosynthesis [5]. This emphasizes the importance of maintaining optimal conditions for growing canavalia.

However, adult canavalia plants can tolerate short-term frosts down to -10C, which indicates their relative resistance to low temperatures. Interestingly, nitrogen fixation by symbiotic rhizobia is maintained even at elevated temperatures up to 400C, especially if thermotolerant strains are used [11].

Canavalia ensiformis attitude to soil composition. Acidity and structure. C.ensiformis culture shows remarkable adaptability to various levels of soil acidity, facilitating its successful development in the pH range from 4.5 to 8.0. The optimum pH level for this plant is 5.0-6.5, which has been confirmed by research [15]. Interestingly, Canavalia ensiformis prefers well-drained sandy loam and loamy soils, but can also thrive on clay soils, provided there is no stagnant moisture [17].

Salinity. Jack bean, or Canavalia, is a crop that can tolerate moderately saline soils. It is important to note that at the initial stages of seed germination, the plant can tolerate NaCl up to 300 mM without significant reduction in growth rates [17]. This opens up new opportunities for the use of Canavalia in regions with high soil salt content. C.ensiformis can be effectively used to improve soil fertility and ensure crop yields.

Heavy metal pollution. C.ensiformis exhibits resistance to high concentrations of copper and zinc, which makes it a valuable resource in the phytoremediation of contaminated soils [21,24]. Due to the translocation coefficient >1, the plant is able to effectively extract and accumulate heavy metals from the soil, which reduces their content and improves its quality. C.ensiformis can be used to restore the soil ecosystem in industrial areas or lands contaminated with waste.

Symbiotic fixation. C.ensiformis has a unique ability to fix up to 200 kg of nitrogen per hectare with effective inoculation, which makes it an important source of organic nitrogen in crop rotations [17]. This improves soil fertility and increases the yield of other crops. After growing C.ensiformis in the field, the land remains more fertile and prepared for subsequent crops. Recommendations for the use of C.ensiformis in Uzbekistan include growing on solonetzic, depleted and leached soils of the south, in the foothills and valleys. In addition, the plant can be successfully used to restore soils contaminated with heavy metals, and as a green manure, enriching the soil and improving its quality.

In Uzbekistan, especially in the conditions of low-fertility lands of Karakalpakstan, this crop does not require intensive protection from pests and diseases, which makes it economically viable even with a low level of agrotechnical support.

Morphological diversity. Genetic variability of C.ensiformis is manifested in the variability of morphological characteristics, such as seed shape and color, pod length and width, leaf size and shape, plant height, vegetation period, and stem structure. According to Dada et al. (2012), the heritability coefficient of key traits, such as seed weight and pod length, exceeds 80%, making this crop promising for targeted breeding [3].

Ecotypes from tropical regions exhibit predominantly a climbing growth pattern and elongated internodes, while lines bred in arid climates are characterized by a compact habitus and earlier ripening periods. Such variability makes it possible to develop varieties adapted to specific regional conditions.

In the conditions of Central Asia, it is especially important to isolate forms with a shortened vegetation period and increased resistance to salinity. The observed interpopulation variability within the collection fund of C.ensiformis suggests extensive opportunities for adaptive introduction and selection in the agroclimatic conditions of Uzbekistan [15].

Chemical composition and nutritional value. Canavalia ensiformis seeds are distinguished by their rich chemical composition. On average, they contain from 24 to 39% crude protein, from 30 to 42% starch, from 5 to 25% dietary fiber and up to 4% lipids. In addition, they contain B vitamins (in particular, B1, B2, B3) and minerals - calcium, magnesium, iron and phosphorus [16,23]. The protein contained in Jack beans is a rich source of essential amino acids such as lysine, arginine and leucine. This makes this crop a potentially valuable source of protein for both humans and animals. However, the presence of antinutrients - canavanine, concanavalin A, tannins and phytates - limits the possibility of direct consumption of the raw product. Thermal and enzymatic treatment significantly reduces their level, which in turn contributes to an increase in the bioavailability of nutrients [16].

Jack bean starch is characterized by gelatinization ability, resistance to enzymatic hydrolysis and thermal stability. These properties make it a promising component in the production of functional foods, especially in the context of gluten-free products, dietary and specialized mixtures [5].

Comparative studies have shown that C. ensiformis starch has a significantly higher resistance to freeze-thaw cycles compared to potato and corn starch, which makes it especially valuable for the food industry in countries with a hot climate, including Uzbekistan [23].

Application in the food and processing industry and prospects for use. Due to the high content of protein and starch, Canavalia ensiformis is a valuable raw material for the food and processing industry. Thermally processed or fermented seeds are used to produce flour, protein concentrates, starch, and fermented products such as tempeh and miso [16,20]. Jack bean starch exhibits high stability during freeze-thaw cycles, as well as heat resistance and viscosity, making it exceptionally suitable for the production of frozen convenience foods, instant soups, bakery products, noodles, and desserts with a long shelf life [5]. At the same time, the plant protein of this crop is used in gluten-free, dietary, and functional products, including protein drinks, bars, baking mixes, and meat substitutes [16]. In countries with developed food processing, Jack bean is increasingly used as a functional ingredient that helps increase the nutritional value and technological stability of products. Research confirms its promising use in innovative food product formulations [16]. In the context of Central Asia, including Uzbekistan, the relevance of integrating Jack bean into the production of combined grain legume products is significantly increasing, especially given the growing demand for plant proteins and limited agricultural resources.

In addition to the food sector, C.ensiformis shows significant potential in industrial applications. Its starch is used to produce biodegradable packaging materials such as biofilms, mulch films and microcapsules for pharmaceuticals and agrochemicals [20]. It demonstrates compatibility with biopolymers - polylactide (PLA), polyethylenesuccinate (PBS) and others, which helps to improve the strength and moisture resistance of biocomposites [20].

In addition to starch, Jack bean proteins are also of considerable interest, possessing adhesive, film-forming and emulsifying properties. This opens up prospects for their use in the production of environmentally friendly adhesives, emulsion stabilizers, thickeners and bioactive films, which are used in pharmaceuticals, cosmetology and packaging.

Given the growing interest in sustainable biotechnology, the processing of C.ensiformis into biodegradable raw materials can be integrated into the agro-industrial complexes of Uzbekistan. This is especially relevant in the context of the formation of bioeconomy, diversification of agriculture and import substitution.

DISCUSSION

The analyzed materials indicate that Canavalia ensiformis has a wide range of biological and agronomic advantages, which makes it a valuable resource for sustainable agriculture. Its high adaptability to stressful conditions, the ability to symbiosis and the potential for phytoremediation have been confirmed in a number of studies conducted in various regions of Asia, Latin America and Africa.

However, despite the positive characteristics, there are both scientific and practical challenges. In particular, the number of studies devoted to the long-term agronomic stability of canavalia in crop rotation systems, as well as the economic efficiency of its integration into local agro-industrial chains, especially in Central Asia, is limited.

In addition, anti-nutritional compounds such as canavanine and concanavalin A require further study to optimize thermal and enzymatic processing technologies. Breeding studies are needed to develop varieties with reduced levels of these substances, as well as those adapted to the specific soil and climatic conditions of Uzbekistan.

The question of the bioeconomic potential of this crop also remains open: Jack bean starch and proteins are of industrial importance, but studies of their technological compatibility with domestic production platforms remain limited. This creates prospects for development in the field of functional nutrition and biodegradable packaging.

In general, Canavalia ensiformis is a promising object for both fundamental research (physiology, microbiology, genetics) and practical agricultural engineering and biotechnology. Effective use of its potential is possible provided that interdisciplinary tests are carried out and systemic state support for the introduction and processing of non-traditional agricultural crops is formed.

CONCLUSION

Canavalia ensiformis is a strategically important crop that combines resistance to adverse conditions, high nutritional and agronomic value, and potential for industrial use. The ability to form symbiosis with rhizobial bacteria, high biomass productivity, nutritional value of seeds, and adaptability to arid and alkaline soils make this crop very attractive for integration into the agrosystems of Uzbekistan and other regions with similar climatic conditions.

In the conditions of Uzbekistan, C.ensiformis can be effectively cultivated on degraded and marginal soils, especially in regions experiencing a shortage of water resources and limited opportunities for agricultural intensification. Moreover, this crop has significant potential as a source of raw materials for starch- and protein-containing products, as well as biopolymer materials in the food and processing industries. To effectively realize the potential of this crop in the country, it is necessary to conduct varietal and agronomic tests, develop local selection, introduce advanced biotechnological methods of processing raw materials and create a cooperative processing infrastructure. In the long term, Canavalia ensiformis can become a key element of sustainable agriculture, ensuring food and environmental security of the region.

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