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# *Crotolaria juncea* L., A NEW LEGUME CROP FOR CULTIVATION IN RUSSIA: CHARACTERIZATION AND PROSPECTS
(review)

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Abstract

Sunn hemp (*Crotalaria juncea* L.) is a multi-purpose annual legume plant. This is the oldest bast crop grown in tropical regions for fiber (H.R. Bhandari et al., 2016; 2022). In 1791, the plant was brought to Europe where it is cultivated as an alternative green manure crop. Crotalaria has been shown to produce sufficient dry matter to cover and protect the soil from potential erosion, as well as providing nitrogen in amounts useful for subsequent harvests of crops in a diversified crop rotation (D. Scott et al., 2022, A.P. Barros et al., 2022). In the United States, the plant occupies one of the leading places in the list of intermediate cover crops. Dry green biomass contains from 18 to 22 % protein, but can only be used in limited quantities for livestock feed (< 10 % of the silage produced), since sunn hemp during flowering accumulates the toxic alkaloid monocrotaline. The sunn hemp seeds are up to 35-40 % protein, and also contain a small amount (up to 0.1 %) of toxic dehydropyrrolizidine alkaloids (trichodesmine, junsein, apigenin-7-4'-0-diglucoside, apigenin-7-glucuronide, lectin, senecionine and seneciphylline) and amino acids (alpha-amino-beta-oxylaminopropionic, alpha-aminoxylaminobutyric and/or alpha,gamma-diaminobutyric) (V.B. Malashetty et al., 2015; F. Prada et al., 2020). Their use in animal feeding requires special attention and is, if possible, undesirable. The main non-toxic variety currently used in the United States is Tropic Sun. In other varieties, the accumulation of toxic concentrations of alkaloids in the biomass occurs at flowering, so plant biomass for silage should be harvested 60 days after sowing (J.E. Garzon et al., 2021; J.B. Morris et al., 2015). It was noted that pruning shoots to 30 cm 60-100 days after sowing and re-growing for 70 days increases the nitrogen content in the biomass (A.S. Abdul-Baki et al., 2001). In Russia, crotalaria can be an unconventional cover crop in biological farming to reinforce the soil, improve fertility and for reclamation. The area for sunn hemp cultivation may be southern regions, in particular the Krasnodar Territory, the Republic of Adygea and Crimea. Polysaccharides (galactomannans) from the sunn hemp seeds are bioactive growth stimulant for other plants (R.P. Zakirova et al., 2020). These metabolites, obtained as a result of the refining (degumming) process of vegetable oil extracted from seeds, can be comparable in quality to seed extracts from guar (*Cyamopsis tetragonolaba* (L.) Taub) – another currently in demand annual legume crop (E.A Dzyubenko et al., 2023). Secondary metabolites extracted from Crotalaria leaves are a rich source of carbohydrates, steroids, triterpenes, phenols, flavonoids, alkaloids, amino acids, saponins, glycosides, tannins and volatile oils (S.K. Dinakaran et al., 2011). Thus, *C. juncea* has hypolipidemic, antioxidant, antibacterial, antifungal, antidiarrheal, anti-inflammatory, hepatoprotective and many other pharmacological effects. Another practical application of *C. juncea* is the production of cost-effective biofuels (S. Sadhukhan et al., 2016).

Keywords: *Crotalaria juncea,* biological farming, recultivation, galactomannans, natural gum, pharmacology

*Crotalaria* is one of the largest genus in the family *Fabaceae*, the subfamily *Papilionoideae* [1]. The genus is currently assigned to the tribe *Crotalarieae* with another 15 genera divided into three groups (Fig. 1).

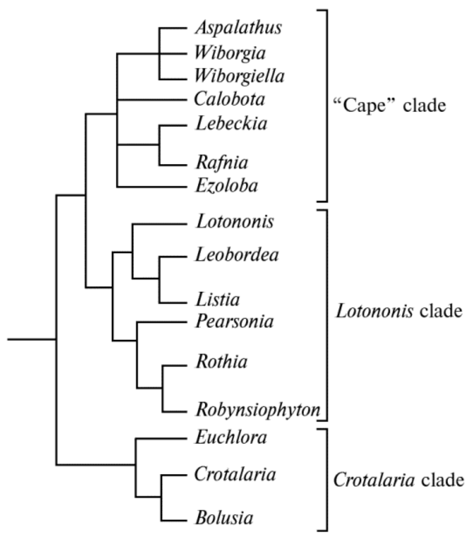


**Fig. 1. Phylogenetic tree of the tribe *Crotalarieae* based on a combination of morphological and molecular genetic synapomorphies [**4, 9].

The *Crotalaria* group consists of three genera, the *Euchlora*, *Bolusia* and *Crotalaria*. The *Crotalaria* genus comprises more than 713 species of annual and perennial plants growing throughout the world [2]. Africa and India are the main centers of *Crotalaria* biodiversity (approximately 540 species), as well as Madagascar [3-5]. In India, the habitat of 73 species is limited to the peninsular territory (Karnataka, Andhra Pradesh, Kerala, and Tamil Nadu), with most of them occurring in the western states (Maharashtra, Tamil Nadu, Karnataka, Kerala) [6]. Approximately 15 representatives of Indian species are endemics listed in the Red Data Book of Indian Plants [7, 8].

In 1753, Carl Linnaeus was the first to describe 12 species of the genus *Crotalaria*, i.e., *C. perfoliata*, *C. sagitalis*, *C. juncea*, *C. triflora*, *C. villosa*, *C. verrucosa*, *C. lotifolia*, *C. lunaris*, *C. laburnifolia*, *C. micans*, *C. alba* and *C. quinquefolia* [9]. In 1786, Jean-Baptiste Lamarck was the first to propose a general classification of species in the genus. The existing sectional classification of *Crotalaria* based on morphological charaacters is not fully consistent with its molecular phylogeny. Some members of the genus *Crotalaria*, particularly *C. cornetii*, *C. peschiana*, *C. prolongata*, and *C. variegata* are indicators of the copper and cobalt ions in the environment, capable of their hyperaccumulation (≥ 50 μg Cu/g DM and ≥ 5 μg Co/g DM) [10]. It is known that the metallophytes *C. cobalticola* and *C. peschiana* do not require high concentrations of copper during early ontogenesis and can grow on an uncontaminated substrate for a relatively long time [11].

The purpose of this review was to summarize the data available in scientific literature on the cultivation of the leguminous crop *Crotalaria juncea* which is atypical for the Russian Federation.

Botanical description and distribution of the species *Crotalaria juncea*. *C. juncea* plants have been grown as a bast crop in India since 600 BC. In the 1960s, *C. juncea* was the main source of income for the country's economy. The plant name is due to its resemblance to rush grass (*Spartium junceaum* L.), a Spanish Mediterranean shrub with green shoots and sparse yellow leaves [12].

*C. juncea* is an erect, shrubby annual plant, typically 1 to 4 m tall [13].

Pubescent stems are up to 2 cm in diameter. The leaves are alternate, simple, linear-elliptic to oblong-lanceolate in shape, up to 15 cm long and 3 cm wide, bright green in color, usually with an acute tip. Stipules are 1-2 mm long, slender. The petiole is approximately 3-5 cm in length. The inflorescence is a leaf-shaped, opposite raceme 10-50 cm long, loose, consisting of 6-20 flowers. Spectacular butterfly-shaped flowers are bisexual, zygomorphic, 5-membered. If cross-pollination is absent, self-pollination occurs due to stimulation of the stigmatic surface by insects or wind [12].

The main insect pollinators of the crop are three species of bees, the *Xylocopa fenistroides*, *X. latipies* and *Megachile lanata* [14, 15]. The flowers are also visited by *Apis florea* and *A. indica*, but they are not effective pollinators because of their smaller bodyweight. The calyx is five-lobed, 1.5-2.0 cm long, covered with short brown hairs. The blades are 3-4 times longer than the tube. The corolla is bright yellow, elliptical, with a reddish tint. Ten stamens are free almost to the base. Bracts are elliptical, up to 3-5 mm in length. The fruit is a cylindrical bean, from 3.0 to 5.5 cm long, velvety, with 6-12 heart-shaped seeds 4-6 mm in diameter, dark brown to almost black in color. Depending on the variety and environmental conditions, the number of seeds varies greatly from 18,000 to 30,000 per kg of crop [16]. The Hawaiian cultivar Tropic Sun produces 30,000 to 35,000 seeds/kg.

The plant traditionally grows in Asian countries, especially in its tropical part (Bangladesh, Bhutan, India), but is widely cultivated in drier areas of the tropics, subtropics, and in areas with a temperate climate and hot summers. *C. juncea* grows in many countries of the African continent from the Atlantic coast to the Red Sea, from Tunisia to South Africa and on the islands of the Indian Ocean (Fig. 2).

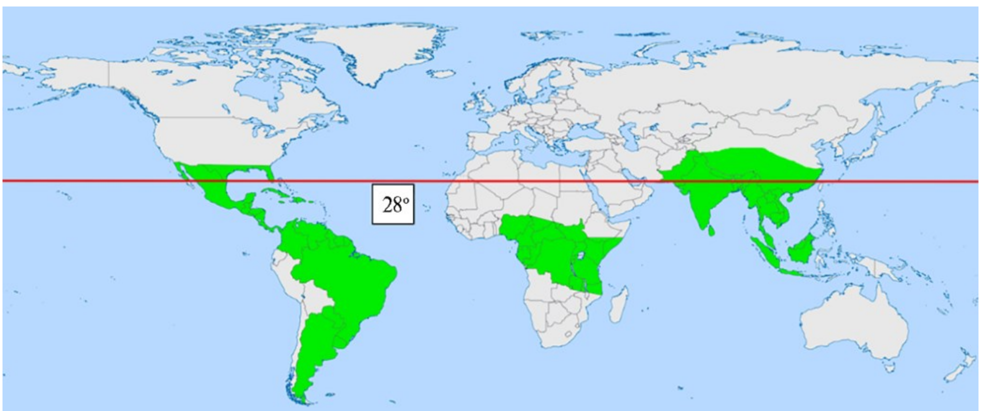


**Fig. 2. Distribution of *Crotalaria juncea* L.** (area highlighted in green).

The species was first introduced to Europe in 1791 as a cover and bast crop [6, 17]. The BECOOL project (https://www.becoolproject.eu/) has now been launched to assess the potential for growing non-conventional lignocellulosic crops in diversified crop rotations across Europe [18, 19].

The *C. juncea* came to the USA from the Hawaiian Islands where its large-scale research has been carried out since the 1930s. Now *C. juncea* occupies one of the leading places in the list of intermediate green manures in the USA southeast (e.g., Florida, Texas, Alabama, Oklahoma, Georgia) [20]. The plant is also grown in the north (Washington), but not intensively.

Features of growing *Crotalaria juncea*. The culture has a C3 type of metabolism. It is a light-loving, short-day crop [21] which reproduces only by seeds. The optimal air temperature for growth is 28-32 °C. Optimal soil conditions are good drainage, pH 5.0-7.5 and 170-200 mm precipitation during the growing season [16].

Crotalaria can grow either as a monoculture or in a legume-cereal mixture [22], e.g., with millet *Pennisetum glaucum* (L.) R.Br., corn *Zea mays* L., or sorghum/Sudangrass *Sorghum* × *drummondii* (Nees ex Steud.) Millsp. & Chase (Fig. 3). Less commonly, the crop grows together with other legumes, thetephrosia *Tephrosia vogelii* Hook. f. and sesbania *Sesbania sesban* (L.) Merr.), American vetch *Aeschynomene americana* L., Chinese cowpea *Vigna unguiculata* (L.) Walp., hairy indigo *Indigofera hirsuta* L., and thin-leaved rattle *Crotalaria ochroleuca* G. Don [23].


**Fig. 3.** ***Crotalaria juncea*** **L.** (1) **and sorghum** ***Sorghum*** **×** ***drummondii*** **(Nees ex Steud.) Millsp. & Chase** (2) (photo courtesy of Stacy Swartz and Daniel Calzadilla) **grown in a mixture; 5 weeks after sowing** (left)**, and mature plant roots** (right) **[26].**

Sowing crotalaria immediately after harvesting corn and soybeans remains the land fallow for less time thus minimizing soil degradation. This crop increased nitrogen content in a 0-5 cm soil layer compared to fallow [24, 25]. In crop rotation, corn can follow crotalaria. The residual effect of planting *C. juncea* provided higher corn yield, freshness of spikelets with straw, and greater productivity of marketable cobs compared to the control [26].

Crotalaria is not particularly demanding on soil fertility, but on poor soils, it will not produce the same biomass as on rich soils. It was noted that the crop might not form seeds north of the 28° parallel. Nevertheless, in the conditions of the Russian Federation, crotalaria is a candidate crop for use in a modern biological farming system. As a complementary non-traditional legume plant, it will improve the state of soil ecosystems [27]. The area for crotalaria cultivation in our country could be the southern regions with a warm temperate climate, in particular the Krasnodar Territory, the Republic of Adygea or Crimea.

We did not find scientific publications on the cultivation and use of crotalaria on the territory of the Russian Federation. It is known that at the Vavilov Federal Research Center the All-Russian Institute of Plant Genetic Resources (VIR), there is a collection of crotalaria lines. The latest seed adaptability assessment of the *C. juncea* performed in Kuban dates back to 1978-1984. However, the research was not continued.

In crotalaria monoculture, early sowing dates, from June 15 to July 15 are preferable [28, 29]. In the Republic of Uzbekistan, this is early April-May [30]. Sowing dates vary depending on location, but sufficient soil moisture and frost-free, warm weather will ensure rapid emergence and high yields. Late sowings leads to abundant branching. The seed rate for commercial sowing is ~ 17.0-34.0 kg/ha [31], sowing is continuous, in double rows. For fiber production in Brazil and India, seeding rates are higher, up to 60.0-100.0 kg/ha. With a decrease in crotalaria planting density, the weed population also decreases [32]. For better germination, the seeding depth should be 2.5 cm, with 10 cm distance between plants in a row and row spacing no more than 10-20 cm. The recommended crop dencity is 48-100 plants per 1 $m^2$ [33, 34]. For paper production where fine fibers are required, the distance between rows can be up to 30-36 cm [21]. Increasing the distance between rows leads to a decrease in fiber diameter, making plants susceptible to lodging, which affects seed production. Planting density generally does not affect plant height, but unthinned plants reach greater height and average biomass, which may be due to increased competition for light energy. However, dry shoot biomass was greater at higher planting densities [35]. Low sowing density helps to increase the diameter of the stem and the number of formed lateral shoots. Due to less competition, there are more branches per plant.

Reports on the rate of application of mineral fertilizers vary. After germination, N at 30 kg/ha and $K_2O$ at 40 mg/kg are recommended [22, 36]. The phosphorus $P_2O_5$ dosage is 20 kg/kg though the soils with low levels of this element require a higher dose [37, 38]. In a recent study, for typical gray soils in the Tashkent region, the optimal rate (kg/ha) was $N_{120}P_{160}K_{120}$ [39]. With sufficient humidity, temperature and soil fertility, the plant growth rate is 14.0-30.0 cm per week, or 2.0-4.3 cm per day.

Treatment of crotalaria seeds with native inoculants for Chinese cowpea (*Bradyrhizobium japonicum*, *Rhizobium leguminosarum*) forms a legume-rhizobil symbiosystem, enhancing the atmospheric nitrogen fixation in crops and its accumulation in the soi [40, 41]. For crotalaria inoculation, highly specific rhizobia of the genus *Methylobacterium* have been isolated [42], namely, *M. nodulans* strain ORS2060 [43] and the closely related strain CMCJ317 [44]. Additional application of organic fertilizers to the soil induces the development of the *R. leguminosarum* population [45]. A better dosage of organic fertilizers is 3-5 t/ha. Increasing the content of humic and fulvic acids in soil organic matter provides stimulating and stabilizing effects, since these compounds significantly improve growth and increase the titer of rhizobia.

Keeping seeds in hot water (70 °C) for 8 h before sowing provides surface sterilization and stimulates germination [46]. An example of another *Crotalaria* species, the *C. verrucosa,* shows that aggressive chemical compounds can also serve as sterilizing reagents, e,g., sulfuric ($H_2SO_4$) and hydrochloric (HCl) acids [47, 48] provide a higher elimination of microorganisms from seeds. Additional ultraviolet radiation (UV-B) increases the activity of enzymes (peroxidase, polyphenol oxidase, superoxide dismutase and phenylalanine ammonialyase) and the production of reactive oxygen species, e.g., superoxide anion, hydroxide ion, and hydrogen peroxide. These forms are extremely active and cytotoxic [49]. Thus, growth activation under irradiation may be an adaptive mechanism of plant tolerance to stress [50].

The optimal harvest time ensures the highest quality crotalaria fiber. Although opinions vary, the general recommendation is that it should be done at the mature fruit stage when the plant has 40, 60, 80, and 100% dry yellow beans that produce a characteristic cracking sound when shaken [51]. Usually this is the 133-155 days after the flower has fully opened (anthesis). Flowering occurs 60-71 days after sowing. Sometimes the minimum period from sowing to flowering is 20-25 days. The full growing season is 153-226 days [52]. If crotalaria is grown for too long, the bast fibers can become lignified which will complicate their further processing. Cutting shoots to 30 cm 60-100 days after sowing [53, 54], and then 70-day re-growing the plant increases the nitrogen content of the biomass [54]. The optimal time for cultivation is 170 days. The yield is harvested mechanically with a combine or manually.

To date, the productivity of crotalaria in the humid subtropics has been poorly studied [25], and information on cultivation in temperate climates is lacking [55]. According to some reports [56], the production of *C. juncea* green biomass during the pre-monsoon period in India was 22-27 t/ha. Moreover, depending on soil conditions, the fiber yield was 0.12-0.60 t/ha, and the seed yield was up to 10-22 t/ha.

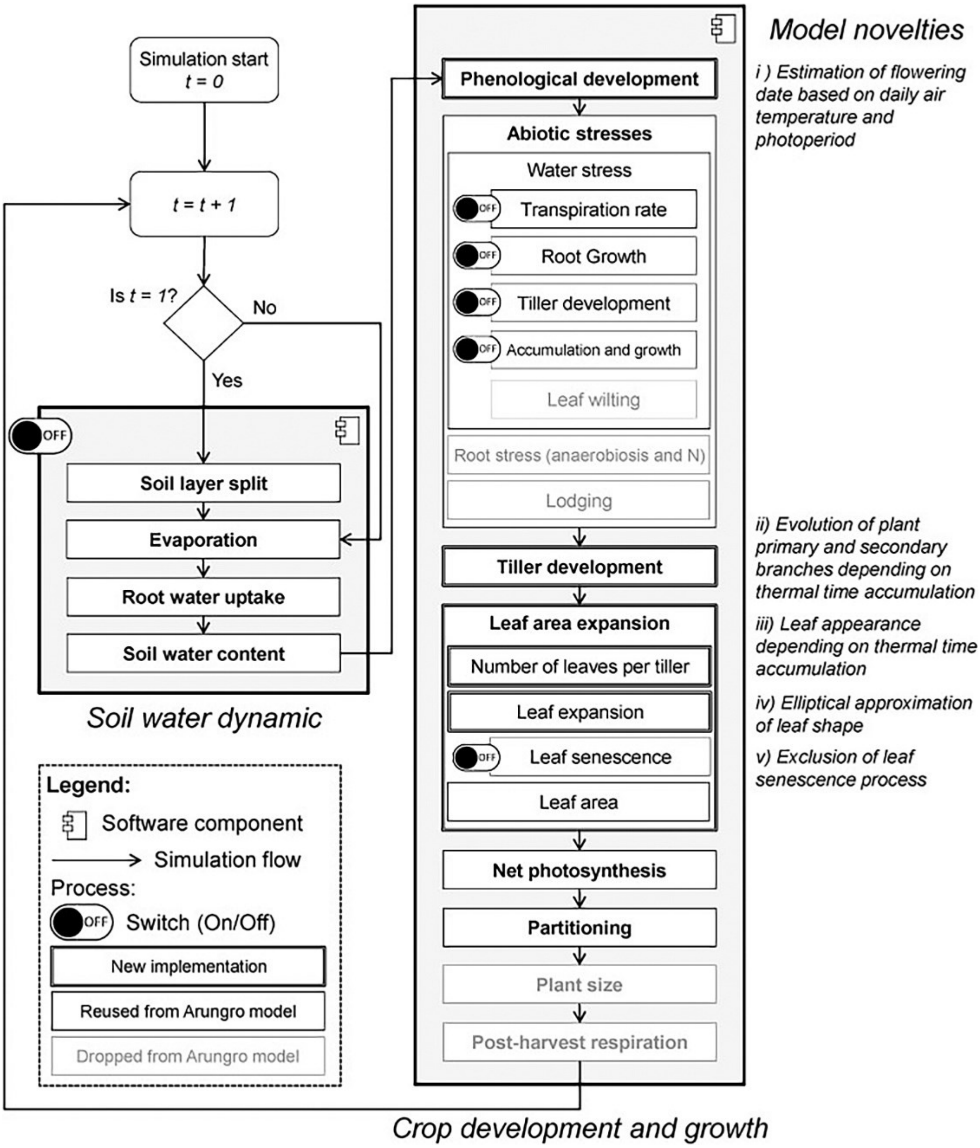


**Fig. 4. Flowchart showing the main *Crotalaria juncea* L. yield modeling processes incorporated in the SunnGro program.** Boxes with a light gray border indicate processes that were excluded from the original implementation of the Arungro model developed for sugarcane [57].

Recently, an international team from Italy, Spain and Greece developed a simulation model called SunnGro which showed high accuracy in predicting crotalaria productivity in different soil and climatic conditions using biophysical modeling methods [57]. The simulator was based on finding empirical relationships between production/biometric traits and harvest time. The previously created Arungro model for assessing the growth dynamics of giant reed plants (*Arundo donax* L.) was taken as the basis for new algorithms. T. Stella et al. [58] presented an algorithmic description of Arungro. Figure 4 shows the processes implemented in the adapted SunnGro module. To calculate and reproduce data on crop productivity with regard to the external limiting factors, the authors used data from long-term experiments (1999-2018) performed at different times and densities of crop sowing in three different locations (one for each country) [57].

Diseases and pests of *Crotalaria juncea*. Of the serious diseases reported in the United States, crotalaria is susceptible to anthracnose caused by the fungus *Colletotrichum acutatum*. Plants are also susceptible to powdery mildew (*Microsphaera diffusa*) and root and stem rot (*Sclerotium rolfsii*) [59]. Treating seeds with fungicides and crop rotation are the most common practiced measures to combat the pathologies.

The main insect pests of *C. juncea* in the United States are the pulse pod borer moth (*Etiella zinckenella* Treitschke, 1832) and the bella moth (*Utetheisa bella* L.) [60]. In Florida, these insect pests have been reported to attack beans with little or no seed production. In India, the main insect pests of crotalaria are the crimson-speckled moth (*Utethesia pulchella* L.) which feeds on leaves and seed pods, and the codling moth (*Cydia pomonella* Linnaeus, 1758) which damages apical shoots by feeding there and causing excessive branching and cessation of apical growth [61]. Additional insect pests reported to periodically attack the crop are caterpillars of crotalaria pod borer *Argina astrea* (Drury, 1773) and *Argina syringa* (Cramer, 1775) fed plamt leaves, and the southern green stink bug *Nezara viridula* L. [60]. As in the case of disease control, the main protective measures include treating crops with insecticides. To avoid outbreaks of pests and the spread of diseases, the crop should be returned to crop rotation no earlier than in 3 years.

Economic importance and use of the species *Crotalaria juncea*. *C. juncea* is a multi-purpose crop. Of all the species of the genus, only *Crotalaria ruminata* is grown for its fiber the harvest of which accounts for about 8% of the stem dry biomass [6, 17]. The fiber is 10.0% moisture, 67.8% cellulose, 16.6% hemicellulose, 3.5% lignin, 0.3% pectin, 1.4% water-soluble substances and 0.4% fat and wax. Nanocellulose of various morphologies is extracted from biomass using acid hydrolysis. The highest yield (94.83%) was obtained when using 32% $H_2SO_4$ solution, the lowest yield (12.03%) when using 72% $H_2SO_4$ solution. However, in the latter case, the product had the highest thermal stability among other nanocellulose morphologies [62].

Crotalaria fiber is classified as soft and is used mainly in the production of cigarette paper, fishing nets, bags, and ropes [21, 56, 61]. In terms of strength, it is superior to jute, but inferior to flax, agave fiber (sisal) and textile banana (Manila hemp, or abaca) [63]. Basal shoot diameter and plant height were found to significantly correlate with fiber yield. The thickest fiber is usually found in the middle of the stem [64, 65]. Research conducted at commercial greenhouses in Texas evaluated the feasibility of producing and using shorter core fibers when growing plants in soilless potting. The fiber can exceed kenaf (*Hibiscus cannabinus* L.) in terms of bast length and width. Additionally, unlike *H. cannabinus*, *C. juncea* can grow in soils infested with root-knot nematodes [6]. Moreover, the species can be a predecessor of crops (e.g., potatoes, tobacco, soybeans, etc.) prone to damage by these parasites [66]. The culture exhibits nematostatic activity against *Meloidogyne* spp. [67-70], *Heterodera glycines* and *Rotylenchulus reniformis* [71, 72]. A significant relationship was revealed between positive mycotrophy and an increase in plant resistance to *Meloidogyne javanica* and *M. incognita* upon inoculation of the culture with an arbuscular mycorrhizal fungus (*Glomus interradices*) [73].

Due to the use of a continuous system of cultivation of rice and wheat with high doses of inorganic fertilizers, the soil agroecosystem is disrupted, requiring the integration of legumes as green manure into crop rotations. It is known that adapted tropical legume plants accumulate greater dry biomass, nitrogen and potassium in the soil per 1 ha [74-77] compared to other types of winter legumes already in the virginal period of ontogenesis (35-60 days) [28, 59, 78]. It has been shown that crotalaria as a predecessor significantly increases the yield of rice, wheat, rye and corn in crop rotation [56, 76, 79-81. *C. juncea* has also been proposed as a green manure for organic strawberry production [82]. *C. juncea* as a green manure for different crops exibits a significant positive correlation between plant heights, green and dry biomass, and number of root nodules [83].

Due to land shortages, fodder crop cultivation is not attractive to many Indian farmers, leaving cattle owners in India dependent on expensive concentrates [84]. The nutritional value of crotalaria is no less than that of clover and alfalfa [85, 86]. Its hay contains a significant amount of protein, from 18 to 22%. However, due to alkaloids (trichodesmin, junsein, apigenin-7-4'-0-diglucoside, apigenin-7-glucuronide, lectin, senecionine, seneciphylline and monocrotaline) in the dry biomass, the crop is used to a limited extent for silage, no more than 10% of volume. Toxic alkaloids are contained in the form of free bases in seeds and shoots, so their inclusion in the diet of animals requires a special attention and separate study [87-89]. Plant seeds may also contain toxic amino acids ($\alpha$-amino-$\beta$-oxylaminopropionic, $\alpha$-aminoxylaminobutyric and/or $\alpha,\gamma$-diaminobutyric) [87, 88]. In animals. toxicants lead to refusal to eat and general weight loss, an increased excitability, lameness and constant diarrhea. Horses may develop tenesmus and, less commonly, pulmonary adenomatosis and severe dyspnea. Nephrosis occurs in pigs, hair loss and difficulty breathing in sheep [90, 91].

The main non-toxic crotalaria cultivar currently used in the United States is Tropic Sun released in 1983. In other varieties, the accumulation of toxic concentrations of alkaloids in the biomass occurs at the flowering stage, 45-60 days after sowing [92, 93]. To meet the needs of most livestock and avoid the toxic effects of these compounds, plant biomass for silage should be harvested at a specified time [53].

In experiments with bacterial biofilms, the crotalaria alkaloid kaempferitrin, a flavonol glycoside exhibited antimicrobial properties against the Gram-positive pathogenic bacterium *Staphylococcus aureus* [94]. Aqueous extracts of the crotalaria plants have an allelopathic effect against weeds [95-98]. Moreover, extracts from 4-week shoots reduced the number of cereal weeds, broad-leaved weeds, and sedges, having a stronger inhibitory effect than extracts obtained later in the growing season [97].

*C. juncea* has some potential for resistance to heavy metals, particularly tolerance to the accumulation of cadmium, nickel, and chromium ions [99-102]. To a certain extent, it can be used in the technology of phytoreclamation (phytoextraction) of technogenically-disturbed lands [74, 103]. Inoculation with toxicant-resistant strains of rhizobacteria from the genus *Streptomyces* significantly increases phytoextraction of cadmium from a crop [104].

*C. juncea* seeds contain 45.2% carbohydrates, 36.4% protein, 4.2% fat, 10.8% moisture and 3.3% ash. A small proportion (up to 0.1%) of toxic dehydropyrrolizidine alkaloids is also present [105]. Polysaccharides (galactomannans) resulted from degumming of seed oil can be used as physiologically active growth-stimulants for exogenous treatment of other plants, in particular cereals [106]. Their further purification by precipitation produces a viscous colloidal solution, the gum. This gum is a natural food additive or a thickener (stabilizer) in addition to the high-molecular gum extracted from guar *Cyamopsis tetragonoloba* (L.) Taub, another leguminous crop non-traditional for Russia. The *C. juncea* gum is used in the mining industry to break down oil-bearing formations [107].

The *C. juncea* can be used in pharmacology and medicine [108]. The seeds cleans the blood, treat impetigo, psoriasis, other skin diseases, it also stimulates menstrual cycle. The juice from the leaves is used to relieve swelling and treat leprosy. In Indian folk medicine (Ayurveda), the leaves are used as an emetic, laxative, abortifacient, analgesic meanse, and to treat diarrhea and bleeding disorders. Crotalaria flowers are useful in the treatment of gonorrhea and blood diseases [108].

Secondary metabolites isolated from crotalaria leaves, flowers, and seeds provide a rich source of carbohydrates, steroids, triterpenes, phenols, flavonoids, saponins, glycosides, tannins, anthraquinones, chebulic acid, ellagic acid, gallic acid, chebulic acid, and volatile oils [109]. The plant has hypolipidemic, antioxidant, antibacterial, antifungal, antidiarrheal, anti-inflammatory, hepatoprotective, hypolipidemic and pharmacological effects. We especialy highlight the results of assessing the antibacterial activity of alcoholic extracts from the seeds and flowers of *C. juncea* against *Citrobacter freundii*, *Escherichia coli*, *Enterococcus faecalis*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Shigella flexneri*, S*taphylococcus aureus*, *Shigella dysenteriae* and *Vibrio cholerae* when grown on an agar medium. It was shown that an ethanol extract from seeds had a higher antibacterial effect than an extract from flowers [110]. The zone of growth inhibition varied from 14.00 to 18.00 mm. Although the results were positive, still they turned out to be worse than for ciprofloxacin used in the experiment as a standard [111].

Compounds extracted from *C. juncea* seeds in sodium phosphate buffer are highly active against the bacterial pathogen *Xanthomonas oxanopodis* pv. *punicae* [112]. Analysis of antifungal activity in vitro revealed the peptides cj-AFP and cp-AMP in seeds, which are capable of inhibiting the growth of filamentous fungi Fusarium oxysporium (113, 114). These proteins were subjected to de novo amino acid sequence analysis, finding no homology with existing proteins in the data bank. The discovery of these peptides may contribute to the development of biotechnological products — transgenic plants resistant to fungal diseases.

Another practical application of *C. juncea* is the production of low-cost biofuel from seed oil [115]. It has been noted that the anaerobic fermentation of cow manure added with of 20% crotalaria serves as a potential source of additional biogas production [116]. Since plant fiber consists of lignocellulosic biomass and is difficult to microbially transform, alkaline pretreatment is necessary [117]. Alkali destroys lignin, neutralizes the acidity of the biomass and increases the methane ($CH_4$) production. Sodium hydroxide is the best in terms of alkaline decomposition of agricultural waste [116]. It has been shown that when plant raw material is processed before fermentation, the $CH_4$ production is 89% higher than without pre-treatment [115].

F u r t h e r  p r o s p e c t s  f o r  r e s e a r c h. Currently, there is a growing need for fiber production and the development of organic farming technology. Because crotalaria can be grown on a large commercial scale as a cover crop and bast crop [118], many countries around the world are gradually introducing it into diversified crop rotations as a green manure to improve the soil health and reduce root-knot nematode abundance. An effective agrotechnical technique that increases the adaptation of a crop to the conditions of a certain soil-climatic zone can be the use of biological products based on a consortium of beneficial nodule and associative rhizobacteria, as well as arbuscular mycorrhizal fungi. Dur to creation of a legume symbiosystem, the mineral nutrition and tolerance of the macrosymbiont to various stresses improves [119, 120].

Efforts should be focused on introduction of the crop into various agroclimatic zones of our country. The limiting factor for now remains the high cost of seeds accounting for 4.5USD per 1 kg.

As a multi-purpose crop, crotalaria is of interest as a raw material for the production of high-quality fiber, a source of lignite cellulose in the production of biofuel, and green manure. The potential is being assessed of using crotalaria for livestock feed and as a remediator plant, accumulating in green biomass toxicants from the soil ecosystem during its gradual phytorecultivation (sanitation).

The pharmaceutical use of the crop is a separate area. In this case, it is permissible to cultivate plants in both fields and greenhouses on soilless substrates with minimal use of mineral fertilizers, herbicides and other chemical protectanys, but with organic growth regulators and microbial biological products. The vast majority of alkaloids found in the genus *Crotalaria* must be studied to evaluate their pharmacodynamic properties and to develop new alkaloid-based drugs [121].

Information on the crop genetic variation is still limited. In recent years, genetic and breeding studies have been carried out on crotalaria grown in Brazil [121-124]. Since the pollination in the crop can usually be controlled, the results of these studies indicate the possibility of using heterosis.

A germplasm bank can serve to maintain the genetic purity of the crop and to select more resistant lines and varieties through micropropagation followed by cultivation in greenhouse microclimates [122]. However, before this, it is necessary to assess the variability of the chromosome set in the *C. juncea* varieties, especially their ploidy, in order to obtain hybrids with high fertility. In addition, methods for growing the resulting seedlings must be standardized for different hydroponic systems (chemo-, aggregate-, and ionoponics).

Thus, this review is the first in the domestic special literature that summarizes data on physiology and cultivation of *Crotalaria juncea*, a non-traditional leguminous crop in the Russian Federation. In the southern Russian regions, *C. juncea* may serve as an intermediate crop in new diversified crop rotations and as a raw material for gum production instead of or in addition to guar. The abiotic factors limiting cultivation of this tropical crop in Russia are the lack of heat and, in some sites, moisture supply, photoperiod, soil pathogens and the absence of soil nitrogen fixing bacteria. Field conditions and the use of biologicals based on a consortium of beneficial nodule and associative rhizobacteria complementary to the genus *Crotalaria* will partially avoid these problems. Organic additives, e.g., the compounds based on humic acids of various origins (peat, coal, sapropel, zoohumus, etc.), can be used as physiologically active plant growth stimulants. However, the decisive role in the creation of stable legume-rhizobium symbiosystems based on *C. juncea* plays its genotype. So far, the main suppliers of *C. juncea* seeds for Western countries are India, Africa and Pakistan. The Hawaiian variety Tropic Sun is among the promising varieties for research. Nevertheless, creation of Russian crotalaria varieties possessing all the necessary biological and economic characteristics is relevant. The plants can be adapted for cultivation for seeds in greenhouses and hotbeds equipped with neural vision and a system for automatic control of growth parameters. Soilless potted culture excudes the limiting influence of soil matrix and adsorption processes on plant development and absorption of nutrients from substrates. Solid substrates that replace soil are mineral wool, coconut fiber, zeolite, vermiculite, etc. Probably, in such phytotechnical complexes, *C. juncea* plants will be shorter due to shorter internodes. Neertheless, due to precise control of the microclimate, the plants will confidently produce beans.

## REFERENCES


1. *Legumes of the world.* G. Lewis, B. Schrire, B. MacKinder, M. Lock (eds.). Royal botanical gardens, Kew, 2005.
2. *Crotalaria juncea L.* Plants of the world online. Facilitated by the Royal Botanic Gardens, Kew. Available: https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:322601-2. No date.
3. Le Roux M.M., Boatwright J.S., van Wyk B.-E. A global infrageneric classification system for the

genus *Crotalaria* (*Leguminosae*) based on molecular and morphological evidence. *Taxon*, 2013, 62(5): 957-971 (doi: 10.12705/625.1).
4. Subramaniam S., Pandey A.K. Taxonomy and phylogeny of the genus *Crotalaria* (*Fabaceae*): an overview. *Acta Biologica Indica*, 2013, 2(1): 253-264.
5. Polhill R.M. *Crotalaria in Africa and Madagascar*. CRC Press, Florida, 1982.
6. Bhandari H.R., Shivakumar K.V., Kar C.S., Bera A., Meena J.K. Sunn hemp: a climate-smart crop. In: *Developing climate resilient grain and forage legumes*. U.C. Jha, H. Nayyar, S.K. Agrawal, K.H.M. Siddique (eds.). Springer, Singapore, 2022: 277-296 (doi: 10.1007/978-981-16-9848-4_13).
7. *Red data book of Indian plants*. M.P. Nayar, A.R.K. Sastry (eds.). Calcutta, 1987.
8. Subramaniam S., Pandey A.K., Geeta R., Mort M.E. Molecular systematics of Indian *Crotalaria* (*Fabaceae*) based on analyses of nuclear ribosomal ITS DNA sequences. *Plant Systematics and Evolution*, 2013, 299: 1089-1106 (doi: 10.1007/s00606-013-0781-2).
9. Yaradua S.S. A review of the genus *Crotalaria* L. (*Crotalarieae, Fabaceae*). *Int. J. Sci. Res. Publ.*, 2018, 8(6): 316-321 (doi: 10.29322/IJSRP.8.6.2018.p7840).
10. Brooks R.R., McCleave J.A., Malaisse F. Copper and cobalt in African species of *Crotalaria L. Proceedings of the Royal Society B: Biological Sciences.*, 1977, 197(1127): 231-236
11. Boisson S., Le Stradic S., Commans M., Dumont A., Leclerc N., Thomas C., Mahy G. Copper tolerance of three *Crotalaria* species from southeastern D.R. Congo at the early development stage. *Biotechnologie, Agronomie, Société et Environnement*, 2016, 20(2): 151-160 (doi: 10.25518/1780-4507.12836).
12. Kundu B.C. Sunn-hemp in India. *Proc. Soil Crop Soc.*, 1964, 24: 396-404.
13. *Crotalaria juncea* L. In: *PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale)* /M. Brink, E.G. Achigan-Dako (eds.). Wageningen, The Netherlands, 2011.
14. Abrol D.P. Insect pollination and crop production in Jammu and Kashmir. *Curr. Sci.*, 1993, 65(3): 265-269.
15. Free J.B. *Insect pollination of crops*. Academic Press, London—New York, 1970.
16. Dempsey J.M. Fiber crops. The University Presses of Florida, Gainesville, Florida, 1975.
17. Bhandari H.R., Tripathi M.K., Babira C., Sarker S.K. Sunnhemp breeding: challenges and prospects. *The Indian Journal of Agricultural Sciences*, 2016, 86(11): 1391-1398 (doi: 10.56093/ijas.v86i11.62879).
18. Scott D., Freckleton R.P. Crop diversification and parasitic weed abundance: a global meta-analysis. *Scientific Reports*, 2022, 12(1): 19413 (doi: 10.1038/s41598-022-24047-2).
19. Barros A.P., de Carvalho Silva A., de Souza Abboud A.C., Ricalde M.P., Ataide J.O. Effect of *Cosmos*, *Crotalaria*, *Foeniculum*, and *Canavalia* species, single-cropped or mixes, on the community of predatory arthropods. *Scientific Reports*, 2022, 12: 16013 (doi: 10.1038/s41598-022-20188-6).
20. Bhardwaj H.L., Webber C.L., Sakamoto G.S. Cultivation of kenaf and sunn hemp in the mid-Atlantic United States. *Industrial Crops and Products*, 2005, 22(2): 151-155 (doi: 10.1016/j.indcrop.2004.08.002).
21. White G.A., Haun J.R. Growing *Crotalaria juncea*, a multi-purpose fiber legume, for paper pulp. *Economic Botany*, 1965, 19: 175-183 (doi: 10.1007/BF02862829).
22. Fall T., Freidenreich A., Swartz S.M., Vincent C.I., Li Y., Brym Z. Questions and answers for using sunn hemp (*Crotalaria juncea* L.) as a green manure cover crop. *EDIS*, 2020, 5: 1-4 (doi: 10.32473/edis-ag443-2020).
23. Desaeger J., Rao M.R. The potential of mixed covers of *Sesbania*, *Tephrosia* and *Crotalaria* to minimise nematode problems on subsequent crops. *Field Crops Research*, 2001, 70(2): 111-125 (doi: 10.1016/S0378-4290(01)00127-7).
24. Garcia R.A., Li Y., Rosolem C.A. Soil organic matter and physical attributes affected by crop rotation under no-till. *Soil Science Society of America Journal*, 2013, 77(5): 1724-1731 (doi: 10.2136/sssaj2012.0310).
25. Schomberg H.H., Martini N.L., Diaz-Perez J.C., Phatak S.C., Balkcom K.S., Bhardwaj H.L. Potential for using sunn hemp as a source of biomass and nitrogen for the piedmont and coastal plain regions of the Southeastern USA. *Agronomy Journal*, 2007, 99(6): 1448-1457 (doi: 10.2134/agronj2006.0294).
26. Colombo J.N., Puiatti M., Santos R.H.S., dos S. Dias L.A., Silvestre H.C. Successive crops of broccoli, green corn and pea after taro (*Colocasia esculenta*)-sunn hemp (*Crotalaria juncea*) consortium. *Acta Agronymica*, 2021, 69(4): 331-338 (doi: 10.15446/acag.v69n4.61794).
27. Bhardwaj K.K.R., Datt N. Effects of legume green-manuring on nitrogen mineralization and some microbiological properties in an acid rice soil. *Biology and Fertility of Soils.*, 1995, 19(1): 19-21 (doi: 10.1007/BF00336341).
28. Stute J.K., Shekinah D.E. Planting date and biculture affect sunn hemp productivity in the Midwest. *Sustainable Agriculture Research*, 2019, 8: 26-35 (doi: 10.5539/sar.v8n2p26).
29. Cook C.G., Scott A.W., Chow P. Planting date and cultivar effects on growth and stalk yield of sunn hemp. *Industrial Crops and Products*, 1998, 8(2): 89-95 (doi: 10.1016/S0926-6690(97)10013-9).

30. Negmatova S.T., Nurullaeva M.Sh. Effectiveness of introducing crotalaria plant into the crop rotation system. *Science and Innovation International Scientific Journal*, 2022, 1(4): 212-228 (doi: 10.5281/zenodo.698160) (Uzbek.).
31. Balkcom K.S., Massey J.M., Mosjidis J.A., Price A.J., Enloe S.F. Planting date and seeding rate effects on sunn hemp biomass and nitrogen production for a winter cover crop. *International Journal of Agronomy*, 2011, 2011: 237510 (doi: 10.1155/2011/237510).
32. Morris J.B., Chase C., Treadwell D., Koenig R., Cho A., Morales-Payan J.P., Murphy T., Antonious G.F. Effect of sunn hemp (*Crotalaria juncea* L.) cutting date and planting density on weed suppression in Georgia, USA. *Journal of Environmental Science and Health, Part B*, 2015, 50(8): 614-621 (doi: 10.1080/03601234.2015.1028855).
33. de Oliveira M.N., de Morais S.V.G.M., e Costa M.I.G., de Bezerra G.G. Biomass of *Crotalaria juncea* asa function of plant densities in the semiarid region of Northeastern Brazil. *Agronomía Colombiana*, 2020, 38(1): 148-155 (doi: 10.15446/agron.colomb.v38n1.78957).
34. Dzvene A.R., Tesfuhuney W.A., Walker S., Ceronio G. Planting time and stand density effect on radiation interception and use efficiency of maize and sunn hemp intercropping in semi-arid South Africa. *Agricultural and Forest Meteorology*, 2023, 341: 109690 (doi: 10.1016/j.agrformet.2023.109690).
35. Teodoro M.S., Santos F.J.S., Lacerda M.N., Araújo L.M.S. Biomass yield of *Crotalaria juncea* after thinning and at varied sowing densities in the coastal plateau of Piauí state, Brazil. *Revista Caatinga*, 2016, 29(4): 878-884 (doi: 10.1590/1983-21252016v29n412rc).
36. Chaudhury J., Singh D.P., Hazra S.K. Sunnhemp (*Crotalaria juncea* L.). Central Research Institute for Jute & Allied Fibers (ICAR), n.d. Web. 18 May 2012. http://assamagribusiness.nic.in/Sunnhemp.pdf.
37. Rengalakshmi R., Purshothaman S. Plant spacing and phosphorus fertilization on seed production of *Crotalaria juncea* L. *Madras Agricultural Journal*, 1999, 86(1/3): 103-105.
38. Ulemale R.B., Giri D.G., Shivankar R.S., Patil V.N. Effect of sowing dates, row spacings and phosphorous levels on yield and yield attributes of sunnhemp (*Crotalaria juncea* L). *Legume Research*, 2002, 25(4): 273-275.
39. Makhmudov U., Nuritdinovna D. *Science and Innovation international scientific journal*, 2023, Special Issue "ACTUAL ISSUES OF AGRICULTURAL DEVELOPMENT: PROBLEMS AND SOLUTIONS": 639-640 (doi: 10.5281/zenodo.8002813) (in Russ.).
40. Maheshwari N.K., Singh R.P., Manchanda G., Dubey R.C., Maheshwari D.K. Sunn hemp (*Crotalaria juncea*) nodulating bacteriacapable for high antagonistic potential and plant growth promotion attributes. *Journal of Microbiology, Biotechnology and Food Sciences*, 2020, 10: 1-7 (doi: 10.15414/jmbfs.2020.10.3.385-389).
41. Castellano-Hinojosa A., Mora C., Strauss S.L. Native *Rhizobia* improve plant growth, fix N2, and reduce greenhouse emissions of sunnhemp more than commercial *Rhizobia* inoculants in Florida citrus orchards. *Plants*, 2022, 11(22): 3011 (doi: 10.3390/plants11223011).
42. Sy A., Giraud É., Samba R., Lajudie P. de Gillis M., Dreyfus B. Certaines légumineuses du genre *Crotalaria* sont spécifiquement nodulées par une nouvelle espèce de *Methylobacterium*. *Canadian Journal of Microbiology*, 2001, 47(6): 503-508 (doi: 10.1139/w01-044).
43. Sy A., Giraud E., Jourand P., Garcia N., Willems A., de Lajudie P., Prin Y., Neyra M., Gillis M., Boivin-Masson C., Dreyfus B. Methylotrophic Methylobacterium bacteria nodulate and fix nitrogen in symbiosis with legumes. *Journal of Bacteriology*, 2001, 183(1): 214-220 (doi: 10.1128/JB.183.1.214-220.2001).
44. Madhaiyan M., Poonguzhali S., Senthilkumar M., Sundaram S., Sa T. Nodulation and plant-growth promotion by methylotrophic bacteria isolated from tropical legumes. *Microbiological Research*, 2009, 164(1): 114-120 (doi: 10.1016/j.micres.2006.08.009).
45. Maitra D.N., Sarkar S.K., Saha S., Tripathi M.K., Majumder B., Saha A.R. Effect of phosphorus and farmyard manure applied to sunn hemp (*Crotalaria juncea*) on yield and nutrient uptake of sunn hemp-wheat (*Triticum aestivum*) cropping system and fertility status in Typic Ustocrept of Uttar Pradesh. *The Indian Journal of Agricultural Sciences*, 2008, 78(1): 70-74.
46. Rajendraprasad S., Masilamani P., Balakrishnan K. Effect of pre-sowing seed treatments on dormancy of sunn hemp (*Crotalaria juncea*). *Seed Research*, 2017, 45(2): 136-140.
47. Okonwu K., Eboh I.G. Effects of seed treatment on the germination of *Crotalaria verrucosa* L. *Journal of Applied Life Sciences International*, 2017, 10(2): 1-8 (doi: 10.9734/JALSI/2017/31027).
48. Silaeva O.I. *Trudy po prikladnoy botanike, genetike i selektsii*, 2012, 169: 230-239 (in Russ.).
49. Bowler C., Van Montagu M., Inze D. Superoxide dismutase and stress tolerance. *Annual Review of Plant Physiology and Plant Molecular Biology*, 1992, 43: 83-116 (doi: 10.1146/annurev.pp.43.060192.000503).
50. Balakrishnan V., Venkeateshra K., Ravindran K.C. Kulandaivelu G. Protective mechanism in UV-B treated *Crotalaria juncea* Linn. Seedlings. *Plant Protect. Sci.*, 2009, 41(3): 115-120 (doi: 10.17221/2727-PPS).
51. Pacheco J.S., Silva-López R.E.S. Genus *Crotalaria* L. (*Leguminoseae*). *Revista Fitos*, 2010, 5(3): 52.
52. Araújo A.V., de Araújo E.F., Amaro H.T.R., Santos R.H.S., Cecon P.R. Time of harvest and

storability of *Crotalaria juncea* L. seeds. *Revista ciência agronômica*, 2018, 49(1): 1-9 (doi: 10.5935/1806-6690.20180012).
53. Garzon Vendramini J.M.B., Silveira M.L., Moriel P., da Silva H.M.S., Dubeux J.C.B., Kaneko M., Carnelos C.C., Mamede P.A. Harvest management and genotype effects on Sunn hemp forage characteristics. *Agronomy Journal*, 2021, 113(1): 298-307 (doi: 10.1002/agj2.20465).
54. Abdul-Baki A.S., Bryan H.H., Zinati G.M., Klassen W., Codallo M., Heckert N. Biomass yield and flower production in sunn hemp — effect of cutting the main stem. *Journal of Vegetable Crop Production*, 2001, 7(1): 83-104 (doi: 10.1300/J068v07n01_10).
55. Mansoer Z., Reeves D.W., Wood C.W. Suitability of sunn hemp as an alternative late-summer legume cover crop. *Soil Science Society of America Journal*, 1997, 61(1): 246-253 (doi: 10.2136/sssaj1997.03615995006100010034x).
56. Tripathi M., Chaudhary B., Sarkar S., Singh S., Bhandari H., Mahapatra B. Performance of sunn hemp (*Crotalaria juncea* L.) as a summer season (pre-monsoon) crop for fibre. *Journal of Agricultural Science*, 2013, 5(3): 236 (doi: 10.5539/jas.v5n3p236).
57. Parenti A., Cappelli G., Zegada-Lizarazu W., Martín Sastre C., Christou M., Monti A., Ginaldi F. SunnGro: A new crop model for the simulation of sunn hemp (*Crotalaria juncea* L.) grown under alternative management practices. *Biomass and Bioenergy*, 2021, 146: 105975 (doi: 10.1016/j.biombioe.2021.105975).
58. Stella T., Francone C., Yamaз S.S., Ceotto E., Pagani V., Pilu R., Confalonieri R. Reimplementation and reuse of the Canegro model: from sugarcane to giant reed. *Comput. Electron. Agric.*, 2015, 113: 193-202 (doi: 10.1016/j.compag.2015.02.009).
59. Farr D.F., Bills G.F., Chamuris G.P., Rossman A.Y. *Fungi on plants and plant products in the United States*. American Phytopatholgical Society, St Paul, MN, 1989.
60. Seale C.C., Joyner J.F., Pate J.B. Agronomic studies of fiber plants: : Jute, sisal, henequen, furcraea, hemp and other miscellaneous types. *Florida Agr. Expt. Sta. Bull.*, 1957, 590: 16-17.
61. Cook C.G., White G.A. *Crotolaria juncea*: a potential multi-purpose fiber crop. In: *Progress in new crops*. J. Janick (ed.). ASHS Press, Arlington, VA, 1996. 389-394.
62. Mahur B.K., Ahuja A., Singh S., Maji P.K., Rastogi V.K. Different nanocellulose morphologies (cellulose nanofibers, nanocrystals and nanospheres) extracted from Sunn hemp (*Crotalaria Juncea*). *International Journal of Biological Macromolecules*, 2023, 253(1): 12665 (doi: 10.1016/j.ijbiomac.2023.126657).
63. Sengupta S., Debnath S. Development of sunnhemp (*Crotalaria juncea*) fibre based unconventional fabric. *Industrial Crops and Products*, 2018, 116: 109-115 (doi: 10.1016/j.indcrop.2018.02.059).
64. Maiti R.K., Chakravarty K. A comparative study of yield components and quality of Indian bast fibres. *Economic Botany*, 1977, 31: 55-60 (doi: 10.1007/BF02860653).
65. Kumar D., Tripathi M.K., Sarkar S.K., Das A., Shill S. Breeding for improving fibre yield and green biomass in sunn hemp (*Crotalaria juncea* L.) germplasm. *Bangladesh J. Aril. Res.*, 2012, 37(3): 369-376 (doi: 10.3329/bjar.v37i3.12080).
66. Sarkar S.K., Hazra S.K., Sen H.S., Karmakar P.G. Tripathi M.K. *Sunnhemp in India*. ICAR-Central Research Institute for Jute and Allied Fibres (ICAR), Barrackpore, West Bengal, 2015.
67. Patel S., Dhillon N.K. Evaluation of sunnhemp (*Crotalaria juncea*) as green manure /amendment and its biomass content on root knot nematode (*Meloidogyne incognita*) in successive crop brinjal. *Journal of Entomology and Zoology Studies*, 2017, 5(6): 716-720.
68. Mayorga L., Jacobs D., Bui H.X., Desaeger J. Nematicidal effect of sunn hemp root and shoot extracts on eggs and second-stage juveniles of *Meloidogyne javanica*. *Nematropica*, 2022, 52: 72-78.
69. Kankam F., Suen F., Adomako J. Nematicidal effect of sunn hemp *Crotalaria juncea* leaf residues on *Meloidogyne incognita* attacking tomato *Solanum lycopersicum* roots. *J. Crop Prot.*, 2015, 4(2): 241-246.
70. Curto G., Dallavalle E., Santi R., Casadei N., D'Avino L., Lazzeri L. The potential of *Crotalaria juncea* L. as a summer green manure crop in comparisonto *Brassicaceae* catch crops for management of *Meloidogyne incognita* in the Mediterranean area. *European Journal of Plant Pathology*, 2015, 142: 829-841 (doi: 10.1007/s10658-015-0655-2).
71. Wang K.H., Sipes B.S., Schmitt D.P. Suppression of *Rotylenchulus reniformis* by *Crotalaria juncea*, *Brassica napus*, and *Tagetes erecta*. *Nematropica*, 2001, 31(2): 235-249.
72. Wang K.H., Sipes B.S., Schmitt D.P. *Crotalaria* as a cover crop for nematode management: a review. *Nematropica*, 2002, 32(1): 35-57.
73. Germani G., Plenchette C. Potential of *Crotalaria* species as green manure crops for the management of pathogenic nematodes and beneficial mycorrhizal fungi. *Plant and Soil*, 2005, 266: 333-342 (doi: 10.1007/s11104-005-2281-9).
74. Daimon H., Takada S., Ohe M., Mimoto H. Interspecific differences in growth and nitrogen uptake among Crotalaria species. *Japanese Journal of Crop Science*, 1995, 64: 115-120 (doi: 10.1626/jcs.64.115).
75. Ohdan H., Daimon H. Evaluation of amount of nitrogen fixed in *Crotalaria spp*. and nitrogen turnover to the succeeding wheat. *Japanese Journal of Crop Science*, 1998, 67(2): 193-199 (doi: 10.1626/jcs.67.193).
76. Balkcom K.S., Reeves D.W. Sunn hemp utilized as a legume cover crop for corn production.

*Agronomy Journal*, 2005, 97(1): 26-31 (doi: 10.2134/agronj2005.0026).
77. Teodoro M.S., Castro K.N.C., Magalhães J.A. Assessment of legumes with potential use as green manure in the coastal tablelands of Piauí state, Brazil. *Rev. Caatinga*, 2018, 31(3): 584-592 (doi: 10.1590/1983-21252018v31n306rc).
78. Price A.J., Kelton J., Mosjidis J. Utilization of sunn hemp for cover crops and weed in temperate climates. In: *Weed control*. A.J. Price (ed). InTech, 2011: 101-114 (doi: 10.5772/1988).
79. Dabney S.M., Delgado J.A., Reeves D.W. Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, 2001, 32(7-8): 1221-1250 (doi: 10.1081/CSS-100104110).
80. Panse V.G., Abraham T.P., Leelavathi C.R. *Green manuring of crops (Review of experimental results)*. Indian Council of Agriculture Research, New Delhi, 1965.
81. Gupta B.N., Tripathi S.N. Influence of growing sunn hemp as fibre, green manure and dual purpose crop on the yield and economics of rice-wheat sequence under varying NPK levels. *Indian Agriculturist*, 2001, 45(1-2): 65-73.
82. Li J., Zhao X., Maltais-Landry G., Paudel B.R. Dynamics of soil nitrogen availability following Sunn hemp residue incorporation in organic strawberry production systems. *HortScience*, 2021, 56(2): 138-146 (doi: 10.21273/HORTSCI15374-20).
83. Virdi N.S., Neha K., Joshi S., Singh S., Singh P. Studies on variability, associations and genetic divergence for green manuring traits in sunn hemp (*Crotalaria* spp.). *J. Res. Punjab. Agric. Univ.*, 2004, 41(4): 417-422.
84. Reddy V.R., Reddy R.R., Rao D.S., Reedy D.V., Rao Z.P. Nutritional evaluation of sunn hemp (*Crotalaria juncea*) hay as sole roughage and their use in complete ration for sheep. *Indian Journal of Animal Nutrition*, 1999, 16(1): 38-43.
85. Balaraman N., Venkatakrishnan R. Nutritive value of sunn hemp (*Crotalaria juncea* Linn) for hay for sheep. *Indian Veterinary Journal*, 1974, 51(5): 337-341.
86. Krishna N., Prasad J.R., Prasad, D.A. Effect of stage of maturity on chemical composition and nutritive value of sunn hemp (*Crotalaria juncea* Linn.) forage. *Indian Journal of Animal Sciences*, 1985, 55: 1109-1112.
87. Prada F., Stashenko E.E., Martínez J.R. LC/MS study of the diversity and distribution of pyrrolizidine alkaloids in *Crotalaria* species growing in Colombia. *Journal of Separation Science*, 2020, 43(23): 4322-4337 (doi: 10.1002/jssc.202000776).
88. Malashetty V.B., Kage D.N. *Crotalaria juncea* Linn.: a comprehensive review. *International Journal of Current Research*, 2015, 7(04): 14762-14768.
89. Solofomalala A.H.D., Rajemiarimoelisoa C.F., Judicael R.L., Randrianarivo H.R., Rakoto D.A.D., Jeannoda V.L., Boumendjel A. Pyrrolizidine-derived alkaloids: highly toxic components in the seeds of *Crotalaria cleomifolia* used in popular beverages in Madagascar. *Molecules*, 2021, 26(11): 3464 (doi: 10.3390/molecules26113464).
90. Larrea M.I.S.A., Larrea M.D.S.A., Olivos-Oré L.A. Plants, poisonous (animals). In: *Encyclopedia of toxicology (fourth edition). Vol. 7* /P. Wexler (ed.). Academic Press, 2024: 685-703 (doi: 10.1016/B978-0-12-824315-2.00143-3).
91. Anjos B.L., Nobre V.M., Dantas A.F., Medeiros R.M., Oliveira Neto T.S., Molyneux R.J., Riet-Correa F. Poisoning of sheep by seeds of *Crotalaria retusa*: acquired resistance by continuous administration of low doses. *Toxicon*, 2010, 55(1): 28-32 (doi: 10.1016/j.toxicon.2009.06.028).
92. Srisaikham S., Lounglawan P. Effect of cutting age and cutting height on production and nutritive value of sunnhemp (*Crotalaria juncea*) harvest in Nakhon Ratchasima, Thailand. *Acta Horticulturae*, 2018, 1210: 29-34 (doi: 10.17660/ActaHortic.2018.1210.4).
93. Kaneko M., Kato N., Hattori I., Matsuoka M., Vendramini J.M.B. Seeding and harvesting times and climate conditions are important for improving nitrogen and fiber contents of green manure sunn hemp. *Sustainability*, 2023, 15(9): 7103 (doi: 10.3390/su15097103).
94. Shamprasad B.R., Lotha R., Nagarajan S., Sivasubramanian A. Metal nanoparticles functionalized with nutraceutical Kaempferitrin from edible *Crotalaria juncea*, exert potent antimicrobial and antibiofilm effects against Methicillin-resistant *Staphylococcus aureus*. *Sci. Rep.*, 2022, 12(1): 7061 (doi: 10.1038/s41598-022-11004-2).
95. Adler M.J., Chase C.A. Comparison of the allelopathic potential of leguminous summer cover crops: Cowpea, Sunn hemp, and Velvet bean. *HortScience*, 2007, 42(2): 289-293 (doi: 10.21273/HORTSCI.42.2.289).
96. Bundit A., Ostlie M., Prom-U-Thai C. Sunn hemp (*Crotalaria juncea*) weed suppression and allelopathy at different timings. *Biocontrol Science and Technology*, 2021, 31(7): 694-704 (doi: 10.1080/09583157.2021.1881446).
97. Skinner E.M., Díaz-Perez J.C., Phatak S.C., Schomberg H., Vencill W. Allelopathic effects of sunn hemp (*Crotalaria juncea* L.) on germination of vegetables and weeds. *HortScience*, 2012, 47: 138-142 (doi: 10.21273/HORTSCI.47.1.138).
98. Ohdan H., Daimon H., Mimoto H. Evaluation of allelopathy in Crotalaria by using a seed pack growth pouch. *Japanese Journal of Crop Science*, 1995, 64(3): 644-649 (doi: 10.1626/jcs.64.644).
99. Alidoust D., Suzuki S., Matsumura S., Yoshida M. The role of citric acid in enhanced phytoextraction of heavy metals in an andosol by *Crotalaria juncea*. *Fresenius Environmental Bulletin*,

2009, 18(5): 835-842.
100. Agarwal A., Singh H.P., Rai J.P.N. Chromium phytoextraction from tannery effluent-contaminated soil by *Crotalaria juncea* infested with *Pseudomonas fluorescens*. *Environmental Science and Pollution Research*, 2014, 21: 7938-7944 (doi: 10.1007/s11356-014-2719-9).
101. Cardoso P.F., Gratao P.L., Gomes R.A., Medici L.O., Azevedo R.A. Response of *Crotalaria juncea* to nickel exposure. *Brazilian Journal of Plant Physiology*, 2005, 17(2): 267-272 (doi: 10.1590/S1677-04202005000200010).
102. Uraguchi S., Watanabe I., Yoshitomi A., Kiyono M., Kuno K. Characteristics of cadmium accumulation and tolerance in novel Cd-accumulating crops, *Avena strigosa* and *Crotalaria juncea*. *Journal of Experimental Botany*, 2006, 57(12): 2955-2965 (doi: 10.1093/jxb/erl056).
103. Zancheta, A.C.F., de Abreu C.A., Zambrosi F.C.B., Erismann N. de M., Lagôa, A.M.M.A. Fitoextração de cobre por espécies de plantas cultivadas em solução nutritiva. *Bragantia*, 2011, 70(4): 737-744 (doi: 10.1590/s0006-87052011000400002).
104. Thooppeng P., Junpradit C., Rongsayamanont W., Duangmal K., Prapagdee B. Cadmium-resistant *Streptomyces* stimulates phytoextraction potential of *Crotalaria juncea* L. in cadmium-polluted soil. *International Journal of Phytoremediation Volume*, 2023, 25(10): 1318-1327 (doi: 10.1080/15226514.2022.2152424).
105. Ji X., Khan I., Mosjidis J.A., Wang H., Livant P. Variability for the presence of pyrrolizidine alkaloids in *Crotolaria juncea* L. *Pharmazie*, 2005, 60(8): 620-622.
106. Zakirova R.P., Asatova S.S., Safarova N.R., Tashpulatova F.Sh. *Agrarnaya nauka*, 2020, 1: 52-55 (doi: 10.32634/0869-8155-2020-334-1-52-55) (in Russ.).
107. Dzyubenko E.A., Safronova V.I., Vishnyakova M.A. Objectives of guar breeding in the Russian Federation in connection with the prospects of domestic guar gum production (review). *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2023, 58(1): 43-59 (doi: 10.15389/agrobiology.2023.1.43eng).
108. Al-Snafi A.E. The contents and pharmacology of *Crotalaria juncea* — a review. *IOSR Journal of Pharmacy*, 2016, 6(6): 77-86.
109. Dinakaran S.K., Banji D., Godala P., Harani A. Pharmacognostical evaluation study on *Crotalaria juncea* Linn. *American-Eurasian Journal of Scientific Research*, 2011, 6(3): 139-145.
110. Chouhan H.S., Singh S.K. Antibacterial activity of seed and flower parts of *Crotalaria juncea* Linn. *American-Eurasian Journal of Scientific Research*, 2010, 5(3): 212-215.
111. Chouhan H.S., Sahu A.N. Singh S.K. Fatty acid composition, antioxidant, anti-inflammatory and antibacterial activity of seed oil from *Crotolaria juncia* Linn. *Journal of Medicinal Plant Research*, 2011, 5(6): 984-991.
112. Shantaveera S.H.M., Kumara S.H.V., Upadhya P. Comparison study of the antimicrobial activity of seed protein extracts from four medicinal plants against *Xanthomonas oxanopodis* ver. punicae. *World Journal of Pharmaceutical Research*, 2015, 4(4): 948-949.
113. Pelegrini P.B., Farias L.R., Saude A.C.M., Costa F.T., Bloch C., Silva L.P., Oliveira A.S., Gomes C.E.M., Sales M.P., Franco O.L. A Novel antimicrobial peptide from *Crotalaria pallida* seeds with activity against human and phytopathogens. *Current Microbiology*, 2009, 59(4): 400-404 (doi: 10.1007/s00284-009-9451-6).
114. Sadhukhan S., Sarkar U. Production of biodiesel from *Crotalaria juncea* (Sunn-Hemp) oil using catalytic trans-esterification: process optimisation using a factorial and Box-Behnken Design. *Waste and Biomass Valorization*, 2016, 7(2): 343-355 (doi: 10.1007/s12649-015-9454-4).
115. Sinbuathong N., Khun-Anake R., Sawanon S. Biogas production from sunn hemp. *International Journal of Global Warming*, 2019, 19(1-2): 24e36 (doi: 10.1504/IJGW.2019.10023348).
116. Sinbuathong N., Sillapacharoenkul B. Enhancement of biogas production from sunn hemp using alkaline pretreatment. *International Journal of Hydrogen Energy*, 2020, 46(6): 4870-4878 (doi: 10.1016/j.ijhydene.2020.04.058).
117. Chandra R., Takeuchi H., Hasegawa T. Methane production from lignocellulosic agricultural crop wastes: a review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews*, 2012, 16(3): 1462-1476 (doi: 10.1016/j.rser.2011.11.035).
118. Berriel V., Monza J., Perdomo C.H. Cover crop selection by jointly optimizing biomass productivity, biological nitrogen fixation, and transpiration efficiency: application to two *Crotalaria* species. *Agronomy*, 2020, 10(8): 1116 (doi: 10.3390/agronomy10081116).
119. Borisov A.Yu., Shtark O.Yu., Zhukov V.A., Nemankin T.A., Naumkina T.S., Pinaev A.G., Akhtemova G.A., Voroshilova V.A., Ovchinnikova E.S., Rychagova T.S., Tsyganov V.E., Zhernakov A.I., Kuznetsova E.V., Grishina O.A., Sulima A.S., Fedorina Ya.V., Chebotar' V.K., Bisseling T., Lemanso F., Dzhianinazzi-Pirson V., Rate P., Sankhuan Kh., Stougaard Y., Berg G., Makfi K., Eddis N., Tikhonovich I.A. Interaction of legumes with beneficial soil microorganisms: from plant genes to varieties. *Sel'skokhozyaistvennaya biologiya* [*Agricultural Biology*], 2011, 3: 41-47 (in Russ.).
120. Shtark O.Yu., Borisov A.Yu., Zhukov V.A., Nemankin T.A., Tikhonovich I.A. *Ekologicheskaya genetika*, 2011, IX(2): 80-94 (in Russ.).
121. Hazra S.K., Mahapatra A.K., Saha A., Saha D., Bandyopadhyay A., Das A.K., Gupta D., Sen,

H.S. Medicinal importance of Sunn hemp (*Crotalaria juncea* L.) in relation to chemical constituents, bioactivity and conservation. *J. Botan. Soc. Bengal.*, 2005, 59(1/2): 1-11.
122. Ribeiro I.J.A., de Miranda M.A.C., Bulisani E.A., de Almeida L.D., Lovadini, L.A.C., Sugimori M.H., Paradela Filho O. Breeding Crotalaria. I. Self compatibility and resistance to wilt caused by *Ceratocystis fimbriata*. *Bragantia*, 1977, 36(1): 291-295 (doi: 10.1590/s0006-87051977000100028).
123. Miranda M.A.C. Adequacao modelo aditivo — dominante em dois characters de crotalaria: aditive-dominant in two traits of sunn hemp. *Bragantia*, 1991, 50(2): 195-202 (doi: 10.1590/S0006-87051991000200003).
124. Miranda M.A.C., Bulisani E.A., Teixeira J.P.E., Mascarenhas H.A.A. Herança da pigmentação com antocianina em *Crotalaria juncea* L. *Bragantia*, 1989, 48(1): 87-94 (doi: 10.1590/S0006-87051989000100008).