# Developing Tall Wheatgrass and Building the "Coastal Grass Belt" Post-print

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## Abstract

Tall wheatgrass (Thinopyrum elongatum) is a perennial cool-season forage grass characterized by tolerance to saline-alkaline conditions, waterlogging, and drought, as well as high biomass production. Since its introduction to China in the 1950s, it has long been utilized as a wild parent for wheat wide hybridization. Despite introduction attempts during the 1980s–1990s, large-scale cultivation has not been achieved in China to date, nor have any approved cultivars been registered. In 2020, Li Zhensheng proposed the concept of establishing a "Coastal Grass Belt" utilizing coastal saline-alkali wasteland in the Bohai Rim region, delineating the prospects for industrialization of tall wheatgrass in China. This article introduces the industrialization background, primary biological characteristics, domestic and international industry development history and current status of tall wheatgrass in China, and proposes recommendations for its industrialization development: driving industry growth through establishing demonstration models of the tall wheatgrass "Coastal Grass Belt", commercial forage production demonstration bases, and livestock demonstration farms; cultivating leading companies to form a complete industrial chain of "leading company + professional cooperatives/large-scale growers". Additionally, recommendations are presented regarding strengthening basic research, accelerating independent cultivar breeding, achieving seed industrialization, and increasing investment in policy funding and scientific talent. The "Coastal Grass Belt" can not only fill the gap in high-quality forage in China but also provide an ecological barrier and protect the ecological environment.

## Full Text

## The Era Demand for Industrialization of Tall Wheatgrass in China

With socioeconomic development and changes in dietary structure, China's food security has gradually evolved from staple food security to feed grain security [1-3]. In 2022, the planting areas of corn, rice, and wheat in China were 4.31$×$10^{5}$, 2.95×10^{5}, and 2.35×10^{5} km^{2}, respectively, representing increases of 43.45×10^{8} t, a 2.25-fold increase compared with 2007, and although they declined to 9.65×10^{7} t in 2021, this still represented a 2.23-fold increase over 2007. During 2016–2020, the annual import of dry hay averaged 1.71×10^{6} t [3]. The total import va
Year Plan" proposes maintaining self-sufficiency rates of approximately 85×10^{8} t of high-quality forage, leaving a gap of nearly 5.0×10^{7} t. Based on current average yield levels, at least 3.7×$10^4
km^2 of additional high-quality forage planting area will be needed to fill this gap.

Among the more than 20 artificially cultivated forage species in China, alfalfa (*Medicago sativa*), silage corn (*Zea mays*), and oats (*Avena sativa*) account for 71.6% of planting area and 94.2% of production. These crops are mainly grown in Gansu, Inner Mongolia, Qinghai, Hebei, Ningxia, and other provinces [4]. This region faces dual pressures of water shortage and land scarcity, limiting potential for expanding forage planting area. Implementing "grass-crop rotation" on medium- and low-yield fields can develop grass-based animal husbandry while improving soil fertility [2]. The Third National Land Survey revealed that in 2021, China had 1.28$×10^{6} km^{2} of cultivated land, with two-thirds classified as medium-and low-yield fields according to a 2020 Ministry of Agriculture and Rural Affairs bulletin. Long-term, these medium- and low-yield fields remain crucial for China's food security. For example, since the imple
and low-yield fields in the Bohai Rim region have achieved a grain yield increase of 1.0×$10^7
t over five years [5]. China's basic national condition dictates that high-quality forage production must avoid competing with grain for land [3,6].

China has approximately 7.80$×10^{5} km^{2} of marginal land, including 5.67×10^{5} km^{2} of undeveloped reserve cultiva
grade cultivated land [7]. Marginal land suffers from prominent soil constraints, low grain yields, poor planting be
alkali land constitutes an important component of marginal land, with China having 1.20×10^{5} km^{2} of saline-alkali land with salinity constraints. Among these, Shandong, Hebei, Tianjin, and other areas in the Bohai Rimre
km^2 of coastal saline-alkali land [7]. With annual rainfall of 500 600 mm, this region is favorable for developing grass-based animal husbandry. Establishing a "Coastal Grass Belt" by planting salt-tolerant forage on coastal saline-alkali land can compensate for the shortage of high-quality forage, safeguard national food security, and protect the ecological environment [3,5,6,8]. Using appropriate cultivation techniques, grain crops can still achieve certain yields on light to moderate saline-alkali soils with salt content of 0.2% 0.4%. However, on moderate to severe saline-alkali soils with salt content >0.4%, grain yields are often low and unstable, while the potential for developing salt-tolerant forage is substantial [3,6,9]. By 2021, China had certified 651 forage varieties [10], but fewer than 20 were salt-tolerant varieties, with even fewer suitable for coastal

saline-alkali conditions [3]. Therefore, salt-tolerant forage varieties represent the main bottleneck for constructing the "Coastal Grass Belt" [3,6], and tall wheatgrass (*Elytrigia elongata*) is one of the preferred species that meets these requirements.

## Main Biological Characteristics of Tall Wheatgrass

Tall wheatgrass is a perennial, cool-season bunchgrass belonging to the Poaceae family, Triticeae tribe, and *Elytrigia* genus. Native to southeastern Europe, Asia Minor, and southern Russia, it is widely cultivated in the United States, Canada, Australia, Argentina, and parts of Europe, commonly used for establishing saline-alkali pastures, soil remediation, or as an energy plant [5]. Introduced to China in the 1950s, it has long served as an important genetic resource for wheat improvement. During the 1980s 1990s, multiple introductions from the Soviet Union, United States, and Canada were made for windbreak, sand fixation, and forage trials [11], yet reports of large-scale cultivation remain scarce [5,12].

**(1) Salt-alkali, waterlogging, and drought tolerance.** Tall wheatgrass is among the most salt-tolerant forage grasses [13-15], capable of withstanding 750 mmol/L NaCl stress (equivalent to 1.25 times seawater concentration) [14,16]. Its salt tolerance exceeds that of smooth bromegrass (*Bromus inermis*), perennial ryegrass (*Lolium perenne*), wild barley (*Hordeum brevisubulatum*) [17], bermudagrass (*Cynodon dactylon*), tall fescue (*Festuca arundinacea*), Rhodes grass (*Chloris gayana*) [18], and other *Elytrigia* species such as quackgrass (*Elytrigia repens*) [19]. Our previous research found that tall wheatgrass is suitable for cultivation on saline-alkali land with salt content of 0.4% 1.0% [9,20]. It thrives in pH ranges of 5.3 10.0, with an optimum pH of 7.5 9.0 [21,22]. Tall wheatgrass exhibits considerable waterlogging tolerance [23-25]; even after 30 days of seawater submergence, its vegetative rhizomes can still regenerate [26]. In addition to salt-alkali and waterlogging tolerance, tall wheatgrass also demonstrates drought resistance [27-29] and can grow in arid and semi-arid regions [30].

**(2) High biomass.** Tall wheatgrass is the most productive cool-season forage grass in terms of biomass [31,32]. On non-saline land, fresh forage yield at flowering stage exceeds 3,000 t · km^-2, with maximum yields approaching 4,000 t · km^-2 [21,33]. In semi-arid regions on saline-alkali land, dry matter yield reaches 500 800 t · km^-2 [34]. Pot experiments show that under waterlogging conditions, tall wheatgrass dry matter yield is 4.2 times higher than that of corn [35]. In the Yellow River irrigation area of Inner Mongolia with salt content of 0.3% 0.9% and pH 7.5 10.1, establishment rates of 60% 80% and hay yields of 675 2,250 t · km^-2 have been achieved [11]. In the Yellow River Delta region with salt content of 0.2% 0.9% and pH 7.8 9.0, fresh forage yields reach 1,800 2,250 t · km^-2.

**(3) Good nutritional quality.** Tall wheatgrass provides high-quality roughage for cattle and sheep [5,36,37], with nutritional quality primarily determined by harvest timing. Crude protein content exceeds 20% at seedling and regrowth stages, 14% 16% at jointing stage, and approximately 10% at heading to flowering stage [38-40]. In vitro dry matter digestibility at heading stage ranges from 41.8% 54.8% [38], with neutral detergent fiber content of 53.2% 56.3%, acid detergent fiber content of 28.6% 30.2%, crude fat content of 3.4% 3.9%, and carbohydrate content of 1.9% 2.4% [41].

**(4) Well-developed root system for saline-alkali land improvement.** Tall wheatgrass produces large root biomass [42] that can absorb sodium ions from soil and shallow groundwater [43]. It tolerates heavy metals, can be irrigated with saline drainage water rich in boron [44] and selenium [45], and can remediate heavy metal-contaminated soils [46-48]. The black "humus" produced around tall wheatgrass roots binds with inorganic colloids, clay minerals, and fine sand to form "micro-aggregate structures." Its perennial nature reduces soil tillage and water erosion, increases soil organic matter, and protects the ecological environment [49]. Saline-alkali land improved by tall wheatgrass can subsequently be used for grain crop cultivation.

**(5) Suitable growing conditions.** Tall wheatgrass thrives in regions with annual average temperatures of 5℃ 20℃ and daily average temperatures of 2℃ 25℃ [22], and can tolerate daily average temperatures of 30℃ 35℃ and lows of -35℃ [21]. It is most suitable for areas with annual precipitation of 350 600 mm [22]. Generally, it can grow for 10 15 years [21], or even 25 years [50], with reports of 32-year growth under natural conditions [26]. Considering the need to avoid competing with grain for land, European researchers recommend developing tall wheatgrass on semi-arid marginal lands [32,51]. On rain-fed marginal lands, tall wheatgrass provides better economic returns than rye (*Secale cereale*), with production energy consumption only 40% that of rye and an annual global warming potential (GWP) of -190 t CO2 · km^-2 for tall wheatgrass pasture versus 160 t CO2 · km^-2 for rye [49]. In China, tall wheatgrass can be developed on coastal saline-alkali wasteland with salt content of 0.4% 1.0% in the Bohai Rim region to construct the "Coastal Grass Belt."

## Development History and Current Status of Tall Wheatgrass Industry at Home and Abroad

Since the certification of the first tall wheatgrass variety Largo in the United States in 1937, more than 10 varieties have been certified and promoted worldwide [5,9]. These varieties are currently cultivated on large scales in the United States, Canada, Australia, Argentina, and parts of Europe. In the United States, tall wheatgrass pastures are mainly distributed in the northern Great Plains and western mountainous regions, with the Platte variety in the central plains, Alkar in the west, and Jose primarily promoted in the southern plains [52]. The Jose variety alone is planted across more than 1,000 km^2 in Oklahoma, Texas, and New Mexico [50]. Canada cultivates only the cold-tolerant variety Orbit, bred in 1966, which is suitable for all saline lands in the country [53,54]. In Australia, commercial seed production began in 1968, with large-scale promotion in the 1980s and annual seed production of 30 70 t in the 1990s [55]. Currently, tall wheatgrass pastures exist in southern Australia, including New South Wales, Victoria, Western Australia, and South Australia. In Argentina, three varieties have been certified and promoted since introduction in the 1960s, with tall wheatgrass pastures covering 1.0$×$10^4 km^2 in the Salado River basin [56]. In Europe, tall wheatgrass is used as an energy plant on semi-arid marginal lands as an alternative to corn and rye [21,34,35]. Globally, more than 20 forage seed companies market tall wheatgrass seed, most of which are American companies, forming a complete industrial chain of seed production, sales, and forage utilization.

Between 2000 and 2022, 89 tall wheatgrass-related research papers were published in international journals, with authors from the United States, Australia, Argentina, and Europe (including Poland, Spain, Germany, Czech Republic, Hungary, Bulgaria, and Portugal) accounting for 33.0%, 12.4%, 10.3%, and 28.9% of these publications, respectively. During the same period, China published only 4 papers in international journals (4.1%) . Most Chinese research has been published in domestic journals, with 44 related papers published since 2000.

In 2021, the National Forestry and Grassland Administration included tall wheatgrass in China's main forage species catalog. Despite nearly 70 years since its introduction, tall wheatgrass has not yet formed an industry in China, with no certified varieties or supporting cultivation techniques. Forage-utilized tall wheatgrass is decaploid (2n=10x=70), with complex genetic foundations and high heterozygosity, and basic research on important forage traits such as yield, quality, and stress resistance remains weak [9]. Since 2012, Zhensheng Li's research team at the Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, has conducted tall wheatgrass line identification in Caofeidian and Nanpi in Hebei, Haixing, and Dongying in Shandong, screening the salt-tolerant and high-yielding line C2 (tentatively named "Zhongyan No. 1") [41].

## Suggestions for Industrialization of Tall Wheatgrass in China

### Strengthen Basic Research and Establish a Molecular Design Breeding System

Currently, systematic molecular breeding research on tall wheatgrass has not been conducted worldwide, with countries still employing traditional population selection methods. Tall wheatgrass molecular breeding technology lags far behind that of rice and wheat [9]. Therefore, we recommend that China strengthen basic research by conducting germplasm resource screening, genome structure and sequence variation studies, and identifying molecular modules and functional genes for important forage traits (such as salt tolerance, high yield, quality, and palatability). Developing tissue culture, genetic transformation, and gene editing technologies would establish a tall wheatgrass molecular design breeding technical system, enabling China to achieve a "corner overtaking" in tall wheatgrass breeding research.

### Conduct Variety Breeding and Accelerate Variety Certification

Addressing the long breeding cycle of tall wheatgrass, we propose research on breeding methods to improve efficiency. Tall wheatgrass requires vernalization and long-day conditions for normal flowering. By studying vernalization and photoperiod conditions, accelerated breeding methods can be established. Research on anther culture should be conducted to establish a haploid induction and doubling technology system. Combined with field individual/population mixed selection, seedling salt tolerance identification, off-site selection, reproductive isolation, long-day treatment, and accelerated breeding methods, salt-tolerant and high-yielding varieties can be selected. Breeding selection indices should focus on yield (regrowth ability, cutting tolerance), quality (crude protein content, digestibility, palatability), and stress resistance (salt-alkali tolerance, waterlogging tolerance, drought tolerance, etc.). The hybrid F1 of "wheat × tall wheatgrass" maintains perennial characteristics like tall wheatgrass but exhibits faster development and higher biomass [57]. If apomixis issues in hybrid F1 can be resolved through gene editing technology, it may serve as a novel salt-tolerant forage to replace tall wheatgrass in the future. We recommend that national forage variety certification authorities open a green channel, add tall wheatgrass variety regional trial sites in the target areas of the "Coastal Grass Belt," accelerate variety certification, and strive to achieve a "from 0 to 1" breakthrough for Chinese tall wheatgrass varieties. Using the molecular design breeding system, new varieties with higher salt tolerance (1.0% 1.5% salt content) and high yield and quality should be cultivated to enable continuous variety replacement.

### Establish Standardized Seed Production Demonstration Bases to Realize Seed Industrialization

Given the light weight of tall wheatgrass seeds, harvesting machinery should be modified to reduce seed loss and improve threshing efficiency. Cleaning machines suitable for tall wheatgrass seeds should be developed or improved. Seed coating technology should be studied to enhance germination rates. Technical regulations for field cultivation management, seed harvesting, cleaning, and processing should be formulated, targeting seed yield and quality. In cooperation with relevant seed companies, standardized seed production demonstration bases should be established in the Bohai Rim region to achieve market-oriented industrialization of tall wheatgrass seed production, cleaning, coating, and sales.

**Accelerate Trials and Demonstrations to Drive Industrial Development and Protect the Ecological Environment**

**(1) Conduct regional adaptability research and establish demonstration models of the tall wheatgrass "Coastal Grass Belt."** Research should focus on water and fertilizer requirements of tall wheatgrass populations on moderate to severe saline-alkali land, saline water irrigation technology, and the development of fully mechanized, low-cost, high-yield cultivation techniques. Optimal harvest timing and cutting techniques should be determined by balancing yield and quality. Silage inoculants and modulation technology suitable for tall wheatgrass should be developed [58], and technical conditions for hay drying should be determined to formulate haymaking technical regulations. Multi-year, multi-site trials should be conducted in the "Coastal Grass Belt" target region for adaptability research. Key demonstration and promotion areas should be identified, and cooperation with breeding enterprises, forage companies, and cooperatives/large growers should be established to create 100-mu/1000-mu demonstration models of the tall wheatgrass "Coastal Grass Belt." This will promote the formation of a "cattle/sheep farm + forage company + large grower" industrial prototype for tall wheatgrass cultivation, forage processing, and utilization. For example, in Dongying, Shandong, integration of the Yellow River Estuary Tan sheep industry, beef/dairy cattle industry, and tall wheatgrass industry can be achieved. Through field demonstration meetings, technical training, and news publicity, the effects of high-yield cultivation techniques, hay/silage products, and livestock feeding results can be showcased, providing a paradigm for tall wheatgrass industrialization and driving industrial development.

**(2) Produce high-quality forage oriented by market demand and establish commercial forage production demonstration bases and livestock demonstration farms.** Oriented by the nutritional requirements of cattle and sheep for high-quality forage, 1000-mu-scale tall wheatgrass commercial forage demonstration bases should be established to produce premium forage products (silage, hay, grass meal, grass pellets, etc.). Relying on large-scale livestock farms, scientific assessment of tall wheatgrass feeding effects and economic benefits should be conducted based on indicators such as meat yield, meat flavor quality, and milk production. According to the nutritional requirements of cattle and sheep at different developmental stages, tall wheatgrass roughage should be introduced to design precise dietary formulations. Cooperating with large-scale livestock farms, tall wheatgrass livestock demonstration farms should be established to drive large-scale application of tall wheatgrass forage. Additionally, grazing on tall wheatgrass saline-alkali pastures can be utilized to achieve ecological livestock production.

**(3) Foster leading enterprises and promote industrial chain integration driven by animal husbandry.** Following the principle of "integrating planting and feeding, planting for feeding, and determining planting by feeding," and according to the layout and planning of the animal husbandry industry, leading enterprises should be supported to promote industrial chain integration through the "leading company + professional cooperatives/large growers" model. On one hand, large livestock farms and family farms with conditions should be encouraged to establish their own tall wheatgrass pastures on saline-alkali land to ensure forage self-sufficiency. On the other hand, leading companies should be fostered and supported to closely connect supply and demand parties, enabling order-based production of tall wheatgrass forage. The task of grass planting should be assigned to professional cooperatives and/or large growers, who can consolidate scattered plots of moderate to severe saline-alkali wasteland to establish forage bases. Leading companies should focus on developing forage markets, purchasing machinery and equipment required for forage production, signing agreements with professional cooperatives/large growers at protective prices, and establishing professional technical teams to provide one-stop technical services for seed, fertilizer, and "planting, management, harvesting, and sales." While supplying forage products to livestock enterprises, leading companies can also absorb organic fertilizer produced by animal husbandry, achieving planting-feeding circulation while ensuring healthy and sustainable development of herbivorous livestock.

**(4) Establish an ecological barrier of the "Coastal Grass Belt" to protect the ecological environment.** Coastal saline-alkali wasteland is marginal land with fragile ecological environments [7]. Due to high soil salinity in coastal areas, the common method for urban road greening is to replace the soil with low-salinity soil before planting ornamental plants. This method is costly and unsuitable for large-scale application. Similarly, due to high soil salinity, wild plants on sea and river dikes have shallow root systems and often face slope collapse during rainy seasons, causing severe soil erosion. This results in high maintenance costs and unsatisfactory results. Tall wheatgrass can be used for urban road greening in these areas using original soil or only shallow soil replacement. With its extensive root system, salt tolerance, and waterlogging tolerance, tall wheatgrass is suitable for protecting sea and river dikes [26]. We recommend using tall wheatgrass for urban road greening and sea/river dike protection in coastal saline-alkali regions to leverage its ecological functions.

### Increase Policy, Funding, and Scientific Talent Investment

**(1) Enhance social publicity and transform mindsets.** In agricultural regions, awareness of artificial grass planting is weak, and the concept of "grain over grass" is deeply rooted. Therefore, relevant departments should continuously strengthen social publicity to guide governments, enterprises, and professional cooperatives/farmers to adopt the concept that "planting grass is planting grain." Professional cooperatives and large growers should be guided to treat grass planting like grain planting, learning and adopting scientific cultivation techniques (fertilizer application, irrigation, timely harvesting, etc.) to grow grass well. The economic benefits of the tall wheatgrass "Coastal Grass Belt" are built on the foundation of scale and mechanization. Professional cooperatives and large growers should be guided to conduct large-scale planting, cooperating with leading companies and livestock enterprises for order-based production.

**(2) Scientifically plan grass planting land and provide policy and funding support.** To avoid "grass-grain land competition," the tall wheatgrass "Coastal Grass Belt" targets saline-alkali land with salt content of 0.4% 1.0%. In practice, moderate to severe saline-alkali land with grain yields below 50 kg per mu contributes minimally to national food production after deducting seed costs, but has tremendous potential for forage development. We recommend that government departments at all levels formulate policies based on local conditions, scientifically plan grass planting land, and improve the utilization efficiency of saline-alkali land. Since the implementation of the "National Alfalfa Development Action for Revitalizing the Dairy Industry" and "Grain-to-Forage" programs, alfalfa and silage corn planting areas have increased rapidly, promoting the development of grass-based animal husbandry. We recommend expanding the "Grain-to-Forage" program to include salt-tolerant forages such as tall wheatgrass. The "Coastal Grass Belt" can transform saline wasteland into artificial grassland, increasing high-quality forage area and filling the gap in China's high-quality forage supply. We recommend that the state introduce timely policies to encourage and guide social capital to construct the "Coastal Grass Belt," launch "Coastal Grass Belt" subsidies, and support the development of salt-tolerant forages such as tall wheatgrass.

**(3) Cultivate a tall wheatgrass talent team.** For a long time, tall wheatgrass research in China has focused on distant hybridization with wheat. However, research on its utilization as forage is weak and scattered, and industrial technology talents are lacking. We recommend that the state cultivate and introduce talents in tall wheatgrass research, form research teams, and explore the establishment of a molecular design breeding technical system from the perspectives of genomics, molecular module discovery of important forage trait genes, genetic transformation, and gene editing. By conducting tall wheatgrass variety breeding and cooperating with leading companies and livestock enterprises to achieve industrial application, the construction of the "Coastal Grass Belt" can be accelerated.

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*Note: Figure translations are in progress. See original paper for figures.*