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Potential Challenges and Food Security Responses to Climate Change in China and Mongolia in the Post-COP28 Era

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Abstract: After the COP28 Conference, many countries are increasingly concerned about their future practices regarding food security. In North Asia, the Northeast China is the major food production base for the country. Across the border, the economy of Mongolia is heavily reliant on agricultural production and animal husbandry. In recent years, climatic extremes such as droughts and floods, combined with human-induced overgrazing, have posed alarming threats to food security. This review illustrates the challenges and constraints these two countries are facing due to climate changes and summarizes the existing measures and established programs in both countries. Furthermore, we develop the "Climate Resilient Agriculture" (CRA) framework for improving agricultural resilience. This framework emphasizes the importance of international institutions, such as the World Bank, and developed countries to provide more financial and technological support to bolster climate resilience in Northern Asia. Finally, we conclude by encouraging cross-border co-production and collaborations among governments to implement the CRA framework to tackle future climatic challenges.

Key words: agricultural sensitivity; climatic extremes; climate resilient agriculture (CRA); food security; China and Mongolia

1 Introduction

The global food demand is projected to increase to meet the needs of an expected global population of 9.7 billion by the 2050s (Hasegawa et al., 2022). Climatic changes may pose threats to food prices and availability, potentially leading to increased hunger (Van Dijk et al., 2021). The expansion of agriculture and the unsustainable use of land and resources, which contribute to increased carbon emissions, are inter-

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connected challenges for food production. Unfortunately, the current plans for sustainable agriculture fall short of the goals set out in the Paris Agreement (UN, 2015), particularly in support of the vulnerable agricultural countries in South Asia, including densely populated and economically underdeveloped nations such as India, Pakistan, and Bangladesh. In addition, persistent conflicts and natural disasters have resulted in catastrophic food insecurity in South Sudan and Palestine (IEA, 2023).

In response to the pressing challenges posed by climate change, the United Nations (UN) and various countries have been taking decisive action. The 28th Conference of the Parties (COP28[①]) Conference provided the first global assessment of the implementation of the Paris Agreement (UNFCCC, 2023a). On the 1st of December 2023, during the COP28, 134 countries signed the United Arab Emirates (UAE) declaration on Resilient Food Systems, Sustainable Agriculture, and Climate Action, thereby committing to integrate agriculture and food systems into their national climate action plans by 2025 (Food Systems Pavilion, 2023). The COP28 also witnessed a consensus on a global adaptation framework that outlined the criteria for enhancing climate resilience, including finance, technology, and capacity-building (CISION PR Newswire, 2023).

Climate change and food security are two pivotal challenges that are closely intertwined. Projected changes in the frequency, intensity, and spatial extent of extreme climatic events are expected to have compounded impacts on food systems (AghaKouchak et al., 2020). Agriculture, which is essential for food production, relies on natural resources (including biodiversity, land, vegetation, rainfall, and sunlight), which are inextricably linked to climatic conditions (Alfieri et al., 2017). A global analysis has revealed challenges in the main crops like maize, rice, wheat, and soybean, which have experienced yield increases in only 61%–76% of their global harvested areas. This implies that 24%–39% of these cropland areas are no longer showing yield increases; and more troubling is that 43% of global rice and 44% of global wheat production are currently from these climatically vulnerable areas (Ray, 2012). Food exemplifies global inequities, as it provides clear evidence that wealthy areas consume excessively, while millions of people are still suffering from starvation. Unsustainable food systems contribute at least one-third of the global greenhouse gas emissions, exacerbating climate change and resulting in destructive cycles of droughts and floods (WRI, 2023).

In 2021, extreme weather events such as torrential rains, floods, heatwaves, wildfires, and cold snaps seriously threatened agricultural production worldwide. Russia, the largest wheat exporter, saw a 15% drop in overall yields. Similarly, Australia and Canada, the second and third largest wheat exporters, experienced spring wheat crop declines of 41% and 24%, respectively (FAO, 2021a). Natural disasters related to extreme weather have caused USD 2.6 trillion in damage and resulted in the loss of 475000 livestock in the last two decades (Li et al., 2015).

Food security has emerged as a major concern amid epidemics and global climate change. The climate crisis has become a significant driver of poverty and hunger, hindering progress towards achieving the United Nations Sustainable Development Goals (SDGs) (UN-Environment Program, 2022). COP28 aimed to address the climatic challenges of food production (IPCC, 2021). In response, many countries are exploring resilient agricultural solutions. The Climate-resilient Agriculture (CRA) framework was developed to improve the long-term productivity of agricultural production systems to reduce the risks and losses caused by climate hazards and accelerate the return to a stable production state (ABD, 2009).

Climate change poses increasing challenges to local food security, particularly in sensitive regions such as China and Mongolia in Northern Asia (Chan et al., 2023). However, increasing annual and seasonal rainfall has improved the drylands (e.g., in Northwestern China), making them more favorable for the growth of grains in the long run. Northeast China, with its fertile black soils and humid climate, has become a major cereal-producing region (Chan et al., 2024a). In Mongolia, the extreme climate and severe desertification have significant impacts on both agricultural production and livestock farming. Food shortages are exacerbated by the uneven distribution of water resources and land desertification. In response, there has been an urgent call for achieving CRA by improving agro-ecology and strengthening agricultural infrastructure. Also, adequate financial mechanisms are needed to increase agricultural productivity and ensure food security (ABD, 2009; Chan et al., 2022).

2 Global climate change and the challenges to food security

2.1 Regional extreme events and climate change trends in recent years

The climate crisis is causing unprecedented disruption to life and livelihoods worldwide, marked by record-high temperatures (FAO, 2023a). The next decade will be a critical window for achieving the 1.5 ℃ temperature control target (FAO, 2021a). Since industrialization began in the 1840s, human-induced climate change has led to more frequent and intense extreme weather events, escalating the risks of drought and flooding with consequent societal Losses (Chretien et al., 2015). The global inventory under-

① The 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change (UNFCCC) was held from 30 November to 13 December 2023 in Dubai. The Cop28 conference reached the 'UAE Consensus', completed the first global assessment of the Paris Agreement and raised the need for increased climate adaptation funding. It provided new impetus to future climate action after this conference (Post-COP 28 Era).

scores the importance and urgency of the Paris Agreement's temperature goal (Ceris, 2023). However, the stocktaking results are discouraging, and have revealed that the world is not yet on track to limit the temperature rise to 1.5 ℃ by the end of the century.

For example, extreme events have caused catastrophic losses in recent years, impacting food stocks, prices, and international trade (Reddy, 2015). Natural disasters, such as floods, hurricanes, and droughts, can inflict significant damage on infrastructure and farmland. Heatwaves and droughts can exacerbate the challenges facing crop production, farmer health, and the labor force, leading to declining food production (Lesk et al., 2016). This, in turn, affects the incomes of farm households and leads to an increase in food prices due to reduced crop yields and inadequate food supplies (Chan et al., 2024b) (see Table 1). Hasegawa et al. (2021) emphasized that food security risks can have far-reaching consequences across the socioeconomic spectrum, potentially causing food shortages and famine in numerous regions.

Climate-sensitive regions should develop agricultural adaptation strategies to cope with extreme and complex weather since they lack long-term resilience to multiple hazards. Agricultural production, especially food production, is affected by numerous factors, and an unpredictable climate exacerbates this pressure (COP28, 2023b). To ensure agricultural security in response to extreme and complex climate changes, a more robust agrometeorological service system must be established. This includes strengthening agrometeorological monitoring and forecasting as well as improving the agricultural insurance system (Huang and Yang, 2017).

Table 1 Some examples of extreme events and agricultural losses in recent years

Extreme events	Disaster situation	Agricultural losses	Citations
Floods in Pakistan (2022)	Climate change made the floods worse by up to 50% and three times Pakistan's 30-year average rainfall was recorded	Flooding wiped out 45% of the country's cotton crop, costing an estimated $10 billion USD in damages, and food prices rose by 29%	Nanditha et al., 2023
Heatwave and drought in China (2022)	More than 80% of the Yangtze River Basin is in drought. The speed and intensity of the drought are the most extreme since 1961	At least a 20% water deficit (more than 1.05 million ha) for major crops (i.e., rice, barley, and maize), which suffered severe drought in the Yangtze River basin	Chan et al., 2022
Tropical storms and typhoons in the Philippines (2022)	The storms unleashed heavy rains and landslides. They affected 1.8 million people across the Philippines, and more than 150 towns and cities were without power	More than 10 million ha of crops have been affected (especially rice, maize, and cocoa), and more than 300000 people are suffering food shortages	UN News, 2022a
Alternating droughts and floods in Africa (2021–2023)	Africa (Kenya, Ethiopia, etc.) is dealing with the worst drought in 40 years, with rivers drying up and an increasing frequency of severe droughts and floods	Agricultural productivity growth in Africa has fallen by 34% since 1961, food imports have been forecast to increase by threefold, and nearly 23 million people face acute food shortages	UN News, 2022b
Extreme drought in Spain (2022–2023)	Spain is experiencing a prolonged period of drought, which is attributed to 36 consecutive months of below-average rainfall	Spain's olive oil production has decreased by 50% year-on-year. By April 2023, the price of olive oil in Spain had increased by 47%. The lack of rainfall has also affected 60% of Spain's agricultural areas, causing irreversible damage to more than 3.5 million ha of crops	Spain English News, 2023

2.2 Food production patterns and challenges in China and Mongolia

China's vast geographical area and diverse climatic and geographical conditions have led to the evolution of agricultural systems with different characteristics in the different regions (Qiu et al., 2022). For example, the distinctly different regions include the area of south of the Huaihe River, the eastern part of the Northeastern Three Provinces and the southeast edge of the Qinghai-Tibet Plateau (humid zone); the Northeast lowlands, the North China lowlands, the southern part of the Loess Plateau and the southeast part of the Tibetan Plateau (semi-dry zone); the Northeastern plains, the North China plains, the southern part of the Loess Plateau and the southeastern part of the Tibetan Plateau (the semi-humid zone); the eastern part of the Inner Mongolia Plateau, the Loess Plateau and the bulk of the Qinghai-Tibetan Plateau (semi-arid zone); and Xinjiang, western Inner Mongolian Plateau and northwestern Tibetan Plateau (arid zone). As these various regions possess distinct natural conditions, such as climate, topography, soil, and water, farmers have developed different types of agriculture according to their local conditions (Table 2).

In general, the distribution of food production in China exhibits distinct characteristics (Figure 1). The Eastern cultivation and Western pastoralism practices involve cultivation mainly distributed in the semi-humid and humid plains, with pastoralism mainly distributed in the semi-arid and arid regions of the North and the Qinghai-Tibetan Plateau (which roughly coincides with the 400 mm precipitation line). The southern rice and northern wheat practices involve rice cultivation dominating in the more humid southern areas, while in the drier northern regions, wheat is the predominant crop (Qi et al., 2018). In Northeast China, spring wheat is the main crop, while Northern and Southern China mainly rely on winter wheat (Yang and Huang, 2021).

Table 2 Four major agricultural types in China

Type of agriculture	Environmental conditions	Distribution	Main crops
River valley agriculture	High altitude and low temperature	Tibet and Xinjiang regions	Barley, wheat, oilseed rape, and rice (Wang and Li, 2021).
Oasis agriculture	Low rainfall, many sunny days, large day/night temperature differences, high crop yields	Xinjiang and Gansu Hexi Corridor	Cotton, maize, wheat (Chen et al., 2010)
Dam agriculture	Thick, flat soils, large arable areas, good water conditions	Intermontane basins, river valleys, and foothills of Yunnan and the Guizhou Plateau	Cocoa, natural rubber, tea (Qiu et al., 2022)
Irrigated agriculture	Arid and semi-arid regions with low rainfall, rely on irrigation	Hetao Plain, Ningxia Plain, and Hexi Corridor in Northwest China	Rice, wheat, maize, potatoes, and apples (Zhou et al., 2016)

Above the North Qinling-Huaihe River line, the land is predominantly arid, and irrigation is primarily achieved through watering. Crops such as wheat, cotton, groundnuts, and maize are grown in this region. In Northeast China, crops are grown once a year, while either triennial or annual crop cultivation is practiced in the North China Plain (Gan, 2023). The land is mainly used for paddy rice production which is the primary crop below the South Qinling-Huaihe River line. Additionally, cotton, oilseed rape, sugar cane, and other crops are also widely cultivated. Most of these areas have biannual to triple maturation cycles (Chan et al., 2024a).

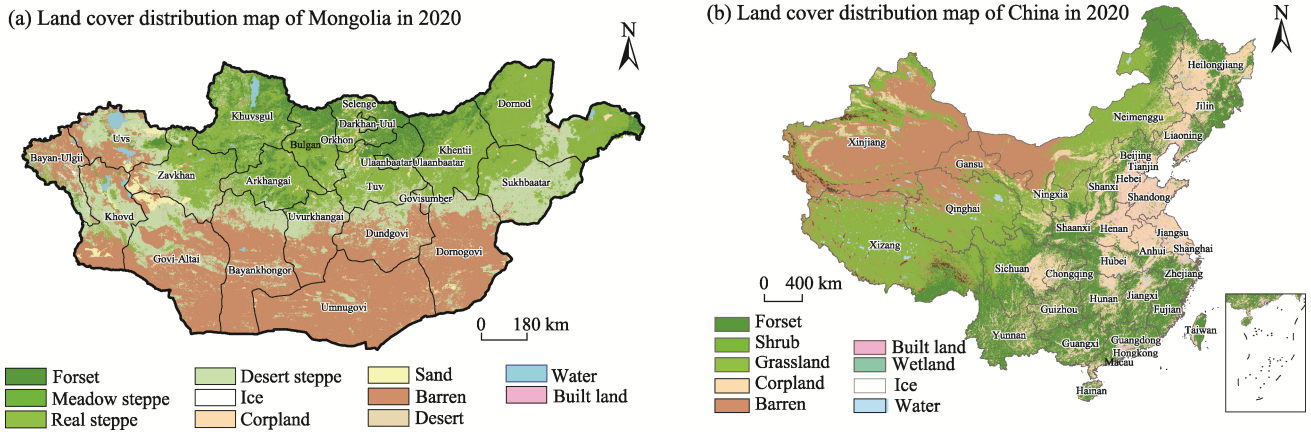

Figure 1 Distribution of land cover types in Mongolia and China in 2020
Note: Data source: Wang et al. (2022)

In Mongolia, the Gobi Desert covers approximately one-third of the land area, which limits the suitable land for agriculture (Figure 1). Even though agriculture and animal husbandry constitute nearly half of the country's economic activities, these sectors face challenges with low levels of development, outdated production technology and the prevalence of rudimentary agriculture and animal husbandry practices. This situation has resulted in a high demand for food, vegetables, fruits, poultry meat, and eggs. The average Mongolian farm operates at a subsistence level. The limited application of fertilizers, and problems with weeds, pests, and diseases contribute to diminished soil fertility, and the farmers rely heavily on natural resources for the planting and harvesting of crops (FAO, 2022a).

The main crops of Mongolia are divided into two categories food crops (mainly wheat) and vegetables. Food crops are widely grown in in Central Province, Selenge Province, Burgan Province, and other areas of Ulaanbaatar, and a small amount of rapeseed is also grown. In addition, vegetables such as potatoes, cabbages, roti, cranberries, cucumbers, tomatoes, celery, and a small amount of watermelon, are also grown.

Mongolia has a brief growing season of only four or five months, coupled with scarce arable land resources and challenging climatic conditions. These factors, combined with a rudimentary cropping pattern, contribute to lower food yields and per capita shares compared to other countries. Scientific and technological progress holds enormous potential for increasing food production. However, Mongolia is already suffering from poverty, food insecurity, and malnutrition, making it particularly vulnerable to the impacts of climate change on food production. Conversely, regions with milder climates could experience positive effects, as the warmer weather may enhance agricultural yields (Shao et al., 2021).

2.3 Challenges: Impacts of climate change on food security in China and Mongolia

China is experiencing an increasing frequency of extreme heat events, a rise in the occurrence of extreme precipitation events, and an elevation in the climate risk index, all within

the context of global warming (Li et al., 2021). The frequency of extreme heat events in China has exhibited a significant increasing trend from 1961 to 2022, with the frequency in 2022 being the highest since 1961 (Sweileh, 2020). In addition, the frequency of extreme daily precipitation events in China has been steadily increasing. The average intensity of typhoons making landfall in China since the late 1990s has shown fluctuations, aligning with an upward trend in China's climate risk index (Chen et al., 2021).

Among the climatic extremes, droughts, floods, and hailstorms are the three most impactful disasters on Chinese agriculture. Climate change is expected to exacerbate this situation by altering temperature and precipitation patterns, resulting in direct or indirect crop yield reductions. Projections indicate that by the 2030s, seasonal droughts alone could cause an 8% reduction in yields of China's three major staple crops rice, wheat, and maize (Yu et al., 2021).

The effects of climate change on agriculture will vary among different regions. In some specific regions, warmer temperatures may enhance the growth of certain crops, but they will often exceed the optimal temperature thresholds, and insufficient levels of water and nutrients could lead to reduced yields (EPA, 2022). The impacts on the three main crops will differ depending on the location within China. For rice production, climate change will be detrimental in Southern China, but beneficial in Northern China. Provinces that are the major producers of rice, such as Hunan, Hubei, Jiangsu, and Jiangxi, will experience significant reductions in production yields (Zhang, 2019).

Climate change will have differing impacts on wheat and maize production in the various regions of China (Fig. 1). Wheat production in Northeastern China is expected to benefit, whereas Central China, including Henan, Shandong, and Hebei, will experience moderate reductions, and Southern China will face severe reductions in wheat production. Maize production is expected to be negatively impacted by climate change in all regions except for certain areas in the Xinjiang Uygur Autonomous Region. This will be especially evident in major maize-producing areas such as Jilin, Heilongjiang, Henan, and Hebei (Liu et al., 2021).

The significant economic implications of climate change on rice, wheat, and maize production pose a serious threat to China's food security. Without adequate technological upgrades and improved farming practices to counteract the reduced food production, there is a risk of declining total domestic food production. If China has to depend on international markets, even partially, to secure its food supply, it would be challenging to achieve self-sufficiency in food production. This is a primary concern of the Chinese government (Edward, 2023).

The Mongolian plateau is a region highly susceptible to global climate change, and Mongolia ranks among the countries most impacted by this phenomenon. Over the last 70 years, Mongolia has experienced a significant increase in the average temperature, which rose by 2.1 ℃. That increase poses a big challenge to achieving the Paris Agreement limit of a temperature rise of 1.5 ℃. Therefore, urgent action is required to address this issue. An assessment of desertification and land degradation in Mongolia revealed that 77% of the land was already degraded due to overgrazing and climate change as of 2021. Natural disasters, such as severe winters, droughts, snowstorms, and dust storms, are escalating in frequency and severity (Lin et al., 2010).

Mongolia is home to approximately 300000 herding households, constituting about 30% of the total population. These households rely heavily on livestock and natural resources for their livelihoods, making them highly vulnerable to the impacts of climate change. As a result, it is crucial to strengthen the herders' risk management capacity for climate change adaptation in Mongolia (Chan et al., 2023). Farmers and herders are particularly concerned about meteorological disasters due to the frequent climatic events such as dust storms, droughts, snowstorms, and low-temperature droughts which lead to widespread die-offs from starvation and cold, as well as crop failures that can cause significant economic losses (Miao et al., 2016).

Due to the escalating challenges posed by increasing climate change in recent years, it is difficult for pastoralists to make seasonal climate predictions based on past experiences. In previous years, for example, new grass and vegetation sprouted in May, which was crucial for replenishing the strength of livestock that had lost about 30% of their weight over the winter. However, in May 2023, there was still a lack of grasslands for grazing. Weather conditions during the winter months are also unfavorable, with December and January being significantly warmer than in previous years. For example, in January 2023, high temperatures of 5.5 ℃ were recorded in some parts of Mongolia. However, March and April were unusually cold (FAO, 2023b).

The increasing frequency of weather anomalies underscores the urgent need for real-time forecasting and monitoring systems. These systems are essential for providing the agricultural industry with accurate information that can enable proactive responses to climate change. Developing robust agricultural and livestock management strategies is crucial for withstanding disasters in advance and minimizing losses (Zhang et al., 2019).

3 Opportunities for bolstering food security

3.1 The global response to ensure food security based on COP28

In December 2023, COP28 reiterated the urgent need for leaders, policymakers, private sector investors, and development banks around the world to prioritize investments in smallholder farmers and seize the opportunity to increase our capacity to adapt to climate change (Eckstein et al.,

2013). The United Nations has called on countries to take immediate action, emphasizing that inaction today will result in serious social and economic consequences in the future. Inaction will lead to reduced food production, higher food prices, and increased hunger, and leave smallholder farmers, who do the most with the least, vulnerable to climate crises (UN News, 2023a). Global Stocktake has made clear that our current efforts are insufficient to meet the goals of the Paris Agreement and achieve a temperature rise of no more than 1.5 ℃ (UN Sustainable Development Group, 2023).

Unsustainable food systems currently account for at least one-third of global greenhouse gas emissions, thereby exacerbating climate change and leading to more droughts and floods that destroy crops. During COP28, 134 countries (which collectively produce 70% of the world's food) agreed to put agriculture and food systems at the heart of their climate action, which is undoubtedly an important and encouraging step forward (FAO, 2022c). Although smallholder farmers are responsible for 35% of the world's food supply and are at the forefront of the climate problem, funding to increase their climate resilience remains woefully inadequate. For example, according to the Climate Policy Initiative, smallholder agriculture and food systems will receive only 0.8% of global climate finance in 2019–2020 (UN, 2022).

At the COP28 conference, an agreement on the climate "loss and damage" fund was adopted, which identifies the sources of funding and the funds to be held in trust by the World Bank. The "loss and damage" fund became operational on 30 November 2023. According to the COP28, no fewer than 15 countries, including the European Union and the United States, had committed a cumulative total of about USD792 million to the fund. In addition, Australia, Estonia, Italy, Portugal, Switzerland, and the United States have committed USD 3.5 billion to the second phase of the Green Climate Fund (GCF). Eight governments announced contributions to the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF), with the total scale of the capital increase exceeding USD 174 million. The Climate Adaptation Fund (CAF) has received nearly USD 188 million in new investment commitments (UNFCCC, 2022).

The reality is that the global demand for climate finance to support sustainable agriculture and resilient food systems is increasing dramatically under climate change, while actual investments are declining (Hasegawa et al. 2022). The UAE announced a commitment of USD100 million to the fund, which aims to provide financial assistance to countries facing extreme risks from climate change to support their efforts to mitigate and recover from climate change. Other notable pledges include Germany's pledge of USD100 million; the UK's pledge of £40 million to the fund and £20 million to other arrangements; Japan's contribution of USD10 million; and the US pledge of USD17.5 million (South-South Galaxy, 2023a; COP28, 2023a).

In the Post-COP28 era, many countries are preparing to submit updated Nationally Owned Contributions (NDCs) by 2025, which will propose actions on specific topics, such as how to accelerate emission reductions, strengthen resilience to climate impacts, and provide the support and finance needed for the transition (Table 3). Several governments have announced new initiatives, actions, or funding to support vulnerable groups in building climate resilience. Over 40 governments, international agencies, and organizations have endorsed the new Locally Led Adaptation Principles, which aim to facilitate a shift towards adaptation projects, funding, and practices led by local participants (UNFCCC, 2023b).

Table 3 Major achievements and controversies at COP28

Achievements	Controversies
1. Completion of the first global stocktaking of the Paris Agreement	1. Widespread controversy about the phase-out of fossil energy does not promote a long-term climate-resilient approach.
2. "Loss and damage" fund	2. The final agreement's articulation of the fossil energy future falls short of expectations
3. New climate finances	3. Insufficient fulfillment of climate commitments by developed countries
4. Methane emission reductions	4. The EU's proposed Carbon Border Adjustment Mechanism (CBAM) is causing controversy
5. Global goal on adaptation and its framework agreed upon	
6. Launch of the Global Tipping Point report	

Note: Source: UNFCCC (2023a)

In recent years, developed countries have fallen short of fulfilling their climate change commitments, with financial support to address climate change being insufficient, sluggish, and unevenly distributed (Climate Policy Initiative, 2022). In 2021, developed countries pledged USD 89.6 billion in climate finance to developing countries, with 68% of it in the form of concessional loans. While this helps with risk prevention, it also escalates the debt burden on developing countries (OECD, 2022).

Developing countries have called on developed countries to uphold their climate finance commitments in full. Both sides also initiated negotiations on new annual climate finance targets at COP28. In addition, they discussed how to make better use of the role of multilateral development

banks (MDBs) in sharing the risk and leveraging private sector finance, and proposed a financial mechanism for loss and damage that would provide financial compensation to affected countries (UN, 2022).

The United Nations Environment Program (UNEP) Adaptation Gap Report 2023 revealed that the current funding raised by developed countries is inadequate to support developing countries in adapting to climate change. The estimated amount of funding is only one-tenth to one-eighteenth of the amount required by developing countries (Wood Mackenzie, 2022).

3.2 China's experiences and options for addressing agricultural problems

As a predominantly agricultural country with a vast population, China considers food security to be a fundamental necessity for the nation and its people. China has faced difficulties in producing, delivering, distributing, and trading food in recent years (Yu et al., 2021). The country's food security is threatened by extreme meteorological events related to global warming, such as extreme heat, drought, and flooding. Over the past 70 years, China's temperature has risen faster than the global average, rendering it highly vulnerable to natural disasters. Since the middle of the 20th century, most provinces have experienced a 5- to 10-fold increase in extreme heat and precipitation events (Sweileh, 2020). With a single growing season, crops in China are vulnerable to high temperatures, drought, and flooding, which have direct impacts on food production and security. For example, Northern China is a significant food-producing area but has always struggled with water scarcity. Despite producing about 60% of the country's food, it only has access to 24% of the freshwater resources, which puts immense pressure on production and makes it more vulnerable to extreme weather events (Zhang, 2017).

In 2022, crop yields in central and Southern China, which are China's primary food production and distribution bases, declined by at least 20% due to extreme heat and drought. The Northeast region of China boasts vast and fertile black soil, and this region serves as a crucial "granary" for the country, accounting for approximately one-quarter of its total grain production. This land is known for its resilience to heat and drought. To safeguard this valuable resource, the Chinese Government has enacted legislation to protect the black soil in the Northeastern Three provinces. Efficient management and conservation of these areas will be a key element in China's future food security strategy (Chan et al., 2022).

To tackle the challenges of global pandemics, regional conflicts, and extreme weather disasters, new programs have been implemented to ensure food security (Guan and Ren, 2023). At the national level, China is actively responding to the call of the COP28 (Liu et al., 2023). The Belt and Road Initiative is a great opportunity for China to engage in South-South cooperation on climate change mitigation and adaptation (Guan and Ren, 2023). Studies have estimated that emissions from China's agri-food system could be reduced by nearly 50% by the 2060s through improved agricultural technologies and dietary changes. Thus, climate-smart agriculture will not only help farmers avoid yield losses and sustain their livelihoods but will also effectively increase their incomes and contribute to the development and transformation of regional agro-ecosystems (China Meteorological News, 2024).

For example, the development of a high-quality grape industry in Ningxia's agricultural transition to drought adaptation has improved the incomes of local farmers. Over the past few decades, the intensification of the warm, dry climates and increasing drought, coupled with irrational agricultural activities, has led to severe local land degradation and a high incidence of poverty (Davenport et al., 2020).

To address this situation, the Asian Development Bank has invested approximately 670 million yuan to help the Northwest Region of China with ecological restoration and the development of sustainable and high-value-added agricultural industries. Through a series of integrated measures such as ecological restoration and water-saving irrigation, the resilience of agriculture in the Ningxia region to the risks of drought and climate change has been strengthened, and industrial development measures have been combined to drive a shift from high-water-consuming, low-value food crops to higher-value crops (e.g. fruits and vegetables) and water-saving cash crops in the region.

Ningxia has successfully established numerous smart agriculture demonstration zones, where unmanned aerial vehicles (UAVs) for seeding and sophisticated intelligent irrigation systems are extensively utilized (Ladisy and Cao, 2023). These advanced systems facilitate precision irrigation, thereby efficiently conserving water resources. Furthermore, the real-time monitoring of soil moisture and crop growth conditions is achieved through the deployment of sensors, enabling seamless digital management of agricultural operations. Ningxia has also embarked on an ecological conservation and restoration project in the central arid zone, and it has significantly bolstered its windbreak and sand-fixation capabilities, along with enhancing soil and water conservation efforts (Liu et al., 2023). The successful implementation of these measures was made possible through substantial financial investments by government departments.

3.3 Mongolia's challenges and assistance in food security

Livestock farming is the most important form of livelihood and the major source of income for 35% of the households in Mongolia. Mongolian herders have long faced the harsh conditions of Mongolia's unusually hot and dry summers and unusually cold winters (FAO, 2023b). Over the past two decades, climate change has led to an increase in the severi-

ty and frequency of extreme cold weather. As a result, the snow-covered land is firmly frozen, preventing livestock from grazing, so the livestock are unable to store fat to protect themselves from the cold, and large numbers of animals die of starvation or cold (FAO, 2019). In Mongolia, the growing season lasts for just 90 days and the weather conditions have grown increasingly unpredictable, so there are great business opportunities for cooperation between China and Mongolia in agriculture and animal husbandry.

For example, a collaboration focusing on the hydrological development of agriculture, modernizing animal husbandry, and engaging in high-tech, high-yield breeding and farming. Six Chinese experts and 13 technicians were deployed to 29 housing units in Mongolia, where they transferred knowledge on animal husbandry, crop production, food safety and trade, and capacity development to local farmers and agricultural extension staff. The experts were primarily from the Inner Mongolia Autonomous Region of China so they shared similarities in language, culture, and agroecological conditions with those they assisted. They introduced 11 new technologies, 42 new varieties of fodder crops, and 80 pieces of agricultural equipment, in addition to organizing 67 training courses and training 4700 people (FAO, 2023c).

In response to Mongolia's relative scarcity of water resources, China has dispatched 19 experts and technicians to Mongolia to provide technical support. Their main tasks include assisting in the construction or improvement of farmland water conservancy facilities and enhancing agricultural disaster resilience. In addition, agricultural science and technology parks have been established in suitable areas along the China-Mongolia border and within Mongolia. These parks introduce intensive technologies and equipment for crop and livestock production, thereby driving local agricultural industrial upgrading and increasing farmers' income, and they have achieved positive results in responding to extreme disaster events (South-South Galaxy, 2023b).

Under the umbrella of the Food and Agriculture Organization of the United Nations (FAO) in the context of the recently launched Phase III of the China-FAO, the South-South Cooperation with China (SSC-China) has been established. This project aligns with the National Program for Food Security (NPFS) in the global context to ensure the global food supply and security issues for developing countries and nations (Dima, 2023).

4 Discussions

4.1 Establishing the Climate-Resilient Agriculture (CRA) Framework

CRA is an integrated approach to managing landscapes—cropland, livestock, forests, and fisheries—that addresses the interconnected challenges of food security and climate change (Jatoi et al., 2022). This CRA framework aims to improve the long-term productivity of agricultural production systems and farmers' incomes through the sustainable use of existing natural resources in the context of intensifying climate change. Its goal is to increase the resilience of agricultural production systems with high exposure and vulnerability to climate change, i.e., to reduce the risks and losses caused by climatic hazards by enabling a rapid return to a steady state (ADB, 2009).

This framework promotes economic, social, and environmentally long-term future development by addressing food security concerns and climate risks, and it consists of three main pillars: sustainably increasing agricultural productivity and farmers' incomes (Productivity), adapting to climate change and building climate resilience (Adaptation), and, when possible, reducing greenhouse gas emissions (Mitigation) (FAO, 2021).

The CRA framework and its recommended practices can help avoid yield losses and increase food production, thereby ensuring food security while maintaining farmers' livelihoods. Beyond incremental measures based on existing technologies, institutions, management, and value systems, agriculture should adopt transformative adaptations in adapting to climate change (UN News, 2023b). That approach is essential to bring agricultural production into line with changing natural landscapes and ecological systems, by continually shifting the geographical locations of production of certain types of crops and animals, as well as the widespread adoption of climate-smart production methods and technologies across the entire value chain (WBG, 2023b).

Extreme weather events, such as droughts and floods, are projected to disproportionately impact agriculture in the warmer and drier climate of the future. To mitigate drought risk and adapt to these changes, the most direct and effective strategies involve building climate-resilient agricultural infrastructure and promoting water-efficient irrigation systems (CISION PR Newswire, 2023). Furthermore, the IPCC AR6 report indicates that the early implementation of water adaptation measures, such as irrigation, rainwater harvesting, and moisture conservation, can have some mitigation effects. However, it is important to note that the effectiveness of these measures in mitigating climate change will decrease significantly if global warming exceeds 2 ℃ (IPCC, 2023).

In response to the increasing climatic risks, we propose enhancing agricultural resilience through the implementation of climate-resilient agriculture (Figure 2), and a top-down approach should be used to develop strategies for adapting to climate change in agriculture. Pilot demonstration work should also be conducted in key areas, such as strengthening agricultural production management and improving agroecology. These initiatives will facilitate effective policy implementation and allow farmers to adapt to the evolving climate.

We recommend the integration of science and technology into agricultural production, increasing investments in re-

search on climate-smart agriculture, and improving the efficiency of agricultural production. Finally, the climate change and food security crises require greater international cooperation, including the use of international financing platforms for resilient agriculture, and learning from successful experiences in other countries (WBG, 2023a).

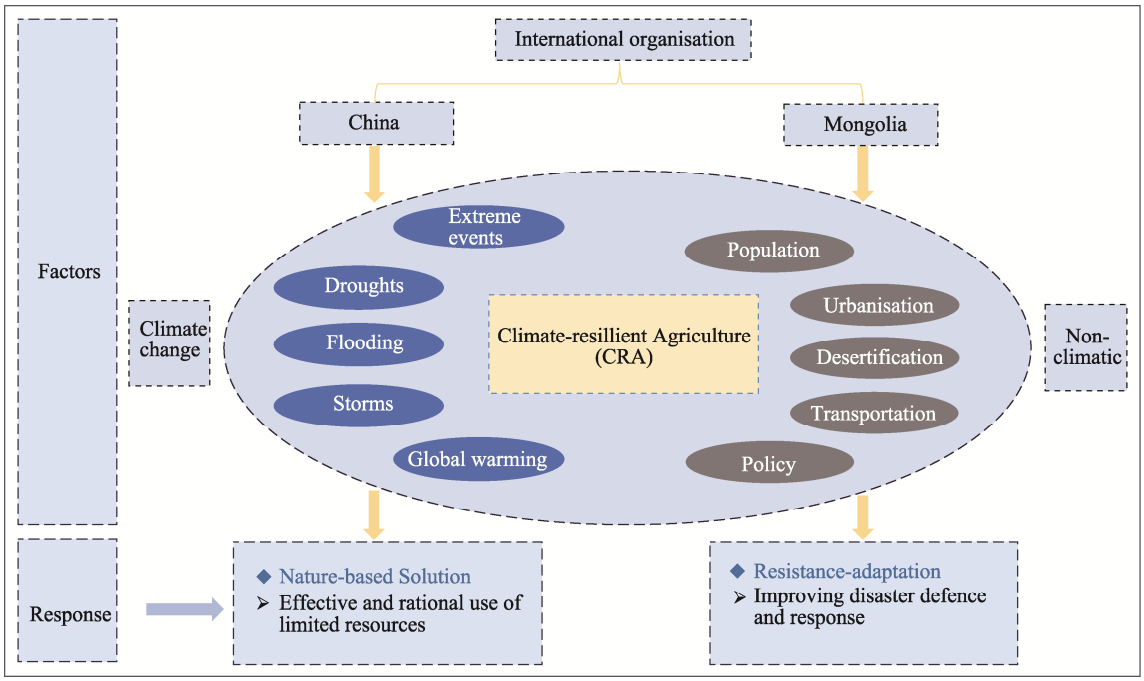

Figure 2 A framework for sustainable agricultural development based on Climate-Resilient Agricultural (CRA) systems

4.2 Practices to ensure food security based on climate-resilient agriculture

4.2.1 Natural solutions based on the rational allocation of water and land resources

CRA can also improve agroecology through the application of Nature-Based Solutions (NBS), such as returning plows to forests and grasslands in ecologically fragile farming areas, creating soil and water conservation forests and protecting forests, restoring grassland vegetation, increasing grassland cover, and reducing soil erosion by increasing vegetation cover, and these solutions can help rejuvenate the water sources to prevent further desertification (Chan et al., 2023).

The study suggests that renewable agriculture, sustainable livestock farming, and climate-smart agriculture have been developed using modern scientific and technological innovations (Coalition for Urban Transitions, 2019). These nature-based production solutions, coupled with the enhancement of resilient agriculture to cope with vulnerabilities, shocks, and stresses, are important directions for global agricultural development.

For example, deforestation and degradation are widespread in South America, such as in eastern Paraguay. The FAO has organized farmers to participate in climate-sensitive agroforestry complex projects by planting trees such as eucalyptus, citrus fruit trees, and Paraguayan holly, as well as by stopping the cutting of native forests for fuel. Smallholder farmers are being incentivized to move from traditionally dominant crops such as cotton and beans to the development of drought and flood-tolerant plantations that are adapted to the frequent droughts and floods that are occurring. These actions can effectively help to counter the economic and food security impacts of disasters as well as safeguard people's livelihoods (FAO, 2021b). Using the Nature-Based Solutions (Figure 2) to re-enhance and restore the vegetated land (e.g., forests, farmlands, etc.) can be a mutually beneficial solution, which can retain the hydrological cycle balance to improve the soil-water conditions, improve water availability for trees and vegetation and relieve the runoff and peak discharge to the catchment (or watershed).

4.2.2 Improving disaster prevention in ecologically fragile areas

Climate-resilient agriculture emphasizes enhancing the adaptability of agricultural infrastructure to climate change and mitigating the risks of agro-meteorological disasters through a combination of engineering and non-engineering measures. For example, in regions that experience severe drought, large and medium-sized irrigation districts can be upgraded with water-saving facilities (Li et al., 2021). Rainwater harvesting and water transfer projects can be

strengthened in arid and water-scarce regions. In contrast, in flood-prone regions, reservoirs can be de-risked and reinforced, and enhancements to farmland drainage and irrigation systems can be implemented (Chan et al., 2024b).

Furthermore, implementing non-engineering measures such as establishing meteorological and hydrological monitoring and early warning facilities, establishing mechanisms for agricultural climate disasters, and improving the agricultural disaster insurance system are also effective strategies for developing climate-resilient agriculture (Rebecca et al., 2021).

Climate-resilient agriculture not only helps to mitigate the adverse effects of climate disasters on agricultural production but also to prevent them. This is accomplished through improvements in crop cultivation and breeding management measures, as well as adjustments to crop varieties and planting structures (Liu et al., 2023). For example, in the Inner Mongolia region of China, local herders have taken rotational and seasonal grazing measures to curb the degradation of grassland caused by the warm and dry climates (Huang and Yang, 2017).

In addition, cultivating new varieties of plants and animals with broad adaptability, such as drought-resistant, waterlogging-tolerant, heat-tolerant, and pest-resistant varieties, is a valuable approach for coping with the increase in extreme weather events (Fuglie, 2021). Adaptive measures can be taken for the specific situations of climate change in the provinces/states of the North Asia Region.

For example, for expanding the cultivation area of winter wheat and adaptation measures for the specific climate change conditions in Mongolia and Northern China, we recommend practices such as expanding the planting borders of winter wheat and tropical crops to the North in light of the changes in hydrothermal conditions, adjusting the cropping and planting structures in arid areas (i.e., in the NW of Inner Mongolia), and reducing the planting of high-water-consuming crops (Ismahane, 2023).

4.2.3 Strengthening interregional exchange and cooperation on key technologies and policies

Global food security is confronted with substantial challenges due to geopolitical conflicts, extreme weather, and other factors. According to the recently released Global Food Crisis Report, approximately 258 million people in 58 countries and regions will experience severe food insecurity in 2022 (FAO, 2022b). This is a significant increase from the 193 million people in 53 countries and regions who experienced food insecurity in 2021 (Eckstein et al., 2013). The SSC is a framework that developing countries can use to share and exchange practical knowledge, experiences, resources, and technologies to address common development challenges (Dima, 2023). The FAO-China SSC Program was established in 2009 with an initial contribution of USD 30 million from the Government of China to help developing countries improve food security and promote sustainable agriculture (FAO, 2023d). China is a key partner of the FAO in SSC in the field of food and agriculture. It has provided extensive knowledge, experience, policies, technologies, and resources, which have assisted other developing countries in addressing numerous challenges. China has contributed USD130 million to the program thus far

The UNEP recommends that governments prioritize interventions that not only stimulate economic growth but also bolster climate resilience. By adopting an integrated risk management approach, and establishing adaptable disaster financing frameworks, developing countries can create more fiscal space to rebuild in an environmentally sound and resilient manner (UNEP, 2021). The Adaptation Action Coalition is a group of developed countries that was launched by British Prime Minister Boris Johnson. This coalition will collaborate with the UN Climate Action Group to promote the Race to Resilience initiative. This initiative aims to provide on-the-ground support for vulnerable groups by translating international political commitments into practical actions. Through this initiative, developed and developing countries will share their knowledge and best practices (CISION PR Newswire, 2023).

4.2.4 Coordinating the allocation of funds and expanding financing

The primary challenge which limits the implementation of the agreement is funding. The World Bank's Climate Change Action Plan (2021–2025) identifies agriculture, food, water, and land as one of the five transformations required to address the climate crisis. World Bank financing for them has increased eightfold to nearly USD 3 billion per year through policy and technical interventions since the adoption of the Paris Agreement (WBG, 2021).

COP28 has successfully committed more than USD 85 billion to climate action through the Loss and Damage Fund (UNFCCC, 2022). For example, the UAE established a Climate Fund worth USD30 billion, while Australia, Estonia, Italy, Portugal, Switzerland, and the United States have committed USD 3.5 billion to the second phase of the Green Climate Fund. The World Bank has also announced its plan to provide an additional USD 9 billion in financial support for climate-related projects in both 2024 and 2025 (OECD, 2022).

Despite these efforts, developed countries have experienced delays in fulfilling their commitment to provide USD 100 billion per year in climate financing (OECD, 2022). On the other hand, developed countries may exert pressure on some developing countries to contribute to the new collective quantitative fund and the loss and damage fund (WRI, 2023b). These actions can support the agricultural sector to implement its Nationally Determined Contributions (NDCs) and contribute to the progress of the long-term climate-resilient and adaptation plans, as well as the eradication of poverty and hunger (Francesco, 2023).

5 Conclusions

This article reviews the recent regional trends in extreme events and their implications for food security. It shows that food production is increasingly threatened by climate-induced disasters, such as droughts and extreme floods, which pose a huge challenge to food security in North Asia, particularly in China and Mongolia. The paper also emphasizes the urgent need to limit global warming to below 2 ℃ or 1.5 ℃ to mitigate these challenges.

This review discusses the measures already taken and the actions initiated by countries around the world at COP28 to address climate change and food security. It also analyzes the efforts and attempts made in recent years by developing countries in North Asia, specifically China, and Mongolia, to cope with the impacts of climatic extremes on food production, as well as the challenges that lie ahead for more effectively improving the CRA framework by following our suggested framework. We appraise the objective factors and effective ways to achieve resilient agriculture using the CRA framework that enhances the climate resilience of agriculture through the establishment of balanced, healthy, and ecologically friendly agricultural systems.

It is worth noting that climate change and extreme events are becoming more frequent, and the vulnerability of agriculture and ecosystems is diverse and complex. To improve the efficiency of agricultural production, we propose a nature-based approach that emphasizes the rational use of available resources and accelerates the structural transformation of agriculture. Moreover, we recommend optimizing the agricultural production infrastructure, increasing investments in weather forecasting and the monitoring of agricultural conditions, improving the mechanisms for protecting against post-disaster losses, and strengthening the resilience of agriculture against disasters. These efforts will require increased funding and multifaceted cooperation (e.g., technical and practical experience) from government departments and relevant organizations to ensure the successful implementation of the CRA.

Developed countries are encouraged to provide targeted financial assistance and regional and intergovernmental multi-party cooperation should be tailored to local conditions. Climate-sensitive regions should strengthen their disaster preparedness. This paper analyzed the objective factors and effective ways to achieve disaster-resilient agriculture and concluded that developed countries should provide more and better-targeted financial support. Developing countries, especially those in climate-sensitive regions, should strengthen their disaster resilience. Finally, multifaceted cooperation among regions and governments, including broader financial and technical support, should always be customized to local conditions.

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COP28 后时代中国和蒙古在气候变化背景下粮食安全的潜在挑战和应对

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摘　要：COP28 会议之后，全球各国都在关注未来的粮食安全实践。在北亚，中国东北和华北地区是主要粮食生产基地。而边境另一侧的蒙古国则严重依赖农业生产和畜牧业发展经济。近年来，人类活动及频繁的干旱和洪水等极端天气对粮食安全构成了威胁。本文阐述了近年来气候变化带来的挑战和制约因素，总结了两国现行的应对措施和既定计划，并在此基础上制定了气候韧性农业（CRA）框架，以提高农业对气候变化的适应性。本文强调了国际组织向气候脆弱区域的发展中国家提供资金和技术支持以加强气候适应能力的重要性。最后，本文提倡各国政府基于 CRA 架构，加强跨界合作，开展共同生产，应对未来气候和粮食安全的挑战。

关键词：农业敏感性；极端气候；气候韧性农业(CRA)；粮食安全；中国和蒙古国