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Climate-Resilient Groundnut Production: Strategies for Sustainable Yield Enhancement

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Groundnut (*Arachis hypogaea* L.) is a major oilseed and grain legume that sustains the livelihoods of millions of small land holding farmers across the semi-arid tropics of Asia and Africa. Because roughly nine-tenths of the global groundnut area is rainfed, the crop is acutely exposed to rising temperatures, erratic monsoon behaviour, intensifying drought spells, and shifting pest and disease pressure associated with climate change. Together, these pressures reduce pod set, kernel filling, and oil quality and increase the risk of pre-harvest aflatoxin contamination, endangering farm revenue as well as food and nutritional security. This article examines the primary approaches to increasing climate resilience in groundnut production, including drought and heat tolerance breeding, water and soil conservation agronomic methods, integrated nutrient and pest management, and the developing role of precision and digital agriculture. It further examines institutional efforts led by ICRISAT and national research systems, and outlines the policy and extension support needed to translate resilience research into on-farm yield gains. An integrated strategy that combines improved genetics with climate-smart agronomy is presented as the most sustainable pathway to stabilizing groundnut yields under an increasingly variable climate.

Keywords: climate resilience, drought tolerance, climate-smart agriculture, sustainable yield, water use efficiency

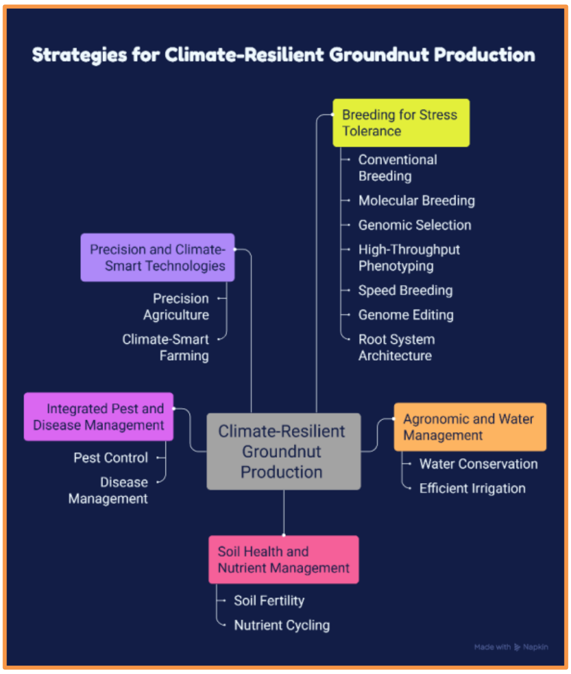
Introduction

Groundnut, also known as peanut, is cultivated on more than 32 million hectares worldwide, producing over 50 million tonnes of pods annually, and remains a vital source of edible oil, protein, and financial revenue for smallholder households in the semi-arid tropics. The crop is grown predominantly by resource-poor farmers in Asia and Africa under rainfed conditions, which makes it highly sensitive to the timing, amount, and distribution of rainfall during its growing season. Climate change is altering the environment in which groundnut is cultivated. Recent years have been among the warmest on record, and forecasts indicate that temperatures will continue to rise throughout the twenty-first century. This will be accompanied by an increase in the frequency of heatwaves, a delayed onset of the monsoon, longer dry spells interspersed with periods of intense rainfall, and an expansion of the ranges of a number of foliar and soil-borne pathogens. For a crop whose flowering, pegging, and pod-filling stages are all highly sensitive to soil moisture and temperature, these shifts translate directly into yield instability and quality loss, including a greater risk of aflatoxin contamination under terminal drought and heat.Building climate resilience in groundnut therefore requires action on multiple fronts at once: developing genotypes that tolerate drought, heat, and emerging biotic stresses; adapting agronomic and water management practices to conserve soil moisture and match crop water demand with an increasingly unpredictable supply; strengthening soil health and nutrient-use efficiency; and deploying integrated pest and disease management alongside precision and climate-information tools.

Climate Change Impacts on Groundnut Production

Drought and erratic rainfall

Moisture stress is the single most significant climatic constraint on production, as over 90% of the global groundnut crop is cultivated under rainfed conditions. Drought occurring during pod formation and filling can reduce pod and kernel yield substantially, with reported losses of up to a third of potential yield, and moisture stress late in the season is closely linked to increased infection by aflatoxin-producing *Aspergillus* fungi. Erratic monsoon onset and premature withdrawal further mismatch crop growth stages with available soil moisture, making terminal drought an increasingly common occurrence even in traditionally reliable rainfall zones.



Heat stress

Flowering and pollination are extremely sensitive to temperatures over 30 degree Celsius, which limit pollen viability, increase flower and peg abortion, and reduce the number of pods that set. Prolonged heat stress during reproductive stages is generally more damaging to seed yield and oil quality than the same stress during vegetative growth, and it frequently compounds the effects of concurrent drought.

Elevated atmospheric CO_2

Elevated carbon dioxide concentrations can enhance photosynthetic rates and above-ground biomass in groundnut under otherwise favourable conditions. In practice, however, this CO_2 fertilisation effect is frequently offset or negated when elevated CO_2 is accompanied by higher temperatures and reduced soil moisture, underscoring that groundnut's response to climate change must be assessed for combined, rather than isolated, stress factors.

Biotic stresses

Warmer and more humid conditions are altering the distribution and severity of major groundnut diseases and pests, including foliar leaf spots, stem rot, and peanut bud necrosis disease, as well as insect vectors that transmit viral pathogens. In addition to abiotic stress tolerance, climate-driven changes in pest and disease pressure add another level of production risk.

Strategies for Climate-Resilient Groundnut Production

Breeding for drought, heat, and multiple-stress tolerance

Long-term climate resilience is still based on genetic improvement since farmers may profit from resistant cultivars year after year without having to pay for additional inputs. Groundnut breeding programmes draw on the genetic diversity present in cultivated germplasm collections and in wild Arachis species, which harbour valuable alleles for drought avoidance, heat tolerance, and disease resistance that can be introgressed into elite backgrounds.

Conventional and molecular breeding: Traditional hybridisation and mass selection continue to be combined with marker-assisted selection (MAS) to accelerate the introgression of drought and heat-tolerance traits, while genome-wide association studies using multi-parent advanced generation inter-cross (MAGIC) populations have identified numerous marker–trait associations for drought-related traits that can underpin genomics-assisted breeding.

Genomic selection and high-throughput phenotyping: Genomic selection uses genome-wide marker data to predict breeding values for complex, multi-gene traits such as drought and heat tolerance, shortening breeding cycles relative to phenotype-only selection. High-throughput phenotyping platforms, using imaging and remote sensing, allow large breeding populations to be screened rapidly for traits such as canopy temperature, root architecture, and water-use efficiency.

Speed breeding and genome editing: Speed-breeding protocols that manipulate photoperiod and temperature can compress multiple breeding generations into a single year, addressing groundnut's relatively long generation time. Genome-editing tools such as CRISPR-Cas9 offer the potential for precise modification of genes governing stress tolerance and disease resistance without introducing foreign DNA, which may ease regulatory pathways relative to conventional transgenics.

Root system architecture: Deeper and more extensive root systems improve access to subsoil moisture during dry spells, and root traits such as root length density and distribution are increasingly used as selection criteria in drought-breeding programmes, alongside physiological traits like osmotic adjustment and controlled transpiration.

Agronomic and water management strategies

Even the most drought-tolerant varieties benefit from agronomic measures that conserve soil moisture and balance crop water demand with variable rainfall.

- Adjusted sowing windows and short-duration varieties help crops escape terminal drought and heat by ensuring that flowering and pod-filling coincide with periods of adequate soil moisture.
- Mulching with crop residues or plastic film reduces soil evaporation, moderates root-zone temperature, and improves moisture retention between rainfall events.
- Micro-irrigation methods, including drip and sprinkler systems, and supplemental or deficit irrigation at critical growth stages (flowering, pegging, and pod filling) markedly improve water-use efficiency compared with flood irrigation.
- Conservation tillage and ridge-and-furrow or broad-bed planting improve infiltration and reduce run-off, increasing the proportion of rainfall stored in the root zone.
- Intercropping groundnut with cereals or other legumes can buffer yield risk, improve overall water-use efficiency of the cropping system, and provide a partial yield safety net when one component crop underperforms.
- Seed hardening and pre-sowing seed treatments with osmotic or hydration agents have been shown to improve early-season drought tolerance and stand establishment.

Soil health and nutrient management

Healthy, well-structured soils stabilise crops against both drought and waterlogging by improving water-holding capacity and root penetration. Balanced application of nitrogen, phosphorus, potassium, and secondary and micronutrients such as calcium, sulphur, and boron supports pod development and helps groundnut plants recover more quickly after moisture stress. Organic amendments, including farmyard manure and compost, and the use of beneficial soil microorganisms such as rhizobium for biological nitrogen fixation and phosphate-solubilizing bacteria, improve soil organic matter, nutrient-use efficiency, and resilience to climatic extremes, while reducing dependence on synthetic fertilizer inputs.

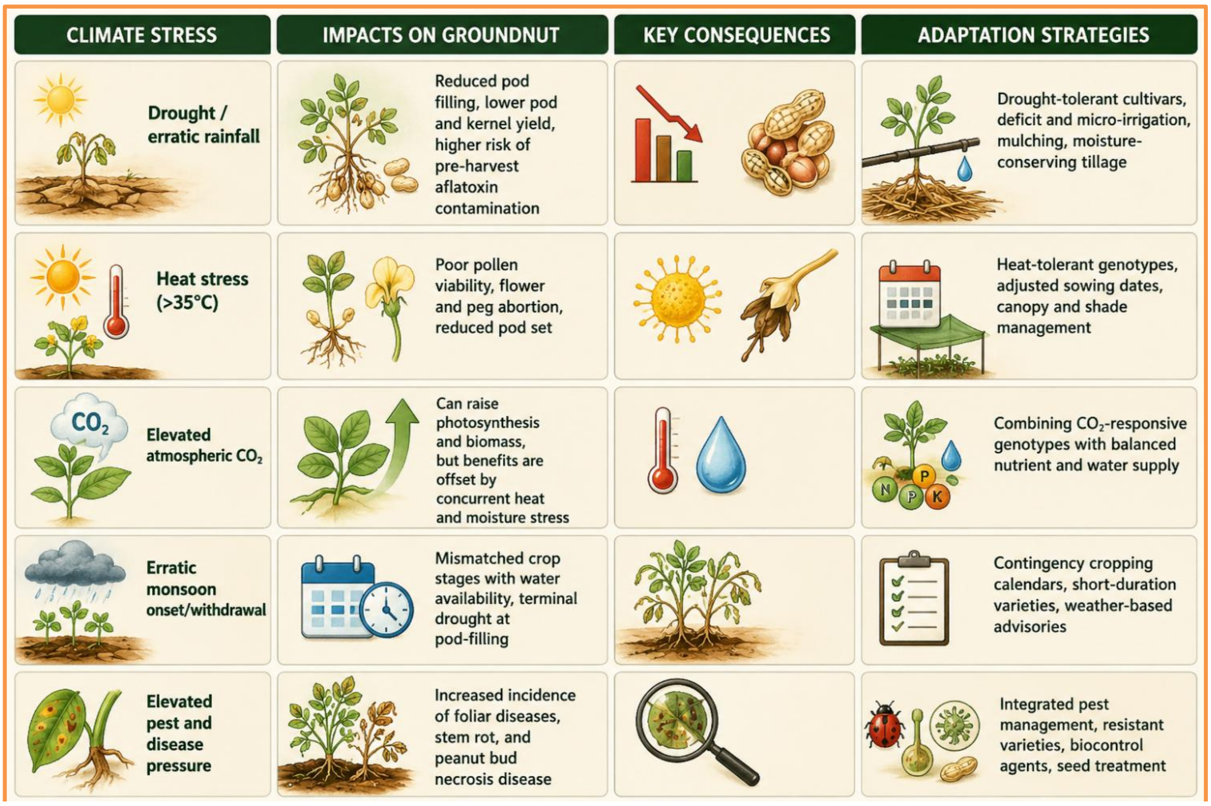
Integrated pest and disease management

As climate change alters the timing and intensity of pest and disease pressure, integrated pest management (IPM) that combines resistant varieties, timely and need-based application of biocontrol agents and selective pesticides, seed treatment, and field sanitation provides a more resilient defence than chemical control alone. Disease-forecasting models linked to weather data can help timely interventions against foliar diseases and stem rot more precisely, reducing both crop losses and unnecessary pesticide use.

Precision and climate-smart technologies

Precision agriculture tools, including as soil moisture sensors, weather-based agro-advisories, satellite and drone-based canopy monitoring, and decision-support systems, enable farmers to more accurately time sowing, irrigation, and input applications in the face of more changeable weather. Climate-smart agriculture approaches that combine these digital tools with resilient varieties and conservation agronomy aim to deliver the joint objectives of higher and more stable productivity, greater resilience to climatic shocks, and lower net greenhouse gas emissions per unit of output.

Summary of Stress Factors and Corresponding Resilience Strategies



CLIMATE STRESS	IMPACTS ON GROUNDNUT	KEY CONSEQUENCES	ADAPTATION STRATEGIES
Drought / erratic rainfall	Reduced pod filling, lower pod and kernel yield, higher risk of pre-harvest aflatoxin contamination		Drought-tolerant cultivars, deficit and micro-irrigation, mulching, moisture-conserving tillage
Heat stress (>35°C)	Poor pollen viability, flower and peg abortion, reduced pod set		Heat-tolerant genotypes, adjusted sowing dates, canopy and shade management
Elevated atmospheric CO_2	Can raise photosynthesis and biomass, but benefits are offset by concurrent heat and moisture stress		Combining CO_2-responsive genotypes with balanced nutrient and water supply
Erratic monsoon onset/withdrawal	Mismatched crop stages with water availability, terminal drought at pod-filling		Contingency cropping calendars, short-duration varieties, weather-based advisories
Elevated pest and disease pressure	Increased incidence of foliar diseases, stem rot, and peanut bud necrosis disease		Integrated pest management, resistant varieties, biocontrol agents, seed treatment

Institutional Efforts and Global Initiatives

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been a central player in groundnut improvement for the semi-arid tropics, maintaining large germplasm collections, coordinating multi-location trials, and developing genomic resources and breeding populations targeted at drought and heat tolerance. National agricultural research systems across South Asia and sub-Saharan Africa complement this work by testing and releasing locally adapted, climate-resilient groundnut varieties, while extension networks and seed systems determine how quickly these varieties reach smallholder farmers. Adoption of climate-resilient groundnut varieties has significantly enhanced productivity, on-farm consumption, and market participation among smallholder families. This shows the concrete advantages of converting breeding improvements into seed that is available to farmers.

Challenges and Future Prospects

- Breeding cycles for a partially self-pollinated, allotetraploid crop like groundnut remain relatively long; wider use of speed breeding, genomic selection, and genome editing can shorten the time to release resilient varieties.
- Seed systems and extension services need strengthening so that climate-resilient varieties reach smallholder farmers quickly and at affordable cost.
- Combined-stress research (simultaneous drought, heat, and biotic pressure) better reflects field conditions than single-stress screening and deserves greater research investment.
- Precision and climate-information tools must be made accessible and affordable for smallholder farmers, not only for well-resourced commercial producers.
- Policy support, crop insurance, and climate-risk financing can help farmers adopt resilient technologies despite short-term costs or risks.
- Continued monitoring of aflatoxin risk under warmer, drier terminal-season conditions is essential to safeguard both food safety and export markets.

Conclusion

Climate change is reshaping the environment in which groundnut is grown, intensifying drought, heat, and shifting biotic pressures that together threaten yield stability, oil quality, and food safety. No single intervention can address all of these pressures; instead, climate resilience in groundnut depends on an integrated strategy that combines genetic improvement for drought and heat tolerance with water-conserving and soil-health-enhancing agronomic practices, integrated pest and disease management, and the judicious use of precision and climate-information technologies. Institutional research led by ICRISAT and national programmes, paired with effective seed delivery and farmer-focused extension, is essential to ensure that resilience gains achieved in research stations translate into stable, sustainable yields in farmers' fields. With continued investment across breeding, agronomy, and policy, climate-resilient groundnut production can safeguard the livelihoods of millions of smallholder farmers while contributing to global food and nutritional security.

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