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Improved production practices for sustainable groundnut cultivation: An Indian perspective

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Abstract

Groundnut acreage, production, and nutritional value are vital to India's oilseed economy. Groundnuts are high in protein and energy, but India cultivates them under energy-starved conditions leading to lower production. Lack of quality seed at the right time, cultivation on marginal and sub-marginal lands, uneven fertilizer use, and lack of crop management techniques are the main causes of low groundnut productivity. To increase and sustain groundnut yield, low-cost production technology must be developed and promoted for farmers. Improved genotypes (Girnar 4 & 5, K-1812, DH 256), crop establishment and management practices, integrated soil fertility and pest management practices, etc. are the most promising groundnut production technologies. They boost productivity, profitability, environmental and social sustainability, and nutritional security. Agronomic techniques like seed replacement with improved varieties, raised bed planting, biofertilizers, secondary and micro-nutrients, foliar fertilizer application, drip/sprinkler irrigation, and integrated weed and pest management modules can boost groundnut productivity. Seed treatment with Tebuconazole 2DS @ 1.5 g/kg of seeds with furrow application of *Trichoderma viride* @ 4 kg enriched in 2.5 t FYM/ha practice found best to control stem rot, collar rot, and dry root rot diseases in groundnut. With the adoption of improved production practices groundnut yield would enhance by 23-42%. Thus, policymakers, agricultural scientists, and farmers to enhance groundnut productivity by utilizing improved farm technology to meet national and local groundnut needs. Thus, this article provides a critical analysis of improved crop management strategies' ability to increase groundnut yield and identifies future research goals to sustain groundnut output in India.

Keywords: Crop management practices, high oleic genotypes, sustainable production, IDM, IPM

Introduction

Groundnut (*Arachis hypogaea*) are leguminous plants that grow annually with indeterminate growth, and produce their fruit, commonly known as peanuts, below the ground. Peanuts are cultivated globally for their oil and seeds, which possess significant quantities of protein, lipids, and nutrients (Heba *et al.*, 2021; Meena *et al.*, 2022) ^[7, 10]. Peanuts are cultivated globally in regions characterized by tropical and subtropical climates. Groundnut is a significant oilseed crop in India, accounting for 35.3% of the total oilseeds produced. In India, groundnut cultivated in an area of 5.75 mha with 11.8 mt production and yield of 2,067 kg ha⁻¹ during 2024-25 (DAFW, 2025) ^[4]. India, although having the largest groundnut area, has a comparatively lower productivity than the United States of America and China. The primary factor contributing to the low productivity in India is due to its cultivation confined to rainfed areas (~85%). This crop is highly susceptible to variations in weather conditions and is grown in soils that have low fertility and a light texture (Gopinath *et al.*, 2022) ^[6]. Despite groundnut ability to tolerate drought, their insufficient nutrient intake results in lower yield. Groundnuts, like other crops, necessitate a substantial quantity of macronutrients (NPKCaS) and micronutrients (FeMnZnCuBMo) to attain ideal growth and development. Hence, it is vital to implement effective crop management strategies to achieve a sustainable groundnut production system.

Enhancing production, guaranteeing food security, and promoting sustainable farming rely on using improved crop management practices in groundnut (Meena *et al.*, 2022) ^[10]. Primarily, the

adoption of advanced agricultural methodologies aimed at enhancing groundnut output. Methods such as precision farming, proper irrigation, and the use of quality seeds enhance groundnut yield. This not only satisfies the increasing need for edible oil but also enhances farmers' income. Furthermore, sustainable agricultural techniques are crucial in promoting resource efficiency through better soil health by reducing environmental harm. Likewise, it is imperative to implement pest and disease control strategies to safeguard groundnut from potential hazards. The utilization of integrated pest management (IPM) techniques and the cultivation of disease-resistant varieties result in increased crop production. These approaches not only improve efficiency but also support sustainable and eco-friendly agriculture, guaranteeing the long-term sustainability of groundnut cultivation for the advantage of farmers and global food security. Below, a concise overview of the production capabilities of different improved crop management approaches is provided.

Selection of suitable varieties/cultivars

Historically, traditional groundnut breeding has depended on the genetic diversity found in farmed cultivars and, to a limited extent, wild *Arachis* species. The process combines the use of

breeding techniques for self-pollinated crops and the integration of phenotyping tools to find, evaluate, and choose genotypes with desirable features. Virgenia and Spanish bunch type genotypes are largely cultivated in India. High oleic content genotypes like Ginnar 4 & 5 have been developed by ICAR-Directorate of Groundnut Research in collaboration with International Crop Research Institute for Semi-Arid Tropics (ICRISAT). These genotypes having >78% oleic content with a yield potential of 2.5-3.0 t ha⁻¹ and are resistant to late leaf spot (LLS), rust, stem rot, and collar rot. All India Coordinated Research Project on Groundnut centres developed high-yielding genotypes of Spanish and Virginia groups suited to different agro-climatic conditions with resistant to pest and diseases are given in Tables 1-3. Pratap Mugphali 1 & 2 are promising cultivars recommended for Rajasthan with a yield potential of >3.0 t ha⁻¹ and tolerant to early leaf spot (ELS), LLS, peanut bud necrosis, *Spodoptera litura*, leaf miner and thrips. Cultivar 'TG 37A' has fresh seed dormancy of up to 15 days, and tolerant to collar rot, rust & LLS, and is recommended for cultivation in Gujarat, Rajasthan, Uttar Pradesh, Punjab, Odisha, West Bengal, Bihar, and Assam. Cultivars like K-6, DH-256, DH-257, K-1812 and Vasishta have been widely cultivated in rainfed regions of Andhra Pradesh and Karnataka.

Table 1: Promising Spanish bunch groundnut varieties in India and their salient features

Variety	Features	State(s) recommended for
VRI 5	Resistant to rust and LLS	Tamil Nadu
Co 4	High oil content, Resistant to rust and LLS	Tamil Nadu
GG 7 (J-38)	Early maturity, tolerant to LLS	Gujarat and Southern Rajasthan
AK 159	High oil content	Maharashtra and Madhya Pradesh
GG 6	Early maturity, high shelling percent	Gujarat
TG 37A	Fresh Seed Dormancy up to 15 days, tolerant to collar rot, rust & LLS	Gujarat, Rajasthan, Uttar Pradesh, Punjab, Odisha, West Bengal, Bihar & Assam
Vikas (GPBD 4)	Resistant to LLS and rust	Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu
TLG 45	Large seeded	Maharashtra
Kadiri 6	Tolerant to leaf spots	Andhra Pradesh
Pratap Mugphali 1 & 2	Tolerant to ELS, LLS, PBND, <i>Spodoptera litura</i> , leaf miner & thrips	Rajasthan
TMV 13	Tolerant to early & mid-season moisture deficit stress, LLS, rust & PBND	Tamil Nadu
Narayani (TCGS 29)	Early maturity & tolerant to mid-season moisture deficit stress	Andhra Pradesh
TG 51	Tolerant to stem and root rot	West Bengal, Odisha, Jharkhand, Assam
VL-Moongphali-1	Resistant to LLS & root rot diseases	Uttarakhand
Jawahar Groundnut 23	Tolerant to drought, ELS & LLS	Madhya Pradesh
Kadiri 9	Tolerant to early & late season drought	Andhra Pradesh
JL 501	Suitable for early as well as late sown conditions	Gujarat & Southern Rajasthan
Ginnar 3	Tolerant to leaf miner & thrips	West Bengal, Odisha & TN
GPBD 5	Resistant to LLS & rust	Jharkhand & Manipur
Pratap Raj Moongphali	Early maturity, tolerant to ELS, LLS, PBND, jassids, thrips, leaf miner & <i>Spodoptera litura</i>	Rajasthan
GJG 9 (J 69)	Tolerant to stem rot	Gujarat
Kadiri Amravathi (K 1535)	Tolerant to early & late season drought, leaf spot & sucking pests (thrips & jassids)	Andhra Pradesh
VRI 8 (VG 09220)	Moderately resistant to sucking pests (thrips & jassids), LLS & rust	Tamil Nadu
GJG 32 (ICGV 03043)	Tolerant to rust & collar rot	TN, AP, Karnataka, Southern Maharashtra, Telangana, Gujarat
Dh-245	High oleic acid (> 70%), resistance to foliar diseases	Karnataka
Nitya Haritha (TGCS 1157)	Tolerance against LLS, rust & PBND	Maharashtra & MP
Avtar (ICGV 93468)	Early maturity, tolerant to PBND, fungal diseases, jassids & pod borer	UP
Phule Unnati (RHRG 6083)	High oil, resistance to LLS, stem rot, rust, <i>Spodoptera litura</i> , thrips	Maharashtra
GG 34	High oil content	Gujarat
Dh 256	Tolerant to mid-season drought, <i>Spodoptera litura</i> , thrips, leaf miner & leaf hopper	TN, AP, Karnataka & Telangana
Pratap Munghali 3 (UG 116)	Moderately tolerant to ELS, LLS, rust, collar rot; moderately resistant to <i>Spodoptera litura</i> , leaf miner, defoliators, jassids, thrips & leaf hopper	Rajasthan

Jagtial Palli 1 (JGC 2141)	Tolerant to early season drought, resistant to leaf spots & rust diseases, tolerant to thrips & jassids	Telangana
K 1812 (Kadiri Lepakshi)	Tolerant to drought, multiple diseases & pests resistant	AP, Telangana, Karnataka & TN
VRI 9 (VG 13163)	Exhibited moderate resistance reaction to LLS and Rust	Tamil Nadu
GG 40 (ICGV 16668)	Recorded 78.4% oleic acid and 3.56% linoleic acid	Rajasthan, TN, AP, Gujarat, Karnataka, Telangana, Southern Maharashtra & Kerala
Visishta (TCGS 1694)	Tolerant to foliar diseases viz., ELS, LLS and rust, High water use efficiency	AP & Western Maharashtra
GG 37 (Sorath Gaurav)	Mutant of TG 38	Gujarat
GG 38 (Sorath Navin)	--	Gujarat
Improved JL 24 (DBG 3)	Resistant to LLS, Susceptible to LLS	Karnataka
GG 39 (Sorath Uttam)	--	Gujarat
Super TMV 2 (DBG 4)	Resistant to LLS	Karnataka
Chhattisgarh Trombay Mungfali (CGTM)	Moderately ELS & PBND Moderately susceptible to LLS & rust	Chhattisgarh, MP
VRI 10 (VG 17008)	Moderate resistance to LLS, rust and moderately resistant to sucking pests & defoliators	Tamil nadu
ICAR-VRI-11 (VG 19721)	Moderately resistant to ELS, Rust, Alternaria blight, Collar rot, Stem rot and dry root rot diseases	Gujarat, Rajasthan, Punjab and Northern Maharashtra
Co 8	Moderately resistant to leaf miner and sucking pest and Moderately resistant to LLS and rust	Tamil Nadu
TCGS 1707 (ICAR-Konark)	Moderately resistance to LLS & rust	Odisha, WB
ICAR-VRI 10 (VG 17008)	Moderately resistant to sucking pest (jassids and thrips)	Bihar, Odisha, WB, coastal Andhra Pradesh and north-eastern States
Sahyadri Durga	Moderately tolerant to leaf miner and <i>Spodoptera</i> and LLS & Rust, High oleic acid (78-80%)	Karnataka
Pratap Mugphali 4 (UG 243)	resistance to ELS, moderately resistance to collar rot, stem rot & LLS, moderately resistance to <i>Spodoptera litura</i> , leaf miner, defoliators, jassids, thrips & leafhopper	Rajasthan

Table 2: Promising *Virgenia* bunch groundnut varieties in India and their salient features

Variety	Features	State(s) recommended for
Manjara (LGN 2)	Suitable for early sown rainfed conditions, tolerant to sucking pests (jassids & leaf miner)	Gujarat & Southern Rajasthan
Snigdha	Resistant to pests & diseases	Kerala
Co (Gn) 5	Tolerant to rust, PBND, leaf miner & <i>Spodoptera</i>	Tamil Nadu
GG 21 (JSSP 15)	High oil content	UP, Punjab & Southern Rajasthan
TBG 39 (TG 39)	Large seeded & high yielding, moderately resistant to rust, LLS and stem rot	Rajasthan
AK 303	Large seeded	Maharashtra
Girnar 2	Large seeded, stay green leaves at harvest, tolerant to rust, LLS, PBND & sucking pests	UP, Punjab & Northern Rajasthan
ICGV 00348	Tolerant to leaf spots and rust	Southern Maharashtra, Karnataka, AP & TN
VRI (Gn) 7	Tolerant to leaf miner, LLS & rust	Tamil Nadu
Kadiri 7 & 8	Large seeded, tolerant to sucking pests and leaf spots	AP
Mallika (ICHG 00440)	Large seeded, resistant to collar rot & PBND	All India
TGLPS 3 (TDG - 39)	High harvest index, bold confectionary type with less aflatoxin, tolerant to <i>A. flavus</i> & LLS	Karnataka
Raj Durga (RG 425)	Moderately resistant to leaf spots, rust, PBND, collar rot & stem rot	Rajasthan
HNG 123	Tolerant to collar rot, stem rot, LLS, <i>Spodoptera litura</i> & leaf miner	Rajasthan, UP & Punjab
GJG-22 (JSSP 36)	Tolerant to collar rot	Gujarat
Raj Mungphali 2 (RG 578)	Resistant to LLS, dry root rot, ELS & rust; tolerant to <i>Spodoptera litura</i> , thrips, jassids & leaf miner	Odisha, WB & Manipur
Birsa Groundnut 4 (BAU 25)	Large seeded, resistant to LLS	Jharkhand
Raj Mungphali 3 (RG 559-3)	High yielding, large seeded, tolerant to <i>Spodoptera litura</i> , leaf miner & thrips	Rajasthan, UP & Punjab
Phule Warna (KDG 128)	Moderately resistant to rust & leaf spot	TN, AP, Karnataka, Southern Maharashtra, Gujarat & Rajasthan
Phule Morna (KDG 123)	Moderately resistant to rust & leaf spot	All India
GG HPS 2	Large seeded	Gujarat
Girnar 4 (ICGV 15083) & Girnar 5 (ICGV 15090)	78-80% oleic acid & 4.6-4.8% linoleic acid, tolerant to LLS, rust, stem rot & PBND, leaf hopper, leaf miner, thrips & <i>Spodoptera litura</i>	Rajasthan, Gujarat, Karnataka, TN & AP
Raj Mungfali 4 (RG 638)	High yielding	Rajasthan, UP and Punjab
ICAR-VRI-12 (VG 19535)	Moderately resistant to early leaf spot ELS, Alternaria leaf blight, Collar rot, Stem rot and dry root rot	UP, Haryana, Punjab, Rajasthan
Himani (TCGS 1522)	Tolerant LSS & rust	AP

ICAR Girnar 6 (NRCGCS 637)	Moderately resistance ELS rust Alternaria blight, collar rot, stem rot & dry root rot less incidence of leaf hopper, thrips & <i>Spodoptera</i>	Rajasthan, UP, Punjab & Haryana
Gujarat Groundnut- 24 (Sorath Urja)	Reaction against tikka, rust, stem rot and collar rot	Gujarat
Gujarat Groundnut- 42 (Sorath Shaan)	Reaction against tikka, rust, stem rot and collar rot	Gujarat

Table 3: Promising *Virginia* runner groundnut varieties in India and their salient features

Variety	Features	State(s) recommended for
GG 14 (JSP 28)	Tolerant to thrips, <i>Spodoptera litura</i> , leaf miner	Northern Rajasthan, Punjab, Haryana & UP
RG 382 (Durga)	Drought tolerant, tolerant to ELS, rust, jassids, leaf miner & thrips	Rajasthan
GG 16 (JSP 39)	Tolerant to PBND, root rot, thrips, <i>Spodoptera</i> , Leaf miner	TN, AP, Kerala & Southern Maharashtra
M 548	Large seeded, high protein content, tolerant to leaf spots & collar rot	Punjab
GJG-HPS-1	Tolerant to PBND	Gujarat
Divya (CSMG 2003-19)	Tolerant to PBND	UP & Rajasthan
Raj Mungfali-1 (RG 510)	Tolerant to collar rot, stem rot, LLS, PBND, thrips, jassids & grass hopper	Rajasthan & Punjab
GJG-17 (JSP-48)	Tolerant to stem rot	Gujarat
GJG 18 (JSP 49)	Moderately resistant to PBND & PSND	Odisha, WB, Jharkhand & Manipur
GJG 19 (JSP 51)	Tolerant to stem rot, dry root rot & rust	Odisha, WB, Jharkhand & Manipur
GG 41 (Padma)	High shelling & oil percent	Gujarat

Tillage management

Tillage is a necessary practice in agriculture that involves utilizing farm tools to manipulate the soil to create ideal conditions for seed germination, seedling establishment, and crop growth. Conventional tillage practices being widely followed by tilling at a depth of 15-20 cm. Excessive deep ploughing led to production of pods in deeper layers of soil creating difficulties during harvesting and is considered undesirable. Groundnut is commonly planted on elevated surfaces with furrows or elevated surfaces with ridges. Raised beds that have a slope of 0.4-0.8% provide advantages such as efficient drainage, avoidance of soil compression in the planting area, and ease of carrying out field tasks, as all movement is limited to the furrows (Kuotsu, 2014) ^[9]. Implementing conservation tillage, such as no-tillage and minimum tillage, produces pod yields comparable to those achieved with conventional tillage practices in Alfisols (Gopinath *et al.*, 2022) ^[6]. Thus, conservation tillage helps to reduce disease incidence and greater nodule size than conventional tillage. After harvesting of wheat, the groundnut crop sown on reduced tillage (one blade harrow) with residue incorporation increased the

yield of *Kharif* groundnut by 31.8% in the assured rainfall zone of Maharashtra (AICRPG, 2021) ^[2].

Planting time

The temperature levels elucidate the ideal timing for planting in a particular region and season of production. The optimal air temperature range for the growth and development of groundnut is generally between 25-30°C. Groundnut output might be negatively impacted by temperatures beyond 35°C. Groundnut is more vulnerable to heat stress during its reproductive stage than the vegetative stage. Lower temperatures result in a delay in the process of germination, which in turn leads to longer groundnut duration. It is recommended to delay sowing groundnut in locations with soil temperature at a depth of 10 cm reaches 18°C or higher for at least three consecutive days. The optimum time of sowing in *Kharif* would be 15th June to 15th July found to be optimum in across the groundnut locations. The best time for sowing groundnut in summer would be the 15th February and 5th May in Rahiri and Kadiri, respectively (AICRPG, 2021) ^[2]. The optimal planting periods for groundnut in various seasons and regions of India are provided in Table 4.

Table 4: Planting time of groundnut for different areas in India

Planting time	Area suitable for
10 th June to 20 th July (<i>Kharif</i> groundnut)	Rajasthan, Uttar Pradesh, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu
15 th October to 15 th November (<i>Rabi</i> groundnut)	Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Telangana, Tamil Nadu
15 th February (Summer groundnut, irrigated condition)	Andhra Pradesh, Gujarat, Karnataka, Maharashtra

Planting geometry, seed rate and planting methods

The plant geometry adopted in a region is influenced by factors such as the growth habit of the cultivar, sowing methods, and farming practices. Row spacing ranges from 30-45 cm with 10-15cm plant to plant spacing is ideal for groundnut cultivation. Wide row spacing can leave the ground exposed, attracting thrips and aphids, which act as vectors for viruses. Recommendations include closer spacing for Spanish/Valencia cultivars (30×10 cm) and wider spacing (45×15 cm) for *Virginia*/Runner cultivars. The research conducted in Junagadh demonstrated a notable increase in pod yield at a spacing of 30×10cm with a combination of 100% recommended fertilizer rates (RDF) with biofertilizers like rhizobium, PSB, and KSB at a rate of 3 L/ha). At Mohanpur, highest pod yield was observed

in the closer spacing of 22.5 × 10 cm with 125% of RDF (AICRPG, 2021) ^[2]. Thus, spacing of the crop primarily defines its seed rate. Recommendations are now being made on seed rates for groundnut cultivars having differential seed sizes. For bunch varieties across locations having recommended plant spacing of 30×10 cm with the seed rate of 100 kg kernel/ha is recommended. For spreading and semi-spreading varieties at 40-45×10 cm, the optimum seed rate recommended is 100-110, 120-140, 145-160, 165-185 and 190-210 kg kernel/ha for hundred kernel weight of 40-50, 50-60, 60-70, 70-80 and 80-90 g, respectively (AICRPG, 2021) ^[2]. The ideal sowing depth is 5 cm; deeper sowing delays germination, resulting in poor root and shoot development and reduced nodulation, negatively impacting yield. Three years study at Bikaner revealed that

sowing of *Kharif* groundnut at the depth of 7 cm produced highest biological yield over depth of 11 cm and statistically at par with 5 cm and 9 cm sowing depths (AICRPG, 2021) ^[2]. Planting geometry with improved spacing recommended for groundnut is given in Table 5. Sowing methods encompass

manual approaches like dibbling and behind-the-plough techniques, as well as the use of tractor-drawn seed drills. The use of a seed drill for sowing is recommended due to its advantages, including faster sowing, prompt emergence, and the establishment of a uniform plant stand.

Table 5: Planting geometry of groundnut for different areas in India

Yield		Percent yield increased over control	Area of study
Conventional	Improved		
30 × 10 cm	22.5 × 10 cm	15.4%	Bikaner, Rajasthan
30 × 10 cm	25 × 10 cm (paired row)	33.3%	Hyderabad, Telangana
30 × 10 cm	30 × 7.5 cm	9.2%	Parbhani, Maharashtra
30 × 15 cm	35 × 20 cm	7.2%	Bengaluru, Karnataka
30 × 15 cm	20 × 10 cm	49.6%	Chitambaram, Tamilnadu
30 × 10 cm	20 × 10 cm	31.5%	Gwalior, Madhya Pradesh
20 × 15 cm	30 × 10 cm	28.9%	Prayagraj, Uttar Pradesh
30 × 10 cm	20 × 10 cm	13.7%	Ratnagiri, Maharashtra
30 × 10 cm	22.5 × 10 cm	10.5%	Sardarkrushinagar, Gujarat

Table 6: Improved planting methods in groundnut

Yield		Percent yield increased over control	Area of study
Conventional	Improved		
Flat bed	Ridge and furrow	67.7%	Chittor, Andhra Pradesh
Flat bed	Ridge planting	12.6%	Mohanpur, West Bengal
Flat bed	Broad bed and furrow	17.8%	Parbhani, Maharashtra
Flat-bed method at 30 × 10 cm spacing	Paired-row planting at 45 × 15 cm spacing	20.1%	Bhubaneswar, Odisha

Nutrient management

Groundnut has a more pronounced reaction to the inherent soil fertility than the direct application of fertilizer. To enhance groundnut yield, it is crucial to provide sufficient fertilization, particularly phosphorus (P) and potassium (K). As crop fixes atmospheric nitrogen (N), recommended N fertilizer application is 20 kg/ha. The fertilization approach entails the delivery of nutrients based on soil testing, to boost soil P and K levels to medium or high, while also giving calcium (Ca) to the pegging zone. Application of 20, 40, and 60 kg P₂O₅ at Junagadh, Bikaner and Puducherry, respectively along with DGRC microbial cultures significantly improved phosphorus use efficiency in *Kharif* groundnut (AICRPG, 2021) ^[2]. The use of potash solubilizing bacteria (KSB) in Semi-arid eastern zone of Rajasthan enhanced groundnut yield over control by 11% (AICRPG, 2022) ^[3]. When soil K levels are low, groundnut responds well to K application, although K:Ca:Mg ratio is important. A balanced ratio is important because excessive K in the pod zone can damage pod quality and therefore split application of K is crucial for nutrient uptake. Application of fertigation of potash uniformly in equal splits at 8 days intervals up to 75 DAS (8 splits) recorded higher pod yield at Junagadh (AICRPG, 2020) ^[1]. Gypsum (CaSO₄ · 2H₂O) application helps to enhance pod filling and oil content in groundnut besides reducing *Aspergillus flavus* and other pod-rot-causing fungus infections. Liquid fertilizers are also being tested for their efficiency in nutrient supply. Pod yield in summer groundnut was significantly higher with 75% RDF + 2.0% Water Soluble Fertilizers applied at 45, 60 and 75 DAS (AICRPG, 2021) ^[2]. Green manuring also helps in nutrient saving by their nutrient-fixing ability. The incorporation of sunhemp at one month before the groundnut crop sowing resulted in a saving of 25% of RDF (AICRPG, 2021) ^[2]. Application of 75% RDK (22.5 Kg K₂O/ha) was produced at par groundnut yield with 100% RDK applied plots. Concurrently, use of potassium solubilizing bacteria (KSB) having significant effect on groundnut yields and monetary returns over control plots (AICRPG, 2022) ^[3].

Application of 75% RDF to the groundnut crop following incorporation of sunhemp as a green manure at 45 Days after sowing resulted in saving of 25% RDF (AICRPG, 2022) ^[3]. Application of 40 kg P/ha + DGRC resulted in higher pod yield and saving 20 kg P per ha (AICRPG, 2022) ^[3].

High pH, especially in calcareous soils, increases micronutrient deficits. Boron (B) deficiency can be corrected by providing 3-4 kg/ha of borax to the soil or spraying 0.1% borax. Iron (Fe) deficiency in calcareous soils can be severe and addressed by applying 10 kg/ha ferrous sulphate or spraying 0.5% + 0.2% urea. Likewise, basal application of 10-20 kg/ha zinc sulphate every three years can solve Zn deficiency (Saha *et al.*, 2015). ^[13] Soil analysis should guide Zn and other micronutrient application to avoid toxicity. Table 7 shows the response of groundnut to micronutrient fertilizer application.

By converting and mobilising fixed or inaccessible nutrients, biofertilizers improve nutrient efficiency. They also reduce the need for external N and P applications by 25% and have the potential to increase crop output by 15% (Jeffries, 2003) ^[8]. Bradyrhizobium, plant-growth-promoting rhizobacteria (PGPR), phosphorus-solubilizing microorganisms (PSM), and arbuscular mycorrhizal (AM) fungi are examples of biofertilizers used in groundnut. Bradyrhizobium not only fixes atmospheric N, but it also secretes siderophores that help soils with Fe chlorosis caused by lime better absorb Fe. *Aspergillus niger* and *Sclerotium rolfsii* are among the soilborne pathogens that are suppressed by PGPR, a mixture of beneficial rhizosphere bacteria that mobilizes macro- and micronutrients and creates growth-promoting hormones (Dey, 2004) ^[5]. Commercial biofertilizers either dry or in solutions, can be applied through seed treatment and also mixing with farmyard manure (FYM), or using irrigation water. Application of *Rhizobium leguminosarum*, *Rhizobium meliloti*, *Bacillus subtilis* and *Fraturia aurantia* soil application each @ 3.0 l/ha resulted in 44% higher yield and net returns of Rs 137484/ha (AICRPG, 2021) ^[2].

Table 7: Response of groundnut to micronutrients

Nutrient	Area of study	Response to micronutrient addition*
FeSO ₄ @ 50kg/ha ⁻¹ (Soil application)	Coimbatore, Tamilnadu	28.7%
ZnSO ₄ @ 25 kg/ha(Soil application)		3.8%
Zn @ 5 kg/ha	Umiam, Meghalaya	23.4%
B @ 1 kg/ha		30.7%
Mo @ 0.5 kg/ha		35.5%
Zn @ 5 kg/ha + B @ 1 kg/ha + Mo @ 0.5 kg/ha		36.6%
Foliar application of ZnSO ₄ @ 0.2%	Mahanandi, Andhra Pradesh	23.5%
Foliar application of micronutrient mixture @ 0.2%		25.5%
2 kg B ha/1	Dhaka, Bangladesh	32.5%
10 kg Zn/ ha	Mohanpur, West Bengal	28.3%
B as 0.25% boric acid		8.9%
P 30 kg/ha + Zn 1.5 g/l	Tigray, Ethiopia	7.5%
Gypsum 400 kg/ha+Zinc 4000 ppm	Prayagraj, Uttar Pradesh	40.5%
ZnSO ₄ @ 30 kg/ha	Zn deficit regions	31.3%

* percent increase over control

Water management

Groundnut is sensitive to moisture stress during flowering, pegging, pod, and seed development. It cannot tolerate stagnant water in its cultivation area. Thus, groundnut cultivation requires good water management practices. Groundnut water needs in India range from 420 to 820 mm, depending on soil type and climate (Nigam, 2009) ^[11]. Groundnut seedlings can withstand 2- to 3-week drought stress. The crop needs frequent but mild irrigation, preferably sprinklers or overhead irrigation systems, during pegging, pod, and seed development (Table 8). Besides yield increase, avoiding moisture stress during pod and seed

development reduces aflatoxin content (Nigam, 2009) ^[11]. Groundnut productivity is affected by irrigation water quality, with suggested limits for saline water being EC <4.0 mmhos/cm and RSC <2 meq/L. Integrated water management with application of hydrogel @ 2.5 kg/ha along with mulching with agro waste @ 5 tons/ha augmented groundnut productivity by 23-30% (AICRPG, 2021) ^[2]. Significantly higher pod yield was observed under application of 70% of irrigation water and foliar nutrition of 0.5% KNO₃ at 50 DAS (AICRPG, 2021) ^[2]. Likewise, pod yield enhanced with irrigation scheduling at 0.8-1.0 IW/CPE in *rabi* groundnut (AICRPG, 2021) ^[2].

Table 8: Improved irrigation methods and yield enhancement in groundnut

Improved method of irrigation	Yield	Method of irrigation in control	Yield in control
Drip	4.0 t/ha	Surface furrow	2.4 t/ha
Drip	3.8 t/ha	Rainfed	0.13 t/ha
Sprinkler	2.8 t/ha		
Micro sprinkler with 100% ET	2.9 t/ha	Surface irrigation	2.0 t/ha
Micro sprinkler at 0.8 Epan	3.1 t/ha	Check basin at 0.8 IW:CPE ratio	2.9 t/ha
Micro sprinkler	4.7 t/ha	Broad based furrow	2.7 t/ha
Drip inline	4.4 t/ha		
Drip	4.1 t/ha		
Drip	1.5 t/ha	Sprinkler	1.3 t/ha
Drip	1.3 t/ha	Surface	1.2 t/ha
Sub surface drip	2.6 t/ha	Surface drip	2.4 t/ha
Drip	2.4 t/ha	Check basin	2.0 t/ha

Weed management

Weed invasion is a major obstacle to the cultivation of peanuts. The degree of weed infestation directly correlates with a yield decrease ranging from 74 to 92% in groundnut. Ensuring a weed-free environment in groundnut fields is essential during the first 45 days after the crop emerges (Priya *et al.*, 2013) ^[12]. Chemical weed control plays a key role in managing weeds in groundnut. The application of pre-emergent Pendimethalin @1.5 kg a.i. ha⁻¹ followed by early tank mix post-emergence of Imizathapyr + quizalofopethyl @ 50:50 ratio helps to enhance pod yield with greater weed control (AICRPG, 2021) ^[2]. Application of Diclosulam 84 WDG @ 25 g a.i ha⁻¹ as pre-emergence followed by inter cultivation/hand weeding at 30 and 60 DAS found better weed control efficiency in Rahuri and Vriddhachalam (AICRPG, 2021) ^[2]. Integrated weed management (IWM) with cultural, mechanical, and chemical can be used economically by the farmers to improve crop yield. IWM in *Kharif* groundnut by pre-emergence application of Pendimethalin 30EC + Imazethapyr 2 EC (Pre-mix) @ 1.0 kg ha⁻¹ followed by manual weeding at 25-30 DAS) led to highest

weed control efficiency (AICRPG, 2021) ^[2]. Application of pre-emergent Pendimethalin 1.0 kg fb Quizalofop Ethyl 5% EC 50 g a.i. ha⁻¹ (POE) at 30 DAS and Diclosulam 84% WDG @ 25 g a.i. ha⁻¹ (PE) fb Quizalofop Ethyl 5% EC 50 g a.i. ha⁻¹ (POE) at 30 DAS (AICRPG, 2023).

Intercropping/ crop rotation

Intercropping or mixed cropping is a widely used practice in rainfed and subsistence agriculture. Its purpose is to reduce the likelihood of crop failures and meet the varied food requirements of families. Groundnut is commonly cultivated alongside cereals such as maize, sorghum, and pearl millet as an intercrop. Intercropping of *Kharif* groundnut with vegetable purpose coriander in 2: 1 row proportion resulted in significant improvement in system yield with economic advantage of Rs 11498/ha in Dharwad, Rs 24973/ha in Gwalior and Rs 83655/ha in Hiriur (AICRPG, 2022) ^[3]. Among millet-based intercropping systems, groundnut + finger millet (2:1) incurred highest groundnut equivalent yield (GEY) of 1606 kg/ha followed by groundnut + finger millet (4:2) of 1522 kg/ha

(AICRPG, 2020) ^[1]. Intercropping of groundnut and pigeonpea, is a widely practiced system in India. Intercropping of Groundnut +Pigeonpea (4:2) produced higher GEY (4500 kg/ha), net returns (Rs.1,54,811/ha) and B:C (3.67) (AICRPG, 2020) ^[1]. Crop rotation is crucial for preserving soil fertility, increasing organic matter, enriching the physical structure of the soil, and minimizing the prevalence of disease-causing agents and insect pest populations. Groundnut-Chickpea sequence is most remunerative with higher GEY (6024 kg/ha), net monetary returns (Rs.1,99,514/ha) and B:C 3.27 (AICRPG, 2020) ^[1]. Implementing a systematic crop rotation not only increases crop production but also reduces expenses associated with disease management and fertilizer usage. Groundnut + maize (5:1), groundnut + maize (4:1) and groundnut + maize (3:1) recorded significantly higher groundnut pod equivalent yield than groundnut + maize (2:1) and Sole maize and was at par with sole groundnut (AICRPG, 2021) ^[2]. Groundnut + foxtail millet in a 5:3 ratio produced the highest pod production among the intercropping treatments (1016 Kg/ha) (ALCRPG, 2022).

Plant protection

Insect pests, wind, and soilborne infections, viruses, nematodes,

weed interference, and storage pests limit groundnut yield and quality. Thrips, jassids, and aphids (sucking pests), leaf miner, tobacco caterpillar, gramme pod borer, and hairy caterpillar (defoliators), white grubs, termites, earwig, and jewel beetle (soil-inhabiting pests), and others damage groundnut crops. Integrated insect pest (IPM) and disease management (IDM) is advised for safe and effective control. Selecting disease resistant varieties is a non-monetary input in groundnut (Tables 1-3). Cultural management techniques including roughing, summer tillage, intercropping with cereals, deep ploughing, and crop rotation minimize pest and disease incidence greatly. Carbendazim 50WP at 500 g/ha or Mancozeb 50WP at 1 kg/ha for leaf spots, Calixin at 250 mL/ha for rust, and Chlorothalonil 75WP at 1 kg/ha for rust and leaf spots are effective chemicals (Table 9). IPM is essential for eco-friendly insect pest management. Resistant cultivars, early seedling pesticide treatment, and economic threshold systemic insecticides are advised for sucking pests. Chemical management for leaf miners is recommended when larvae reach 61-70 per 100 leaves. Pheromone and light traps for moth destruction are also used. Best IPM and IDM modules developed by AICRP groundnut is given in table 9.

Table 9: Technologies for insect-pest management in groundnut (AICRPG 2021 and 2022)

Technology	Details	Target pest/disease	Area
Botanical oils for management of defoliator pests	Foliar spray of Karanj (Pongamia) oil @ 3 mL/L or Azadirachtin 3% @ 3 mL/L or Neem oil @ 3 mL/L or tank mixing of Karanj oil and Neem oil each @ 1.5 mL/L	Tobacco caterpillar, Gram pod borer and Leaf miner	AP, Karnataka, TN
New insecticide molecules for management of defoliator pests	Single foliar spray of Chlorantraniliprole 18.5SC @ 125 mL/ha or Flubendiamide 39.35SC @ 100 mL/ha or Novaluron 10EC @ 500 mL/ha	Tobacco caterpillar and Gram pod borer	Karnataka, TN, Telangana
Neonicotinoid insecticides for management of sucking pests	Single foliar spray of Imidacloprid 17.8SL @ 150 mL/ha or Thiacloprid 480SC @ 125 mL/ha or Thiomethoxam 25WG @ 100 g/ha or Acetamiprid 20SP @ 100 g/ha	Thrips and leaf hoppers	Andhra Pradesh, Gujarat, Karnataka, Telangana
Seed treatments for management of White grubs	Seed treatment with Chlorpyrifos 20EC @ 12 mL/kg or Imidacloprid 48FS @ 2 mL/kg of seed	White grubs	Gujarat, Karnataka
Disinfecting storage bags for Bruchid management	Disinfecting jute bags with Deltamethrin 2.5SC @ 0.5 mL/L protects groundnut pods from Bruchid infestation for six months of storage	Groundnut bruchid	Andhra Pradesh, Karnataka

Table 10: Technologies for disease management in groundnut (AICRPG 2021 and 2022)

Technology	Details	Target pest/disease	Area
Integrated soil-borne disease management	Seed treatment with Tebuconazole 2DS @ 1.5 g/kg of seeds with furrow application of <i>Trichoderma viride</i> @ 4 kg enriched in 250 kg FYM/ha	Stem rot, Collar rot and Dry root rot	AP, Rajasthan
	Deep summer ploughing with mould board plough, then soil application of <i>Trichoderma</i> sp. @ 4 kg/ha enriched in 250 kg FYM/ha as basal (furrow) application, then seed treatment with Tebuconazole 2DS @ 1.5 g/kg seed followed by PGPR @ 625 g/ha of seed, then again soil application (broadcasting) of <i>Trichoderma</i> sp. @ 4 kg/ha enriched in 250 kg FYM/ha at 35 and 70 days after sowing	Stem rot, Collar rot and Dry root rot	AP, Karnataka, Maharashtra, TN
Module for foliar disease management	Seed treatment with Tebuconazole 2DS @ 1.5 g/kg seeds followed by two foliar sprays of Tebuconazole 50% + Trioxystobin 25% 75WG @ 1.32 g/L at 40 and 65 days after sowing	Late leaf spot, Rust and Alternaria leaf blight	Karnataka, Gujarat, TN
	Seed treatment with Tebuconazole 2DS @ 1.5 g/kg seeds followed by foliar spray of Tebuconazole 25.9EC @ 1 mL/L at 40 and 65 days after sowing	Late leaf spot, Rust and Alternaria leaf blight	AP, Maharashtra, TN
	Seed treatment with Tebuconazole 2DS @ 1.5 g/kg followed by furrow application of <i>Trichoderma viride</i> @ 4 kg enriched in 250 kg FYM/ha as basal application, then broadcasting of <i>T. viride</i> @ 4 kg enriched in 250 kg FYM/ha at 40 days after sowing and two foliar sprays of Tebuconazole 29.5EC @ 1 mL/L, starting from initiation of foliar diseases and second spray at 15 days interval	Leaf spots (Early leaf spot and Late leaf spot) and Rust	Gujarat, Karnataka, Tamil Nadu
Trichoderma and Pseudomonas application for disease management in organic groundnut	Seed treatment with <i>Trichoderma</i> sp. (10 g) and <i>Pseudomonas Fluorescens</i> (10 g) per kg seed followed by furrow application of <i>Trichoderma</i> sp. (2 kg) and <i>P. Fluorescens</i> (2 kg) enriched FYM at 250 kg/ha and foliar spray of <i>Trichoderma</i> sp. (2.5 kg) and <i>P. Fluorescens</i> (2.5 kg) per hectare	Soil-borne diseases and foliar diseases	Karnataka, Maharashtra, Odisha
Management module for Peanut Bud Necrosis	Growing border crop with jowar (4 rows), seed rate (200 kg/ha) of groundnut treated with Imidacloprid 48FS @ 1 mL/kg seed followed by foliar sprays of Thiacloprid 480SC @ 0.3 mL/L at 20 days after sowing and Fipronil 5SC @ 1 mL/L at 35-40 days after sowing	Thrips and PBND	AP, Karnataka, Maharashtra

Other viable options to boost Indian groundnut production

1. **Adopting good production techniques:** Implementing effective agricultural practices involves employing various methods such as thorough summer ploughing, growing high-yielding varieties (HYV), treating seeds, optimum seed rates, use of seed and fertilizer drill, gypsum application, precision nutrient management, adopting IPM techniques, implementing crop rotation and intercropping strategies, and employing mechanization for sowing, intercultivation, harvesting, and threshing to minimize cultivation expenses.
2. **Research focus:** Research efforts are to be directed towards development of crop varieties resilient to biotic, and abiotic stresses, as well as the creation of cold-tolerant varieties. Additionally, there is a focus on sustainable integrated nutrient management practices tailored to diverse agro-climatic zones. Research also encompasses the screening and identification of groundnut genotypes that are efficient in low P and Ca soils, as well as those tolerant to soil acidity and aluminum toxicity in acidic soils. Furthermore, efforts are made towards post-harvest technologies, along with the development of at least a 15-day fresh seed dormancy period.
3. **Identifying new cropping systems:** It is essential to identify profitable groundnut-based cropping systems to enhance both groundnut yield and overall system productivity. For instance, the Groundnut-Chickpea (4:2) sequence cropping system, and intercropping with pigeon pea at 4:2 ratio have been identified. Emulating this approach, region-specific profitable cropping systems can be developed across different districts.
4. **Area expansion in non-traditional areas**
 - **Area expansion in North eastern States:** Groundnut cultivation in upland areas of eastern and northeastern hills, particularly in rice-fallow and potato-fallow with residual moisture or with minimal irrigation. In these regions, groundnut is typically sown between October and February, coinciding with a decrease in water levels in rivers following rice harvest. This approach facilitates the growth of short-duration groundnut varieties (80-85 days) that exhibit fresh seed dormancy.
 - **Cultivating spring season groundnut:** Expanding the cultivation of groundnut can be achieved by utilizing the spring season following the harvest of early potato and mustard crops. In Uttar Pradesh, groundnut planting can commence from the first fortnight of January up to the second fortnight of February. Similarly, in Haryana and Punjab, heat-tolerant groundnut varieties can be sown after the wheat harvest.
 - **Growing groundnut in summers in Indira Gandhi canal command area:** This region encompasses the districts of Bikaner and Jaisalmer in Rajasthan, with a total potential area of 2-3 lakh hectares suitable for groundnut cultivation. The temperature can soar up to 55 degrees Celsius. By planting varieties capable of withstanding cold conditions in February, rapid vegetative growth can be achieved, ensuring the plants develop sufficient strength to withstand the intense heat in subsequent stages.
 - **Growing groundnut as intercrop:** Groundnut cultivation can thrive when integrated between fruit crops and widely spaced perennial crops, as well as alongside annual crops such as red gram, castor, and cotton.
 - **By Increasing the use of groundnut in food and food products:** Apart from groundnut oil, other groundnut-derived products such as groundnut butter, baby food, etc.,

can be encouraged. If effective measures are implemented to control aflatoxin levels in these products, there is significant potential for exporting them, consequently boosting groundnut production.

- **Increasing the use of groundnut plant as fodder:** Cultivating groundnut varieties that retain their greenness at the time of harvesting enables them to serve as both green and dry fodder.
5. **Extension activities**
 - Model crop villages, like the "Mithapur" village adopted by ICAR-Directorate of Groundnut Research, Junagadh, serve as prototypes for sustainable agricultural development. They showcase innovative approaches through Farmer's Field Days (FLDs), which can be replicated and scaled up to transform rural communities and enhance production.
 - Regular monthly interactions between farmers and scientists are vital for addressing farmers' issues during the cropping season.
 - Ensuring adequate financial support for research institutes is crucial for transferring the latest technology to farmers through various demonstrations and training programs.
 - Promoting public-private collaborations is essential for enhancing research activities and extending agricultural technologies to farmers.

Conclusion

Enhancing groundnut productivity in India is paramount for sustaining its oilseed economy and ensuring food security. The challenges, including energy scarcity and the availability of quality seeds, underscore the urgent need to prioritize the adoption of low-cost production technologies. This entails a concerted effort towards integrating improved genotypes and implementing sustainable soil fertility management practices. Studies in agronomy have substantiated the effectiveness of various techniques, such as seed replacement and the application of foliar fertilizers, in augmenting groundnut yields. Collaborative efforts among policymakers, scientists, and farmers are necessary for the successful implementation of these strategies. Moreover, embracing good production techniques, with a focus on resilient varieties and sustainable nutrient management, is pivotal. Additionally, the exploration of non-traditional cultivation areas and the promotion of value-added products hold promise in further enhancing groundnut production. Extension activities and fostering public-private partnerships serve as crucial conduits for advancing research and facilitating the dissemination of agricultural technologies to farmers. Through these concerted efforts, India can realize sustainable increases in groundnut production, thereby fulfilling both national and local agricultural requirements.

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