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Agronomic Technologies for Enhancing Onion Productivity under Climate Change in Korea

Development of Mechanized & Smart Cultivation Technologies to Address Climate Change and Rural Labor Shortages

National Institute of Horticultural & Herbal Science
Allium Vegetable Research Center

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Definition, Uses & Functional Components of Onion

Etymology, uses, functional components, and ornamental onion varieties

Definition & Etymology

- Onion: from the Latin unio referring to one undivided round form
- Allium: from the Celtic all(burning, hot), symbolizing the pungent juice
- Cepa: from the Celtic cep or cap, meaning a head-shaped bulb

Uses of Onion

- Culinary & stimulate appetite
- Medicinal
- Ornamental

Key Component Table

Source: Chakraborty AJ et al. 2022

Category	Key Compounds	Key Effects
Organosulfur compounds	Onionin A, Thiosulfinates	Antibacterial, anti-cancer, unique flavor
Flavonoids	Quercetin, Rutin	Potent antioxidant, vascular health
Polysaccharides	Fructans	Prebiotic effects (gut health)

Ornamental Allium Varieties

Giant Allium
Allium giganteum

Purple Allium
Allium aflatunense

Roundhead Allium
Allium sphaerocephalon

Functional Properties

Functional components: Allicin(Anti-cancer, Antiviral), Saponin(Fatigue recovery, Immune enhancement), Flavonoids(Antioxidant, Anti-inflammatory), Polyphenols(Anti-aging)

Used as folk medicine: Folk Natural remedy, Disease prevention &. Known for excellent blood circulation and fatigue recovery effects.

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Global Onion Production Trends

China & India production scale, export competitiveness, major producers, and Korea's position

Global Production Overview

China and India are the world's largest onion producers and remain highly export competitive thanks to strong production infrastructure. The United States, Egypt, and Turkey are also major producers, while Korea's high production costs weaken price competitiveness.

Korea's Cost Burden

High labor & distribution costs limit global competitiveness

Korea's Ranking
Among world onion producers
45th

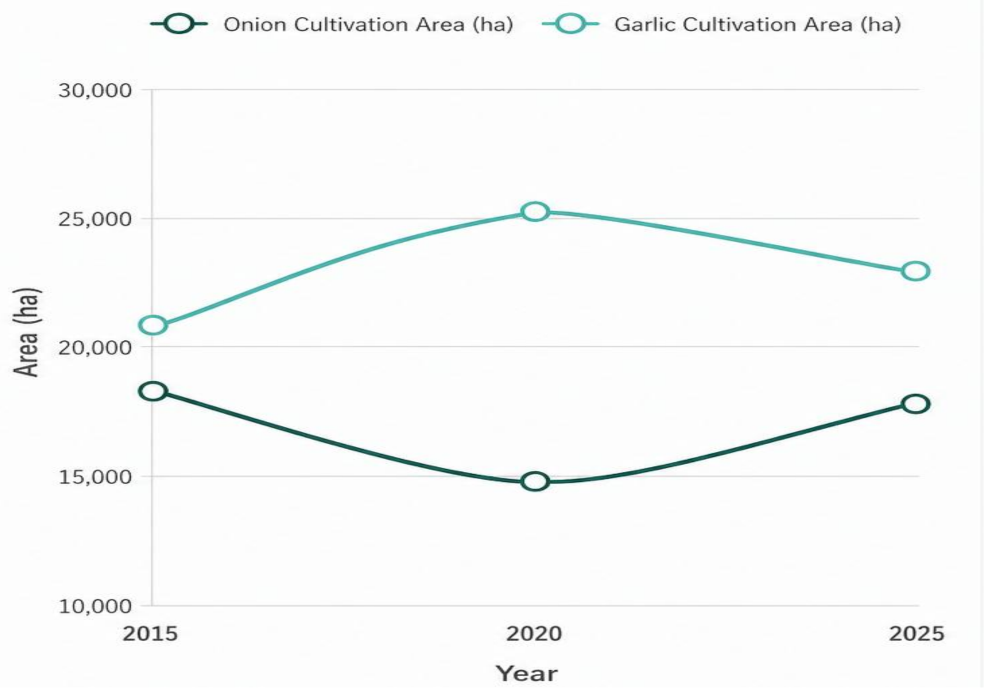
Major Producers

CN	China	25M tons
IN	India	18M tons
US	U.S.	8M tons
EG	Egypt	6M tons
TR	Turkey	5M tons

Korea's Cultivation Area & Production Trends

Changes in onion and garlic area and production over the past 10 years

Onion & Garlic Cultivation Area Trend (ha)

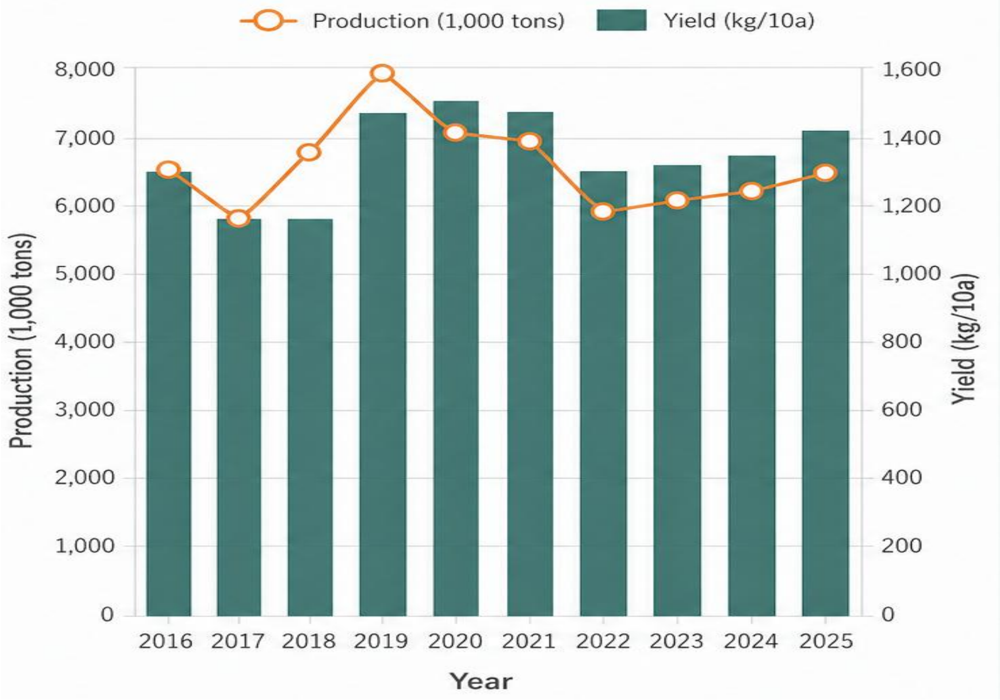


55,000
2024 area (ha)

+3.2%
Vs. last year

-5.8%
vs. 10 years ago

Onion Yield & Production Trend



Area volatility: complementary fluctuation with annual prices creates persistent supply-demand instability.

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Korea Onion Supply Forecast (2025)

2025 onion supply and production outlook with import trends

2025 Onion Supply Forecast

2025 supply is projected at 1.447 million tons, up 2.2% YoY and 3.6% above normal.

- **1.447Mtons** 2025 supply
- **+2.2%** YoY
- **+3.6%** vs. normal
- **+3.5%** Production increase

Import Trends & Impact

Imports in 2025 are expected to decline from the previous year, when fresh onion imports were high, following a surge in private imports (Jan-Feb 2025) and TRQ introduction (Mar 2025).

Rural Demographic Changes & Cost Pressure

Population decline, aging, and rising farm costs are weakening the production base

Rural Demographic Change

1.87M
Projected population In 2030

-53%
vs. 2000

59.7%
Aging rate (2030)

+22.3%
Increase over last 6 years

The rural population is projected to decline by 53%, from 4.03M in 2000 to 1.87M in 2030.

Source: National Data Center

Rising Farm Management Costs

KRW 25.11M
Farm cost per household in 2023

+22.3%
vs. 2017

Farm management costs rose 22.3%, from KRW 20.53M in 2017 to KRW 25.11M in 2023, increasing pressure on farm households.

Source: Agricultural Outlook Center

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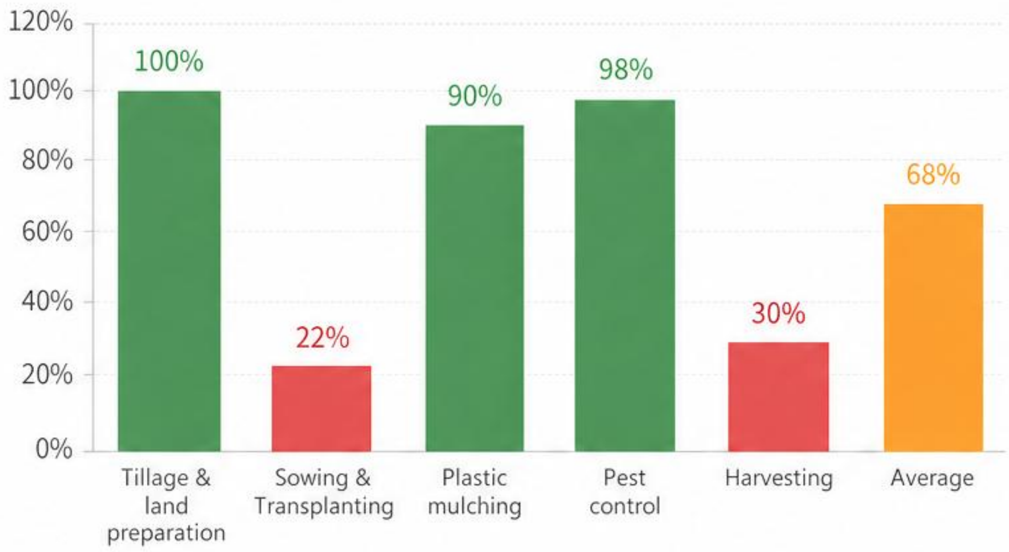
Onion Cultivation Mechanization Rate ('23)

Mechanization by operation, highlighting low sowing/transplanting and harvesting rates

Mechanization Rate by Operation



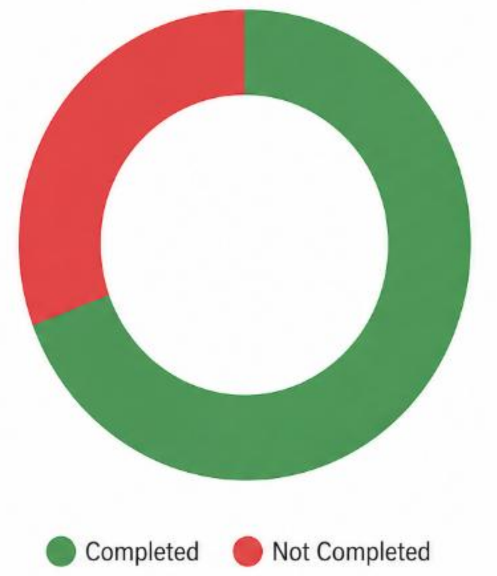
Strength Areas
3 items (60%)

Improvement Areas
2 items (40%)

Overall Average
68%

Insights
Tillage & land preparation, Plastic mulching, and Pest control are strong areas.
Sowing & Transplanting and Harvesting need improvement.

Overall Completion Status



Goal Achievement
Completed 68% toward the goal(80%) **-8pp**

Source: Agricultural Mechanization Statistics, 2023

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Barriers to Onion Mechanization Expansion

Factors limiting mechanization: diverse cultivation practices, shortage of quality seedlings, poor emergence, waterlogging, and disease

Onion cultivation field

22.7%	31.4%	68.9%
Sowing/Transplanting Mechanization	Harvesting Mechanization	Average Mechanization

Challenges from Diverse Cultivation Practices

- **Variation in cultivation systems by region and farm**
  Differences in bed width, number of planting rows, and intra-row/inter-row spacing make mechanization difficult to implement.
- **Missing plants due to limited quality seedlings**
  Insufficient production of uniform, high-quality seedlings for mechanical transplanting leads to a high rate of missing plants after transplanting.
- **Low emergence rate · Waterlogging · Disease damage**
  Poor emergence, waterlogging injury, and disease pressure hinder the wider adoption of mechanized onion production.

Key issue: widely different local cultivation practices reduce farm machinery utilization and diffusion.

Changes in Cultivation Environment

Frequent extreme weather from climate change is expanding risks to growth, yield, and quality

Risks from Extreme Weather

Increasing frequency of extreme weather events such as high temperatures and heavy rainfall threatens yield loss and quality decline.

Key Risks

- Yield reduction
- Increased disease incidence
- Greater quality and price volatility

Recent Major Damage Cases (Onion)

Year	Region	Extreme Weather	Major Damage
2005～2006	Muan	Heavy snowfall · Prolonged snow cover (30 days)	High stand failure rate, root rot
2007～2008	Southwestern region (seedling-growing area)	Excessive rainfall (9.12 days, 232 mm above normal)	Downy mildew outbreaks
2009～2010	Jeju · Early maturing cultivars	Cold spells · Rainfall · Insufficient sunshine	Foliage dieback, gray mold outbreaks
2011～2012	Southwestern region (seedling-growing area)	Abnormally high temperatures	Bolting (early planting fields)
2012～2013	Southern regions	Abnormally low temperatures	Frost damage (mid-late & late planting fields)
2014～2015 2016～2017	Southern regions	Sustained high temperatures during bulbing stage in May	Poor bulb development, yield decline, price surge
2017～2018	Jeonnam region	Leaf blight during harvest	**Yield loss** **Damage over 3,000 ha in Jeonnam**
2021～2022	Nationwide	Intensified drought in winter and spring	Poor early growth, yield decline

Implications: Development of Adaptive Technologies and Proactive Response System

- Develop climate-resilient cultivation technologies and high-performing cultivars under extreme weather scenarios
- Advance damage prediction models and strengthen field monitoring
- Establish early warning and integrated pest management systems in major onion-producing areas (Jeonnam, Gyeongnam, Gyeongbuk)

Allium Vegetable Research Center Overview

Research facility in Muan, Jeollanam-do, Korea's largest onion-producing area

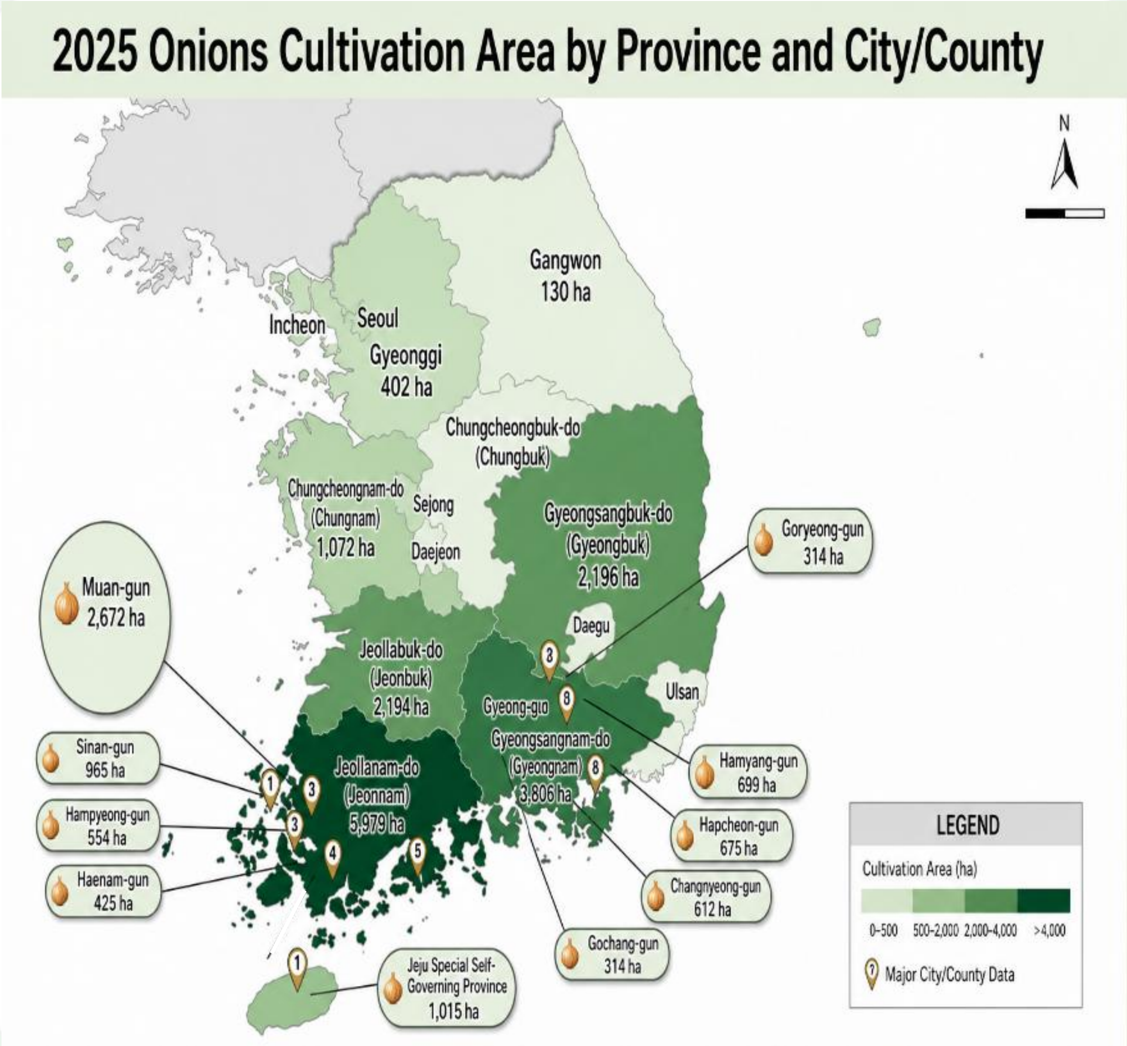
Research Center Overview

Muan, Jeollanam-do
Largest onion-producing area

55,465㎡
Total area (5.5 ha)

Key Missions

- New variety development & distribution
  Onion, Garlic etc. New varieties &
- Labor-saving cultivation & cost reduction
  Labor & cost reduction via mechanized cultivation
- Stable production vs. extreme weather
  Stable production technology for climate change



Vision & Goals

Driving an Allium vegetable industry that satisfies both producers and consumers

VISION: Driving an Allium vegetable industry that satisfies both producers and consumers

Advancing the onion industry through stronger global competitiveness, greater sustainability, and transition to future agriculture

Goal 1: Demand-Driven Variety Development

- Develop varieties with strong stress tolerance and processing suitability
- Strengthen resistance to downy mildew and Fusarium wilt
- Use germplasm and build a digital breeding platform

3 varieties
Superior varieties

95%
Resistance

Goal 2: Labor-Saving Technology Development

- Establish mechanization and mulch-free cultivation technologies
- Develop seedlings for onion mechanical transplanting
- Build a smart integrated growth management system

85%
Labor saving

22.7%
Mechanization rate

Goal 3: Strengthening Supply-Demand Stability

- Advance growth prediction models
- Develop cultivation technologies to mitigate extreme-weather damage
- Strengthen supply-demand stability

1.44M
tons/yr

2.5%
Growth

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Strategies 1 & 2: Superior Variety Development & Digital Breeding

Improving quality through trait diversification for field demand and a precision-breeding platform

Strategy 1: Superior Variety Development & Digital Breeding

Trait diversification for field demand and precision breeding based on phenotype DB and genotype analysis

- Physiological disorder Resistance
  Onion Physiological disorder
- Downy mildew · Fusarium wilt Resistance
- Phenotype DB
  Genotype Analysis
- Precision breeding
  Digital breeding system

Strategy 2: Ensuring Objectivity in Variety Selection & Expanding Distribution

Objective evaluation of newly developed cultivars

- **Strengthen cultivar evaluation panels**
  - Enhance credibility by expanding participation of consumers and farmers

Early dissemination and promotion of newly developed cultivars

- **Regularly operate demonstration plots and strengthen promotional activities**
  - Enable on-site verification of cultivar superiority under field conditions

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Strategies 3 & 4: Mechanized & Smart Cultivation and Extreme Weather Response

Seedlings for mechanical transplanting, mulch-free cultivation, smart farming integration, and advanced damage prediction models

Strategy 3: Mechanized & Smart Cultivation Technology

Mechanical-transplant seedlings, mulch-free cultivation, and open-field smart farming solutions

- Seedlings
- Mulch-free cultivation Efficiency
- Environment & growth big data
- Irrigation & pest control optimization

Strategy 4: Stable Production Against Extreme Weather

Advanced damage prediction models, field monitoring in major production areas, and disaster response manuals

- Damage prediction model
  Heat damage mitigation
- Field monitoring
  Production area communication

Key Achievements: Superior Varieties & Genomics

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Superior onion varieties developed by NIHHS and genomics achievements

Maepsihwang(2015)

Onion juice processing variety
Low pungency, excellent taste

3.162 µmol/L

95% Storability

Moonfive(2016)

mid-to-late maturity,
yellow color, uniformity

Round Bulb shape

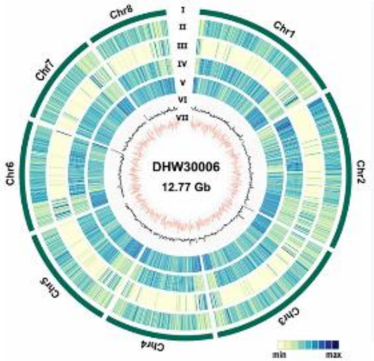
Storability excellent

Mayone(2017)

mid-maturity, yellow color,
uniformity

downy mildew resistance

Storability excellent



Genome analysis(2024)

Analyzed using the doubled haploid onion line “DHW30006”

12.77 Gb

95% Accuracy

Onion genome assembly achievement

12.77Gb Genome size

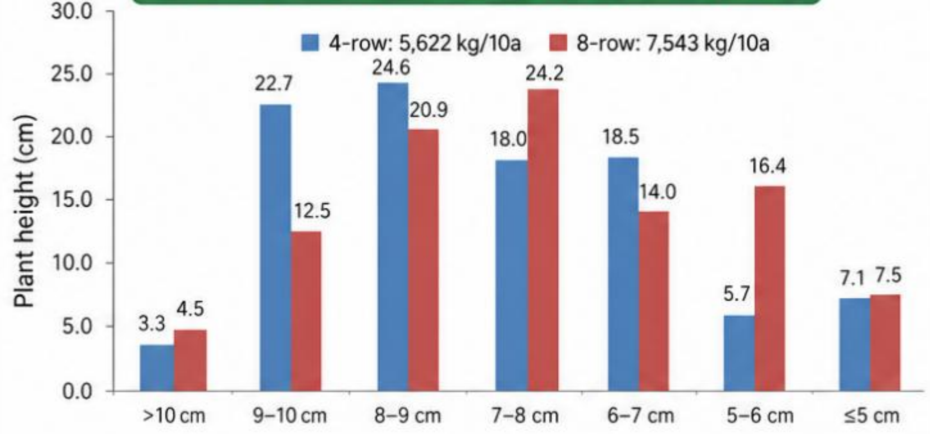
4.5% Gene regions

95% Repetitive sequences

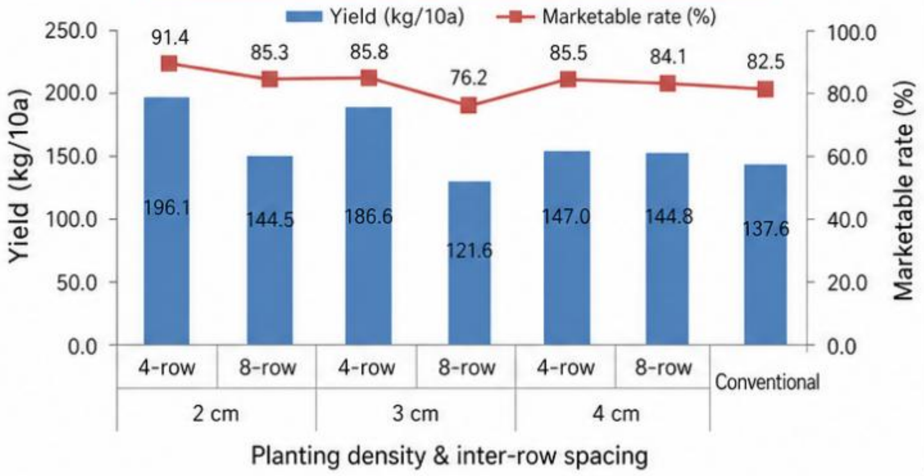
2024 Analysis completed

Key Achievements
: Standard Cultivation Practice for Mechanical Transplanting

1. Plant Growth by Planting Density and Spacing



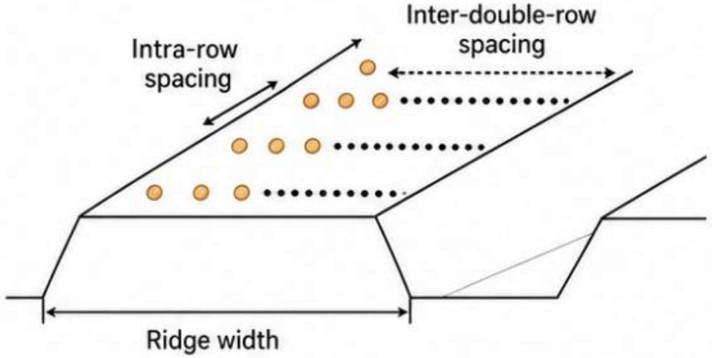
2. Bulb Yield by Planting Density and Spacing



*** 8-row, Double-row spacing: 120 cm**

Intra-row spacing: 12–14 cm

Inter-double-row spacing: 12–15 cm



*** Mulching required in 17.5% or less of the total area**

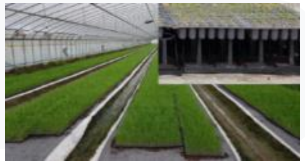
Key Achievements
: Four-Type Seedling Technology Established

Established four seedling-raising types across greenhouse/open-field and bench/soil systems to support mechanical transplanting

Four Seedling-Raising Types

Established greenhouse bench, greenhouse soil, open-field bench, and open-field soil methods to secure stable seedling production for expanding mechanical transplanting.

Greenhouse bench



Greenhouse soil

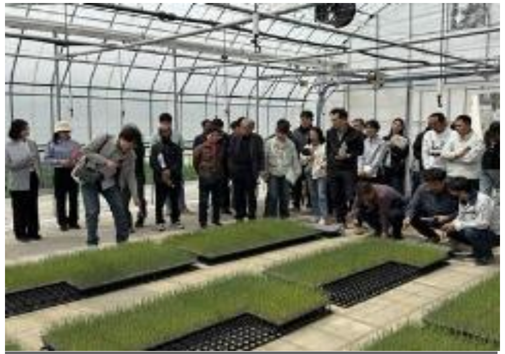
Open-field bench

Open-field soil

Also introduced precise irrigation based on cumulative solar radiation.

- 500J · cm^{-2} Cumulative solar radiation
- 1 ~ 4 Irrigation cycles
- 250~300mL Irrigation volume

Field Demonstration & Briefing



Technical briefing

Field demonstration

A technical briefing in May 2025 and field demonstration in October 2025 strengthened the reliability of open-field seedlings for mechanical transplanting.

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Key Achievements
: Mulch-Free Cultivation for Garlic & Onion Mechanization

Development of Mulch-Free Cultivation Technology for Labor Saving and Higher Mechanization Efficiency

Category	Experimental Content	Key Findings
Planting density	**Planting density** Compared yield and marketability after 5-12% higher density vs. conventional practice	**– No yield difference** No statistically significant yield difference vs. conventional practice **✓ Marketability maintained** Marketability was best at conventional planting distance
Fertilization	**Ridge fertilization** Broadcast fertilization (conventional) vs. ridge fertilization (improved) Validation of treatment effects	**↑ Higher marketability** Ridge fertilization showed better marketability than broadcast fertilization **Higher efficiency** Fertilizer use efficiency improved when applied near roots
Pest & weed mgmt.	**Pest & weed management** Herbicide treatment during spring regrowth and pesticide-residue analysis (onion)	**Safety secured** No phytotoxicity and strong herbicide efficacy **No residue detected** Residue analysis of harvested bulbs detected no residues, confirming safety

Note Institutional foundation prepared for broader field adoption

Service project conducted for disaster insurance development in mulch-free garlic cultivation

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Key Achievements
: Temperature & Moisture Experiment

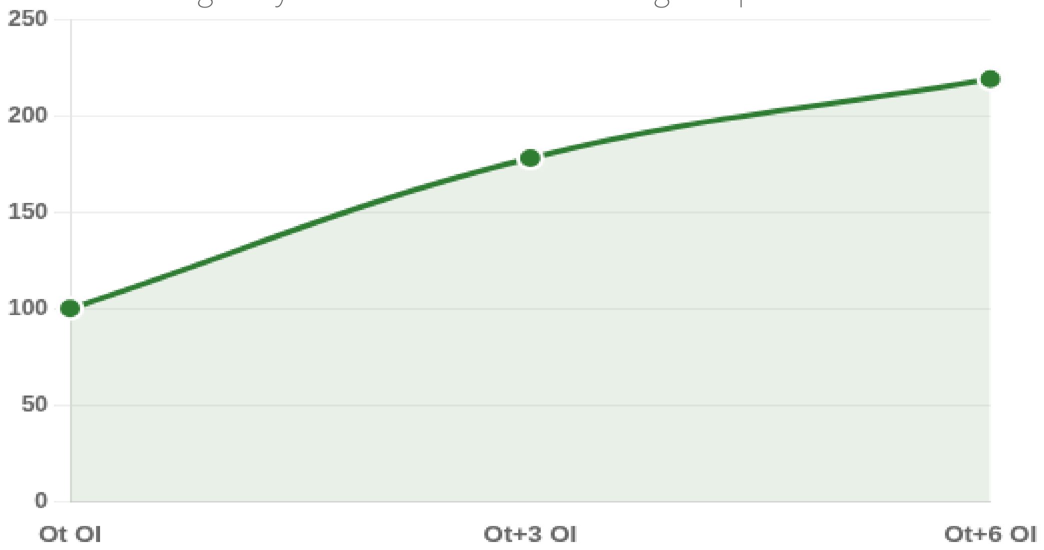
Results at 196 DAT under optimal moisture (OI 30%): yield response to higher temperature

Temperature & Moisture Results

Treatment	Bulb dia. (mm)	Bulb ht. (mm)	Bulb wt. (g)	Mkt. yield (kg/10a)	Mkt. ratio(%)	Yield Index
Ot(Control)	80.2	98.1	258.0	5,894	84.6	100
Ot+3 OI	96.9	107.5	395.8	10,520	98.4	178
Ot+6 OI	106.3	122.2	523.2	12,916	91.4	219

Yield Index Trend

Change in yield index with increasing temperature



Conclusions & Implications

+33%
Bulb wt. increase

+119%
Yield increase

+8%
Mkt. ratio

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Key Achievements: Onion Growth Model (PBCM)

Onion growth prediction model based on climate-change scenarios using a Process-Based Crop Model (PBCM)

Background

(Objective & Use) Supply-demand forecasting, farm-work decision support, and planning directions for climate-response technology development

- Traditional production forecasting (cultivation area × expected yield)
- Impact of climate change
- Growing demand for prediction technologies

PBCM Concept Diagram

Photosynthesis → Respiration → Partitioning

A technology that scientifically integrates core physiological processes inside the crop, interacting with the cultivation environment, to dynamically simulate overall crop growth.

Photosynthesis	→	Respiration	→	Partitioning
CO_2 uptake Energy production		Energy consumption Biological processes		Carbon partitioning Bulb enlargement

Gas-exchange model for photosynthesis prediction

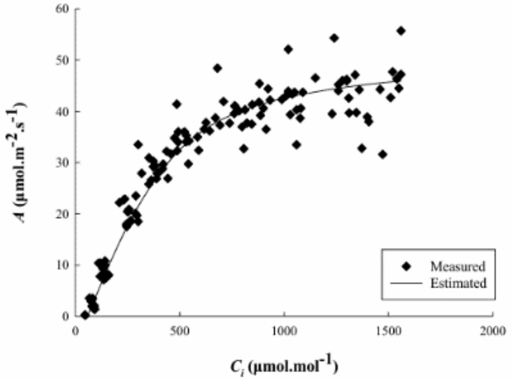

Fig. A-ci curve fitting for estimating net photosynthesis in onion leaves.

Prediction of leaf appearance, growth rate, and leaf area increase

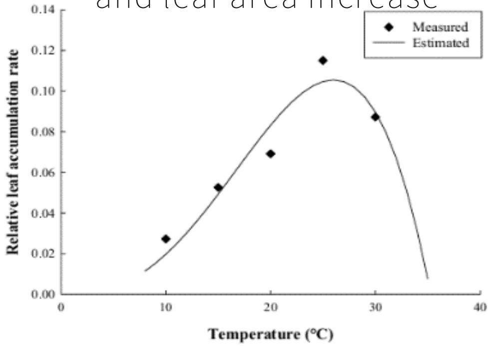

Fig. Relative leaf accumulation rate in onion. Beta distribution function was used to describe the leaf appearance pattern depending on temperature.

Prediction of bulb initiation

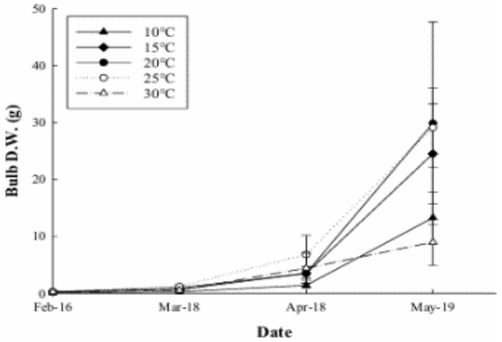

Fig. The timing of bulb initiation in 'Tabo' onion.

Prediction of assimilate partitioning

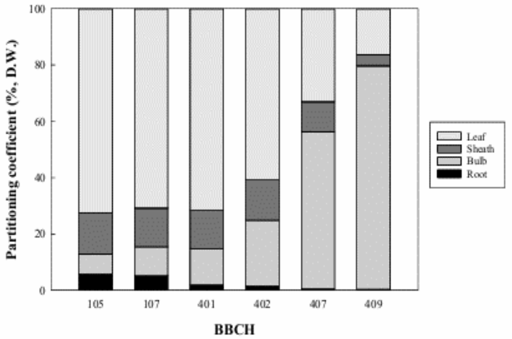

Fig. Carbon partitioning coefficients for root, bulb, sheath, and leaves for 'Tabo' onion throughout plant development.

Key Achievements: Fusarium Wilt Control

Fusarium wilt damage in seedling, cultivation, and storage stages; field validation of antagonistic microorganisms and tray disinfection; rapid outbreak increase at air temperature +6°C

Fusarium Wilt Control Technologies

- Tray disinfection
  Development of an effective disinfection method for reusable onion nursery trays ('23)
- Chemical control
  Selection of fungicides for use during the nursery and pre-transplanting stages, followed by emergency registration of eight products('23)
- Biological control
  Patent application ('24) and field validation('25) of antagonistic microorganisms for the control of Fusarium wilt

* Fungicide · Herbicide& Treatment *Bacillus thuringiensis* Selected


Seedling stage


Cultivation stage


Storage stage

Summary of Control Performance

Antagonistic microorganism	Tray disinfection	Pilot project
95% suppression	99% pathogen removal	6 sites

Key Achievements: Economics of Mechanization

Analysis of labor and cost savings from mechanized onion cultivation

Labor Savings

	Before	After	Reduction
Harvesting	13.0hours	**2.0hours**	85%↓
Transplanting	29.0hours	**5.0hours**	83%↓
Nursery	2.5hours	**1.0hours**	59%↓

Cost Savings

	Before	After	Reduction
Harvesting	KRW 250K	KRW 40K	83%↓
Transplanting	KRW 550K	KRW 100K	83%↓
Nursery	KRW 50K	KRW 20K	62%↓

Investment Efficiency

59%
Reduced labor cost

2.3 years
Payback period

Annual savings	KRW 11.5M
ROI	43%

Source: Agricultural Management Innovation Division, Jul. 2024

Key Takeaway

Mechanized onion cultivation reduced labor by 83-85% and costs by 62-83%. In particular, a 59% cut in labor cost helps improve farm income.

Outlook

If mechanization reaches 40%, annual cost savings are expected to exceed KRW 35.0M.

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Future Plan: Advanced Mulch-Free Cultivation

Development of precise soil temperature and moisture management technologies and an optimal management model

Issue 01

Lower yield than mulching

- Lower soil temperature
  → Delayed early growth
  → Increased frost damage risk

Solution 01

- Deep fertilizer incorporation technique
- Ridge-band application of controlled-release fertilizers

- Determination of optimal plant population density under mulch-free conditions

Issue 02

Greater soil moisture variability

- Post-rainfall waterlogging & rapid drying
  → Elevated moisture stress risk

Solution 02

- Establishment of optimal irrigation intervals for low-moisture-retention mulch-free systems

Issue 03

Weeds

- Absence of mulch film → Loss of light-interception effect → Increased weed pressure

Solution 03

- Registration trials for post-overwintering pre-emergence herbicide application
- Establishment of herbicide registration criteria

- Industry-collaborative research for spring-applicable herbicide registration

Future Plan: Seedlings for Mechanical Transplanting

Establish nutrient management standards by growth stage, identify optimal germination temperature, select wind-protection covering materials, and compare productivity of 40/50/60-day seedlings

Current Status	Research Plan
(Greenhouse) Nutrient management : scheduled quantitative fertilization	Develop nutrient management for greenhouse bench seedlings by growth stage : set spray intervals and concentration across early, middle, and late stages
(Open field) Extreme weather : high temperature at germination and strong wind	• Develop optimal germination temperature and early seedling management • Select cover materials for strong wind and set covering duration
Irregular transplanting dates : persistent rain and high temperature	Analyze productivity by seedling age for different types for mechanical transplanting : 40, 50, and 60-day seedlings (open-field bench, open-field soil, greenhouse bench, greenhouse soil)

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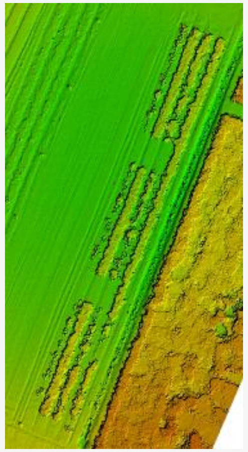
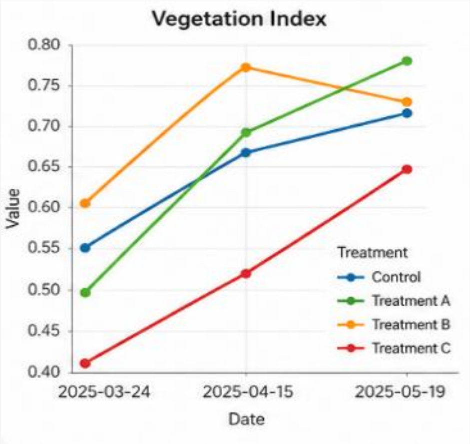
Future Plan: Transition to Smart Farming

Drone- and fixed-camera-based growth assessment, soil-moisture-based variable-rate irrigation, and integrated management guidelines

Growth Assessment Using Drones & Fixed Cameras





RGB
Visible light

NIR
Near infrared

NDVI
Vegetation Index

Smart Farming Integrated Management System

Image-based growth diagnosis
Real-time monitoring of crop status through RGB/multispectral analysis

Soil-moisture-based irrigation
Use precision sensors to assess moisture conditions and build an optimal management system

Standardized growth DB
Accumulate and analyze growth data under greenhouse and open-field conditions

Big data analysis
Integrated analysis of environmental factors and growth information

Future Plan: Proactive Extreme Weather Response

Strengthen field applicability of damage prediction models, build a cultivation package to reduce physiological disorders, and upgrade field support in major production areas

Four Core Directions

Damage prediction model field applicability | In progress

Focused development of heat-damage mitigation cultivation technologies and advanced growth prediction models

Upgrading field support in major producing areas | Expanding

Customized technical support based on data from 7 regions

Cultivation package for reducing physiological disorders | Planned

Develop technologies to stabilize growth under climate stress

Disaster response manuals & scenarios | Completed

Establish staged response scenarios to minimize farm losses

Support Based on Data from 7 Regions

7
Regions covered

512
Experts involved

Conclusion & Expected Impact

Five core outcomes achieved through development and application of cultivation technologies to improve onion productivity under climate change

Productivity & Quality

Productivity improved by 10% through superior varieties and genomics

95% Quality

Labor & Cost

Labor reduced by 83-85% through higher mechanization and mulch-free cultivation

62% Cost reduction

Climate Resilience

Damage reduced by 70% through extreme-weather response models and physiological disorder mitigation

70% Damage reduction

Supply Stability

95% self-sufficiency supported by a projected supply of 1.447 million tons

95% Self-sufficiency

Field-Research-Policy Integration

Built a network across 7 regions and 512 experts

512 Experts

Thank you. The Allium Vegetable Research Center remains committed to developing cultivation technologies that enhance onion productivity in response to climate change.