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Department of Agricultural Engineering

Course Name : **Protected Cultivation**
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Faculty : **Mr. ARUNPANDIAN N (Asst. Professor)**

UNIT - II

PROTECTED CULTIVATION OF VEGETABLE CROPS

PART 5 : POST-HARVEST HANDLING – PRESERVING THE PREMIUM

The Cold Chain Continuum

1. Harvest Physiology & Timing:

- Respiratory patterns:
 - Climacteric (tomato, melon): Harvest at mature green, ethylene surge later
 - Non-climacteric (pepper, cucumber, strawberry): Harvest at full ripeness
- Optimal harvest indices:

Tomato Harvest Stages:

- Mature green: Full size, gel formation in locules, distant markets
- Breaker: First color (10%), local markets
- Pink: 30-60% color, immediate consumption
- Full ripe: 90% color, processing

Capsicum Color Development:

- Days from pollination to harvest:
 - Green: 50-65 days
 - Yellow: 65-75 days
 - Red: 75-85 days
 - Orange: 80-90 days

2. Pre-cooling Technologies:

Comparative Analysis of Methods:

Method	Cooling Rate	Product Loss	Capital Cost	Energy Efficiency
Room Cooling	Slow (12-24 hours)	High (5-10%)	Low	Low
Forced Air	Fast (1-2 hours)	Low (1-2%)	Medium	Medium
Hydrocooling	Very fast (10-30 min)	Very low (0.5-1%)	Medium-High	High

Vacuum Cooling Fastest (20-30 min) Moderate (2-3%) High Medium

Hydrocooling Specifications:

- Water temperature: 1-2°C above product freezing point
- Contact time: 10-15 minutes
- Water sanitation: Chlorine 100-150 ppm, pH 6.5-7.5

3. Grading & Sorting Automation:

Optical Sorting Systems:

- Color cameras: RGB plus near-infrared (NIR)
- Resolution: 0.1mm pixel size for defect detection
- Speed: 3-5 fruits/second per lane
- Parameters measured:
 - Size (diameter, length, volume)
 - Color (RGB values, color uniformity)
 - Defects (bruises, cracks, insect damage)
 - Internal quality (NIR for sugar, dry matter)

Size Grades for Export:

Crop Size Grades Diameter/Weight Range

Tomato Extra Large, Large, Medium, Small 67mm, 57-67mm, 47-57mm, <47mm

Capsicum A, B, C (by weight) 200g, 150-200g, 100-150g

Cucumber Class I, Class II 300g, straight, 200-300g

Strawberry Extra, I, II 25g, 18-25g, 12-18g

4. Advanced Packaging Systems:

Modified Atmosphere Packaging (MAP) Design:

- Target atmospheres:

- Tomato: 3-5% O₂, 0% CO₂
- Pepper: 3-5% O₂, 0-5% CO₂
- Cucumber: 3-5% O₂, 0-5% CO₂
- Strawberry: 5-10% O₂, 15-20% CO₂
- Film permeability requirements:
 - OTR (Oxygen Transmission Rate): 500-5000 cc/m²/day at 23°C
 - CO₂TR: 3-5 times OTR for high respiration produce
 - Water vapor transmission: 10-50 g/m²/day

Active Packaging Technologies:

- Ethylene absorbers: KMnO₄-based, 1g/5kg produce
- CO₂ emitters: Ascorbic acid + sodium bicarbonate
- Moisture absorbers: Silica gel, calcium chloride
- Antimicrobial films: Silver nanoparticles, essential oil coatings

5. Storage Engineering:

Controlled Atmosphere (CA) Storage Parameters:

Crop	Temp (°C)	O ₂ (%)	CO ₂ (%)	RH (%)	Storage Life	C ₂ H ₄ Sensitivity
Tomato (MG)	12-13	3-5	0-3	90-95	4-6 weeks	High
Capsicum	7-10	3-5	0-5	95	2-3 weeks	Low-Moderate
Cucumber	10-12	3-5	0-5	95	10-14 days	High
Strawberry	0-0.5	5-10	15-20	95	7-10 days	Low
Melons	7-10	3-5	0-5	90	2-3 weeks	Low

Chilling Injury Management:

- Symptoms: Pitting, water soaking, internal discoloration
- Safe temperatures:
 - Tropical crops: >10°C (cucumber, pepper, tomato)
 - Subtropical: 5-8°C (some melons)
 - Temperate: 0-2°C (strawberry, leafy greens)

- Intermittent warming: 18-20°C for 24 hours every 7 days

6. Transportation Logistics:

Refrigerated Transport Specifications:

- Pre-cooling requirement: Product at storage temp before loading
- Loading patterns:
 - Air flow channels: 5-10% of floor area
 - Stacking height: Based on packaging strength
 - Pallet patterns: Allow 10cm from walls, ceiling
- Temperature monitoring:
 - Data loggers: $\pm 0.5^{\circ}\text{C}$ accuracy
 - GPS integration: Real-time tracking and alerts

7. Quality Assurance Protocols:

HACCP Implementation for Protected Cultivation:

CCP Hazard Critical Limit Monitoring Corrective Action

Harvest Microbial contamination Clean tools, dry harvest Visual inspection

Sanitize, train workers

Pre-cooling Temperature abuse <4 hours to target temp Temperature recording

Adjust cooling rate

Packing Chemical residues MRL compliance Lab testing Reject batch

Storage Temperature fluctuation $\pm 1^{\circ}\text{C}$ of set point Continuous monitoring

Adjust refrigeration

Transport Temperature break <2 hours above limit Data logger review

Investigate cause

8. Value Addition & Processing:

Minimal Processing Options:

- Fresh-cut vegetables: Washed, cut, sanitized, packaged
- Sanitation: Chlorine (100ppm), ozone (2ppm), peracetic acid (80ppm)

- Shelf life: 7-10 days at 4°C
- Dehydrated products: Solar, hot air, freeze drying
- Quality parameters: Rehydration ratio, color retention
- Pickled products: Gherkins, peppers in brine/vinegar
- Fermentation: 2-3% salt, 15-20°C, 3-6 weeks

By-product Utilization:

- Culled produce: Animal feed, composting
- Plant residues: Biochar production, mushroom substrate
- Packaging waste: Recycling programs

Economic Analysis of Post-Harvest System:

Cost-Benefit of Investment in Post-Harvest Infrastructure:

Infrastructure Investment	Loss Reduction	Payback Period	Market Premium	
Basic cold room	₹10-15 lakhs	15-20%	2-3 years	10-15%
Pre-cooling unit	₹5-8 lakhs	10-15%	1-2 years	5-10%
Sorting line	₹15-25 lakhs	5-10%	2-3 years	15-20%
MAP packaging	₹8-12 lakhs	20-30%	3-4 years	20-30%
Complete system	₹50-80 lakhs	30-40%	4-5 years	30-50%

Integration & Systems Approach

The Protected Cultivation Value Chain Optimization:

Key Performance Indicators (KPIs):

1. Productivity: Yield (kg/m²/year), production cycles/year
2. Quality: Grade A percentage, shelf life (days), taste indices
3. Efficiency: Water use efficiency (kg/m³), energy use (kWh/kg)
4. Economic: Cost of production (₹/kg), net returns (₹/m²/year)
5. Sustainability: Carbon footprint (kg CO₂-eq/kg), pesticide reduction (%)

Digital Integration Platform:

- IoT sensors: Climate, soil, plant health monitoring
- Automated controls: Irrigation, climate, nutrient dosing
- Data analytics: Yield prediction, disease forecasting, optimization algorithms
- Blockchain: Traceability from seed to consumer

Future Trends:

1. AI-driven cultivation: Machine learning for optimal climate recipes
2. Robotics: Automated harvesting, pruning, scouting
3. Vertical farming integration: Multi-layer protected cultivation
4. Renewable energy integration: Solar-powered greenhouses
5. Circular economy: Zero waste, water recycling, nutrient recovery

This comprehensive system, when implemented with precision and integration across all five parts, transforms protected cultivation from mere production to a sophisticated, technology-driven enterprise delivering consistent, high-quality produce with maximum resource efficiency and minimal environmental impact.
