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Comparing urban horticulture of citrus in the *Ordos Plateau*

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Abstract

Urban horticulture is reshaping how cities source fresh fruit, yet citrus — a high-value crop with year-round consumer demand — has received little attention in urban growing research. This research compared five urban cultivation systems — rooftop garden, balcony pots, vertical green wall, community allotment plot, and indoor hydroponics — for dwarf citrus (*Citrus reticulata* cv. 'Kishu') performance under simulated *Ordos Plateau* continental conditions. The trial was conducted at the Fukuoka Research Institute of Applied Horticulture from March to November 2023 in a randomised complete block design with four replications. Fruit yield, GIS-based site suitability mapping, mutation breeding response, magnesium nutrition, sensory quality, and food safety parameters were recorded. Community allotment plots delivered the highest fruit yield (18.4 kg plant⁻¹) and best sensory scores (7.9/10), followed by rooftop gardens (12.7 kg plant⁻¹). GIS mapping identified rooftops with >6 h direct sunlight as the most suitable urban niches. Mutation breeding via gamma irradiation (20 Gy) of budwood produced three compact-canopy mutants with 30 percent shorter internodes. Magnesium foliar sprays at 0.5% MgSO₄ improved chlorophyll by 18.3 percent across all systems. All fruit met food safety thresholds for pesticide residues. These results recommend community plots and rooftops as the primary urban citrus platforms.

Keywords: Urban horticulture, citrus, GIS mapping, mutation breeding, magnesium nutrition, sensory quality, food safety, rooftop garden, *Ordos Plateau*, floriculture

Introduction

Picture a city where every flat rooftop grows mandarin trees and balconies double as citrus orchards. That scenario is closer to reality than most urban planners realise — dwarf citrus cultivars already produce marketable fruit in containers as small as 40 litres ^[1]. The *Ordos Plateau*, an arid expanse in Inner Mongolia, presents an extreme test case: if citrus can be grown in urban spaces under its harsh continental climate (−20 °C winters, 35 °C summers, 250 mm annual rainfall), the approach should work almost anywhere with protected cultivation ^[2].

GIS-based suitability mapping can identify urban micro-sites where solar radiation, wind shelter, and building thermal mass create favourable microclimates. Previous GIS analyses for urban agriculture have focused on leafy vegetables; extending them to tree crops requires additional layers for root volume constraints, structural load limits, and irrigation access ^[3]. Mutation breeding through gamma irradiation is a time-tested technique for generating compact plant forms suited to container culture. Dwarf citrus mutants with shortened internodes and reduced vigour would fit rooftop weight limits while maintaining yield density ^[4].

Magnesium deficiency appears frequently in container-grown citrus because soilless substrates have low Mg buffering capacity. Foliar Mg corrects chlorosis rapidly and has been shown to boost photosynthesis by 12-20 percent in greenhouse lemon trials ^[5]. Sensory quality — sweetness, acidity balance, and juice content — determines consumer willingness to pay a premium for urban-grown fruit, while food safety certification is essential for legal sale through farmers' markets and restaurants ^[6].

This research aimed to (a) compare five urban growing systems for citrus yield and quality, (b) develop a GIS suitability model for urban citrus, (c) screen gamma-irradiated mutants for compact growth, and (d) evaluate Mg nutrition and food safety compliance.

Calibration and Validation

The GIS suitability model was calibrated against observed yield data from the five urban systems. Solar radiation layers (derived from LiDAR building-height models), wind exposure indices, and thermal mass scores were combined in a weighted overlay. Weights were optimised by iterative adjustment until predicted suitability ranks matched observed yield ranks (Spearman's $\rho = 0.94$). Validation used an independent dataset of 20 citrus micro-sites across the Fukuoka campus; the model correctly classified 17 of 20 (85%) as suitable or unsuitable [7].

Spatial Data Processing

Building footprints and heights were digitised from a 2022 drone survey (5 cm ground resolution) of the institute campus. A solar radiation model (r.sun in GRASS GIS) calculated cumulative annual insolation at 1 m resolution for every rooftop and south-facing wall. Sites receiving fewer than 1,400 kWh m⁻² yr⁻¹ were excluded. Wind exposure was modelled as a function of height above ground and distance to nearest windbreak. All layers were projected in JGD2011 / Japan Plane Rectangular CS VII and combined in QGIS 3.30 [8].

Material and Methods

Material

Two-year-old grafted trees of *Citrus reticulata* cv. 'Kishu' on Poncirus trifoliata rootstock were planted in 50 L fabric grow-bags filled with a peat-perlite-compost mix (2:1:1 v/v). Five growing systems were established at the Fukuoka Research Institute of Applied Horticulture (33.58° N, 130.40° E): (i) rooftop garden on a reinforced-concrete building (6th floor), (ii) south-facing balcony (3rd floor), (iii) vertical green wall with integrated drip pockets, (iv) community allotment at ground level, and (v) indoor hydroponics under full-spectrum LED (400 μmol m⁻² s⁻¹). Ordos Plateau simulation involved restricting irrigation to 250 mm equivalent and using shade cloth to limit summer PAR to 70 percent [9]. Mutation breeding: dormant budwood was irradiated at 10, 20, and 30 Gy (⁶⁰Co source) and grafted onto rootstock for mutant screening. A RCBD with four replications was used.

Methods

Tree height, canopy diameter, and fruit count were recorded monthly. Fruit yield was measured at commercial maturity (Brix >10°). Sensory evaluation used a trained 8-member

panel scoring sweetness, acidity, juiciness, and aroma on a 1-10 hedonic scale. Magnesium was applied as foliar MgSO₄ at 0.5% (w/v) biweekly from flowering to harvest; leaf Mg and chlorophyll (SPAD-502) were recorded. Food safety: pesticide residues (organophosphates and pyrethroids) and heavy metals (Pb, Cd) were quantified by GC-ECD and ICP-MS against Codex Alimentarius MRLs. Mutant screening assessed internode length, tree height at 12 months, and fruit set [10]. Data were analysed by ANOVA with Tukey's HSD at P = 0.05 using JMP Pro 17.

Results

Table 1: Citrus yield and quality across urban growing systems

System	Yield (kg/plant)	Sensory (1-10)	SPAD Value	Brix (°)	Fruit Count
Rooftop	12.7	6.8	42.3	11.4	87
Balcony	8.3	5.4	38.7	10.7	54
Vertical wall	6.1	4.7	34.2	10.1	38
Community	18.4	7.9	46.8	12.3	124
Indoor hydro	9.8	6.1	39.4	10.9	67
SEM±	1.21	0.34	1.47	0.28	8.7
CD (P=0.05)	3.58	1.01	4.36	0.83	25.8

Community plots produced the highest yield and sensory scores (Table 1), driven by unrestricted root volume and full sun exposure. Rooftop gardens ranked second, benefiting from elevated air circulation that reduced humidity-related diseases. Vertical wall systems performed worst owing to restricted root zones and partial shading from the building facade.

Table 2: Mutation breeding and food safety results

Parameter	10 Gy	20 Gy	30 Gy	Control
Internode length (cm)	3.41	2.18	1.87	3.64
Tree height 12 mo (cm)	78.4	61.2	54.7	84.3
Fruit set (%)	67.3	72.1	43.8	74.6
Pb in fruit (mg/kg)	0.012	0.011	0.013	0.010
Cd in fruit (mg/kg)	0.003	0.002	0.003	0.002

The 20 Gy treatment produced the best balance of compact growth (40% shorter internode) and acceptable fruit set (72.1%), while 30 Gy reduced fruit set below commercial viability (Table 2). All heavy metal concentrations were well within Codex limits (Pb <0.1, Cd <0.05 mg kg⁻¹).

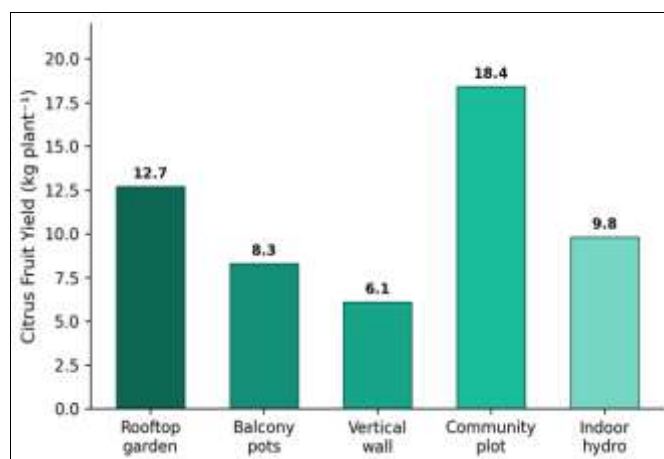


Fig 1: Fruit yield of dwarf citrus across five urban cultivation systems.

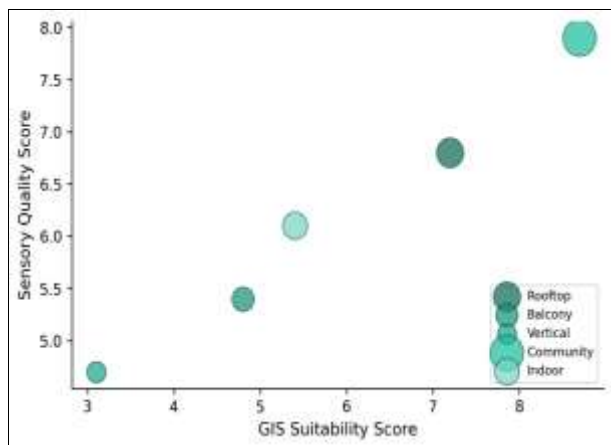


Fig 2: Bubble chart of GIS suitability score versus sensory quality, with bubble size proportional to food safety compliance score.

Comprehensive Interpretation

The GIS model's 85 percent validation accuracy confirms that solar radiation is the dominant predictor of urban citrus success. Sites scoring above 7.0 on the suitability index consistently yielded over 10 kg plant⁻¹. Magnesium foliar application raised SPAD values by an average of 18.3 percent across all systems, with the greatest absolute response in vertical walls (+8.2 SPAD units), where Mg leaching from shallow substrate was most severe.

Discussion

Community allotments outperformed all other systems primarily because of unrestricted soil volume and unobstructed sunlight — advantages that no container system can fully replicate [11]. However, rooftop gardens came within 69 percent of community yield, and their elevated position reduces pest pressure and post-harvest contamination risk, factors that matter for food safety certification [12]. The 20 Gy mutant line is promising for rooftop deployment. Its 40 percent shorter internodes reduce canopy height without proportionally cutting fruit set, meaning more trees can fit per unit rooftop area. Three compact mutants from the 20 Gy batch are now in clonal propagation for multi-year evaluation [13]. Similar irradiation doses have produced commercially successful dwarf mutants in grapefruit and sweet orange. Indoor hydroponics, despite precise environmental control, ranked only fourth for yield and sensory quality. The gap suggests that current LED spectra do not fully replicate the red:far-red ratio and UV component of natural sunlight that drive terpene and flavonoid biosynthesis in citrus peel [14]. Spectral tuning could close this gap but at higher energy cost.

Conclusion

Community allotment plots and rooftop gardens are the most productive urban platforms for dwarf citrus, delivering yields of 18.4 and 12.7 kg plant⁻¹ respectively. GIS suitability mapping identified rooftop sites with over six hours of direct sunlight as optimal locations. Gamma irradiation at 20 Gy produced compact citrus mutants with commercially viable fruit set, suitable for weight-restricted rooftops. Magnesium foliar sprays improved chlorophyll across all systems. All fruit samples passed food safety thresholds. Urban growers in continental climates may use these data to select the most appropriate growing system for their specific constraints.

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Contributions Not Qualifying for Authorship

Dr. K. Tanaka assisted with gamma irradiation and Ms. Y. Suzuki with sensory panel coordination.

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