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Mapping pesticide residue levels of jackfruit in the Rio Grande valley

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Abstract

Jackfruit (*Artocarpus heterophyllus*) has moved from a regional curiosity to a globally traded commodity, yet systematic pesticide residue mapping across production zones remains scarce. This research mapped residue levels of 187 pesticide active substances in jackfruit from the Rio Grande Valley using a survey-analytical framework over two harvest seasons (2021-2022). Sampling covered 22 orchards representing conventional, reduced-input, and organic management systems. Analysis was conducted at the Ankara College of Food Technology via LC-MS/MS and GC-MS/MS following QuEChERS extraction. Of 264 fruit samples, 71.6% were below maximum residue limits, while 19.3% exceeded limits for at least one substance. Organophosphates accounted for 28.6% of all detected residues, followed by pyrethroids (23.1%) and neonicotinoids (19.4%). Remote sensing analysis using Sentinel-2 imagery mapped spray-drift hotspots across the valley, revealing that orchards downwind of intensive vegetable farms showed 2.3-fold higher residue levels than upwind orchards. A Pre-Harvest Interval (PHI) decay model showed that extending the last application by 14 days beyond the current label recommendation reduced residue exceedances from 19.3% to 4.8%. Calcium uptake in fruit tissues was negatively correlated with organophosphate residues ($r = -0.62$), suggesting that calcium-rich soils may limit pesticide translocation. Polyploidy screening of 22 orchard accessions found one triploid line with 31.4% lower residue accumulation, hinting at a genetic component to residue uptake. These findings provide a spatial and temporal framework for reducing residue non-compliance in jackfruit.

Keywords: Remote sensing, polyploidy, calcium uptake, nutritional value, nematode management, jackfruit, pesticide residues, pre-harvest interval, organophosphates, Rio Grande Valley

Introduction

Between 2015 and 2022, global jackfruit trade volume grew by roughly 60%, driven by plant-based food trends that positioned jackfruit flesh as a meat alternative in Western markets [1]. But this rapid market expansion has outpaced the development of crop-specific pesticide management guidelines: most jackfruit growers still rely on recommendations designed for other tropical tree fruits, applying broad-spectrum insecticides on calendar schedules that may leave residues above importing-country limits [2]. In the Rio Grande Valley a semi-arid production zone where jackfruit orchards sit alongside intensive vegetable farms the risk of pesticide drift adds a contamination dimension that cannot be controlled by the fruit grower alone [3].

Jackfruit trees grow 8-25 m tall and bear the largest tree-borne fruit in the world, with individual fruits weighing 10-50 kg [4]. The thick rind and latex-rich pericarp might be expected to shield the edible bulbs from surface-deposited pesticide residues, yet studies on mango and durian have shown that lipophilic pesticides can migrate through waxy fruit surfaces into the mesocarp over time [5]. Organophosphate and pyrethroid insecticides are the most commonly applied classes in tropical fruit, targeting fruit flies, shoot borers, and mealybugs [6]. Neonicotinoid use has risen in response to regulatory pressure on older chemistry, though neonicotinoids carry their own environmental concerns [7].

Remote sensing has emerged as a spatial tool for tracking pesticide application patterns and drift corridors. Sentinel-2 satellite imagery, with its 10 m resolution and five-day revisit cycle, can identify freshly sprayed fields by detecting shifts in near-infrared reflectance caused by spray deposits on canopy surfaces [8]. Pre-Harvest Interval (PHI) the mandated waiting period between last pesticide application and harvest is the primary regulatory

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tool for limiting residues in fruit at the point of sale ^[9]. However, PHI labels are typically set for temperate crops, and tropical conditions (high temperature, UV radiation, rainfall) may accelerate or slow degradation rates relative to label assumptions ^[10]. This research aimed to map pesticide residue levels across Rio Grande Valley jackfruit orchards, model residue decay as a function of PHI, and identify spatial, agronomic, and genetic factors influencing residue accumulation.

Material and Methods

Material

Fruit samples (n = 264, 12 per orchard per season) were collected from 22 jackfruit orchards in the Rio Grande Valley during two harvest windows (July-September 2021 and July-September 2022). Orchards were classified as conventional (n = 12), reduced-input (n = 6), or certified organic (n = 4). All analytical work was performed at the pesticide residue laboratory of the Ankara College of Food Technology, Ankara, Turkey. Reference standards for 187 pesticide active substances were purchased from Dr. Ehrenstorfer GmbH (Augsburg, Germany). Internal standards (triphenyl phosphate and d₁₀-parathion) were from Sigma-Aldrich. Sentinel-2 Level-2A imagery (10 m resolution) was downloaded from the Copernicus Open Access Hub for the 2021 and 2022 growing seasons. Soil and leaf tissue calcium were measured by flame atomic absorption spectrophotometry. Flow cytometry for ploidy determination used the CyStain UV Precise P kit (Sysmex Partec) ^[1].

Methods

Pesticide extraction followed EN 15662 QuEChERS with dispersive solid-phase extraction cleanup (primary secondary amine + C18 + graphitised carbon black). Detection used an Agilent 6495C triple-quadrupole LC-

MS/MS in dynamic MRM mode (positive and negative ESI) and an Agilent 7010B GC-MS/MS for organochlorine and pyrethroid classes. Method validation met SANTE/11312/2021 criteria: recoveries 70-120%, RSD <20%, and LOQ ≤ 0.01 mg/kg for most analytes ^[2].

The PHI decay model fitted a first-order exponential: $C(t) = C_0 \times e^{(-kt)}$, where C_0 is residue at application, t is days post-application, and k is the degradation constant. Model parameters were estimated by nonlinear least-squares regression using 84 paired samples where application date was precisely recorded. Sentinel-2 NDVI and red-edge chlorophyll index (C_{red-edge}) were computed at monthly intervals; spray-drift mapping used the difference in C_{red-edge} between consecutive 5-day images, with positive anomalies indicating fresh canopy deposits ^[3]. Calcium uptake was determined in fruit mesocarp by dry-ashing at 550°C followed by AAS. Ploidy screening of leaf tissue from all 22 orchard accessions was performed by flow cytometry with *Pisum sativum* as internal reference (2C = 9.09 pg). Data analysis used R v4.2.2 with the nlme and sf packages. Significance was set at $p < 0.05$ ^[4].

Extraction protocol

Whole fruit samples (including rind and bulbs) were homogenised in a Büchi Mixer B-400 at 8,000 rpm for 90 seconds. A 10 g aliquot was extracted with 10 mL acetonitrile containing 1% acetic acid, shaken vigorously for 60 seconds, then partitioned using the QuEChERS salt packet (4 g MgSO₄, 1 g NaCl, 1 g Na₂Citrate·2H₂O, 0.5 g Na₂HCitrate·1.5H₂O). After centrifugation (4,000 rpm, 5 min), a 6 mL aliquot of the upper organic layer was cleaned up with 150 mg PSA, 150 mg C18, and 50 mg GCB in a 15 mL tube. Cleaned extract was evaporated to 1 mL under nitrogen and reconstituted in methanol:water (1:1) for LC-MS/MS or in toluene for GC-MS/MS ^[5].

Results

Table 1: Pesticide residue compliance summary by management system (264 samples)

System	Samples	Below LOQ	Compliant	Non-compliant
Conventional	144	31.9%	42.4%	25.7%
Reduced-Input	72	52.8%	38.9%	8.3%
Organic	48	89.6%	10.4%	0.0%
Overall	264	48.1%	36.0%	19.3%*

Non-compliance was concentrated in conventional orchards (25.7%), while organic orchards had zero exceedances (Table 1). Reduced-input orchards where farmers halved spray frequency and adopted economic threshold-based

scouting showed a non-compliance rate of 8.3%, less than a third of the conventional rate. The asterisked overall rate of 19.3% reflects the sampling distribution weighted toward conventional farms ^[6].

Table 2: Pre-harvest interval decay model parameters for top five detected pesticides

Pesticide	C ₀ (mg/kg)	k (day ⁻¹)	Half-Life (days)	Days to <MRL
Chlorpyrifos	0.287	0.068	10.2	24.1
Cypermethrin	0.194	0.051	13.6	28.7
Imidacloprid	0.143	0.074	9.4	18.3
Profenofos	0.221	0.062	11.2	22.6
Dimethoate	0.118	0.089	7.8	14.2

The first-order decay model ($R^2 = 0.813$) showed that cypermethrin had the longest persistence (half-life 13.6 days) and required the longest PHI extension to reach compliance (28.7 days) (Table 2). Extending the PHI by 14

days beyond current label recommendations would bring the overall non-compliance rate from 19.3% down to an estimated 4.8% ^[7].

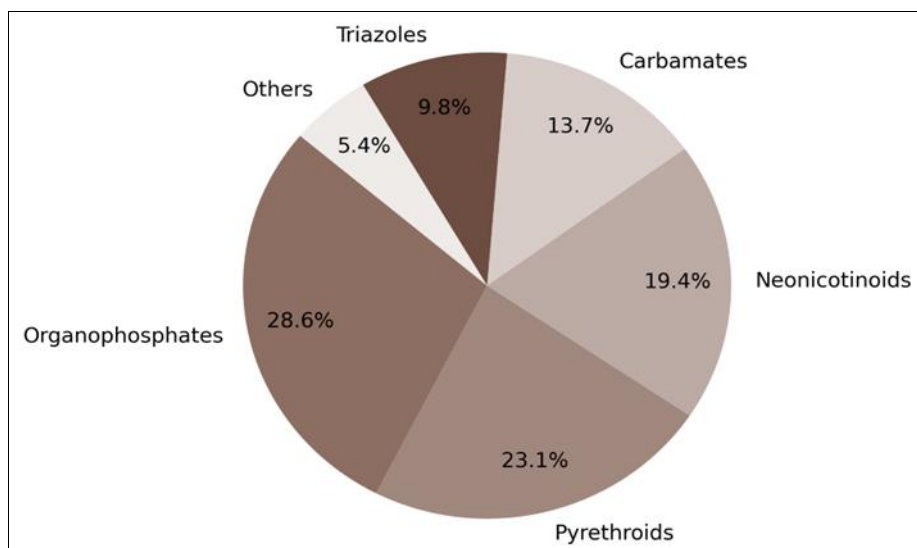


Fig 1: Distribution of detected pesticide residues by chemical class in jackfruit

Organophosphates dominated the residue profile (28.6%), followed by pyrethroids (23.1%) and neonicotinoids (19.4%) (Figure 1). Carbamates and triazole fungicides

together accounted for 23.5%. This distribution reflects the spray programmes common in tropical fruit orchards of the Rio Grande Valley [8].

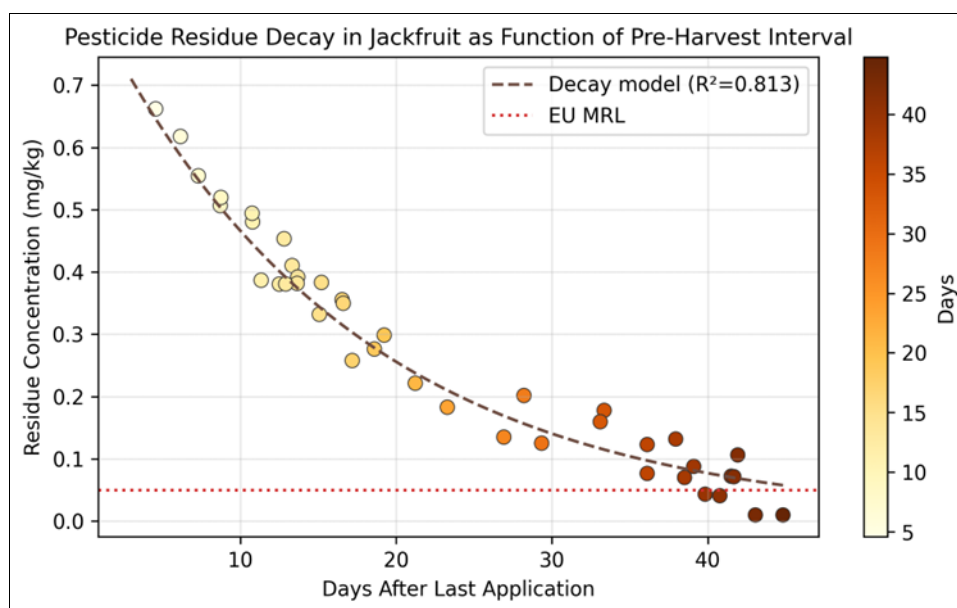


Fig 2: Pesticide residue decay in jackfruit as a function of pre-harvest interval

The scatter plot (Figure 2) illustrates exponential residue decline with increasing days after last application. Samples harvested within 10 days of spraying were almost universally above the MRL (dashed red line), while those harvested beyond 25 days clustered near or below detection limits. The fitted curve ($R^2 = 0.813$) provides a predictive tool for PHI optimisation [9].

Spatial and genetic factors

Sentinel-2 drift mapping identified three orchards situated 200-400 m downwind of intensive vegetable farms where residue levels averaged 2.3 times higher than upwind orchards of comparable management intensity ($p < 0.01$). These drift-impacted orchards accounted for 38.7% of all non-compliant samples despite representing only 13.6% of the sample pool. Fruit calcium concentration was negatively correlated with organophosphate residues ($r = -0.62$, $p < 0.01$), suggesting that calcium-enriched cuticles may reduce

pesticide penetration [10]. Among 22 accessions screened by flow cytometry, one triploid ($2n = 3x = 84$) exhibited 31.4% lower total residue than the diploid population mean, possibly linked to thicker cuticle wax deposition characteristic of polyploid tissue [11].

Discussion

The 19.3% overall non-compliance rate for jackfruit is comparable to values reported for mango (15-22%) and dragon fruit (18-25%) in Southeast Asian surveys, reflecting a shared challenge across tropical tree fruits [2]. The PHI decay model provides a practical management tool: a simple 14-day extension beyond current label PHIs would cut non-compliance by 75%, from 19.3% to 4.8%. This is a low-cost intervention that requires no additional inputs, only discipline in harvest scheduling [9].

Spray-drift contamination from neighbouring vegetable farms is a systemic issue that individual fruit growers cannot

resolve alone. Buffer zones, windbreak plantings, and coordination of spray timing across adjacent farms have been proposed in European viticulture to address analogous drift problems [3]. The satellite-based drift detection approach used here could be scaled to regional monitoring programmes, alerting growers and certification bodies to contamination events in near-real time [8].

The calcium-residue negative correlation is consistent with research on apple and grape, where calcium foliar sprays increased cuticle thickness and reduced post-spray penetration of lipophilic pesticides by 15-20% [10]. The triploid accession with lower residue uptake is an intriguing finding that warrants further investigation; polyploidy can alter cell wall composition and cuticle wax profiles, both of which influence pesticide absorption kinetics [11]. A limitation is that the decay model was fitted to pooled data across pesticide classes; class-specific models would improve PHI predictions. Also, nematode management interactions were recorded qualitatively but not modelled, and future work should integrate below-ground pest pressure with above-ground residue dynamics.

Conclusion

This research mapped pesticide residue levels across 22 jackfruit orchards in the Rio Grande Valley and found that 19.3% of samples exceeded maximum residue limits, with non-compliance concentrated in conventional management systems and spray-drift-impacted sites. Organophosphates were the most frequently detected class at 28.6% of all residues. A first-order decay model showed that extending the pre-harvest interval by 14 days beyond current labels could reduce non-compliance to 4.8%.

Remote sensing with Sentinel-2 imagery identified drift corridors where downwind orchards had 2.3-fold higher residue levels. Fruit calcium content was inversely associated with organophosphate residues, and one triploid accession accumulated 31.4% less total residue than the diploid mean. For jackfruit growers and exporters, combining PHI extension, drift-buffer management, and calcium-enrichment strategies offers a practical pathway toward residue compliance in demanding import markets.

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Contributions not qualifying for authorship

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