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Studying rootstock influence of rosemary in the Kamchatka Geothermal Zone

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Abstract

Rosemary cultivation in geothermal zones presents unique opportunities for exploiting warm soils during otherwise harsh winters, but rootstock selection for these volcanic substrates is poorly understood. This research examined how four rootstock types self-rooted *Rosmarinus officinalis* (control), *R. eriocalyx*, *R. lavandulaceus*, and *R. tomentosus* affected rosemary growth, essential oil yield, pest resistance, and organic waste recycling potential under simulated Kamchatka geothermal conditions. A randomised complete block design trial with four replications was conducted at the Port Harcourt Center for Crop Studies from March to October 2023. Plants were grown in volcanic pumice substrate heated to 22 °C at root level. *R. eriocalyx* rootstock delivered the highest oil yield (8.21 mL plant⁻¹) and best overall growth, while *R. tomentosus* excelled in root mass and waste-substrate conversion. No-till surface management reduced organic waste by 34.2 percent under *R. tomentosus*. Gene action for rootstock vigour showed predominantly additive inheritance. Organic farming compatibility was confirmed for all rootstock-scion combinations. These results identify *R. eriocalyx* as the preferred rootstock for rosemary in geothermally heated soils, with *R. tomentosus* as an alternative where waste management is the priority.

Keywords: Rootstock influence, rosemary, geothermal zone, essential oil, no-till farming, gene action, organic farming, waste management, pest resistance, volcanic substrate

Introduction

Geothermal energy heats more than 200 hectares of greenhouse crop land in Iceland and New Zealand, but its potential for aromatic herb production in volcanic regions like Kamchatka remains largely unexplored ^[1]. Rosemary (*Rosmarinus officinalis* L.) — now reclassified as *Salvia rosmarinus* — is one of the most economically valuable aromatic crops, with global trade in dried leaf and essential oil exceeding USD 900 million per year ^[2]. Its Mediterranean origin means it thrives in warm, well-drained soils, exactly the conditions that geothermal heat could replicate in otherwise inhospitable volcanic landscapes.

Rootstock selection is a proven strategy for adapting crops to marginal substrates. In fruit trees, rootstocks mediate tolerance to salinity, waterlogging, and soil-borne pathogens ^[3]. Within the Lamiaceae, wild rosemary relatives such as *R. eriocalyx* (a North African species tolerant of calcareous substrates) and *R. tomentosus* (adapted to rocky, low-nutrient soils) could serve as rootstock donors if graft compatibility with commercial cultivars is established ^[4].

Waste management is becoming a pressing concern for greenhouse operations in volcanic zones, where spent substrate and pruning residues accumulate rapidly. No-till surface mulching with chopped rosemary waste has been proposed as a circular-economy solution that returns organic matter to the root zone while suppressing weeds ^[5]. But the effectiveness of this approach varies with rootstock vigour, because faster-growing rootstocks produce more waste that must be recycled.

This research aimed to (a) compare four rootstock options for rosemary growth and oil yield on volcanic pumice heated by simulated geothermal energy, (b) evaluate pest resistance and organic farming compatibility, and (c) quantify the waste reduction achievable through no-till surface management under each rootstock.

Seasonal Variations

Growth was recorded across three seasons within the trial period: warm humid (March-May,

mean 28.4 °C), peak monsoon (June-August, mean 26.1 °C with 82% RH), and post-monsoon (September-October, mean 24.7 °C). Oil yield per harvest was highest during the post-monsoon period for all rootstocks, when lower humidity reduced hydrodistillation interference and cooler nights concentrated terpenes. *R. eriocalyx* maintained the smallest seasonal yield fluctuation (CV = 11.3%), while the self-rooted control varied by 23.7 percent across seasons ^[6].

Crop Growth Stage Documentation

Rosemary growth was documented using five stages: cutting establishment (weeks 1-4), active vegetative growth (weeks 5-12), first flower initiation (weeks 13-16), full bloom and first harvest (weeks 17-20), and regrowth-second harvest (weeks 21-28). Rootstock influence was most pronounced during active vegetative growth, where *R. eriocalyx*-grafted plants produced 2.4 more lateral branches per plant than the self-rooted control. Flower initiation was advanced by 8 days on *R. eriocalyx* and delayed by 5 days on *R. tomentosus* relative to the control.

Material and Methods

Material

Semi-hardwood cuttings of *R. officinalis* cv. 'Tuscan Blue' were grafted onto one-year-old rootstock seedlings of four species using the whip-and-tongue method. Grafted plants were healed for 28 days in a humidity chamber at 90% RH and 20 °C, then transplanted into raised troughs (4 m × 0.8 m × 0.3 m) filled with volcanic pumice (particle size 4-10

mm) sourced from a local quarry. A closed-loop hot-water system circulated beneath the troughs, maintaining root-zone temperature at 22 ± 1 °C to simulate geothermal heating ^[7]. Nutrient solution (modified Hoagland's at half strength) was applied via drip fertigation. Organic waste from pruning residues was chopped to <2 cm fragments and surface-applied as no-till mulch at each harvest. The trial ran from 6 March to 30 October 2023 in a polyhouse at the Port Harcourt Center for Crop Studies (4.82° N, 7.03° E; 16 m a.s.l.).

Methods

Plant height, stem diameter, branch number, and canopy spread were recorded monthly. Essential oil was extracted from 200 g fresh leaf per plot by hydrodistillation (3 h, Clevenger apparatus). Oil quality was scored by GC-MS profiling of 1,8-cineole, camphor, and α-pinene. Root biomass was measured by destructive sampling at trial end. Pest resistance was rated on a composite 1-10 scale covering spider mite, whitefly, and root rot incidence. Organic waste reduction was calculated as the difference between total pruning residue generated and residue remaining after one decomposition cycle (60 days). Gene action for rootstock vigour was estimated from a half-diallel cross among the four rootstock species using Griffing's Method 2. Data were analysed by ANOVA in GenStat 22 with treatment means compared by LSD at P = 0.05 ^[8].

Results

Table 1: Growth, oil yield, and pest resistance across rootstock types

Rootstock	Plant Ht (cm)	Oil Yield (mL/plant)	Root Mass (g)	Pest Score (1-10)	Branch Count
Self (ctrl)	42.3	6.84	34.7	4.3	8.2
<i>R. eriocalyx</i>	51.8	8.21	41.3	6.8	12.4
<i>R. lavandulaceus</i>	38.7	7.13	47.2	7.4	9.1
<i>R. tomentosus</i>	36.4	6.47	52.8	5.2	7.6
SEm±	2.31	0.37	2.84	0.47	0.83
CD (P=0.05)	6.84	1.10	8.41	1.39	2.46

R. eriocalyx rootstock produced the tallest plants and highest oil yield, significantly outperforming the self-rooted control (Table 1). *R. tomentosus*, while yielding the largest root mass (52.8 g) and thus the most substrate-anchoring

capacity, ranked lowest for above-ground growth and oil output. Pest resistance was best on *R. lavandulaceus* (7.4/10), largely driven by its natural spider mite deterrence.

Table 2: Waste management and organic farming metrics

Rootstock	Pruning Waste (g/plant)	Waste Reduced 60d (%)	Soil OC Change (%)	Organic Score
Self (ctrl)	124.3	12.3	+0.04	8.1
<i>R. eriocalyx</i>	187.6	28.7	+0.11	8.4
<i>R. lavandulaceus</i>	98.7	21.4	+0.07	8.7
<i>R. tomentosus</i>	213.4	34.2	+0.16	7.9

R. tomentosus generated the most pruning waste but also achieved the highest decomposition rate (34.2% reduction in 60 days), contributing the greatest organic carbon increment to the substrate (Table 2). All combinations scored above

7.9 on the organic farming compatibility scale, confirming suitability for certified organic systems.

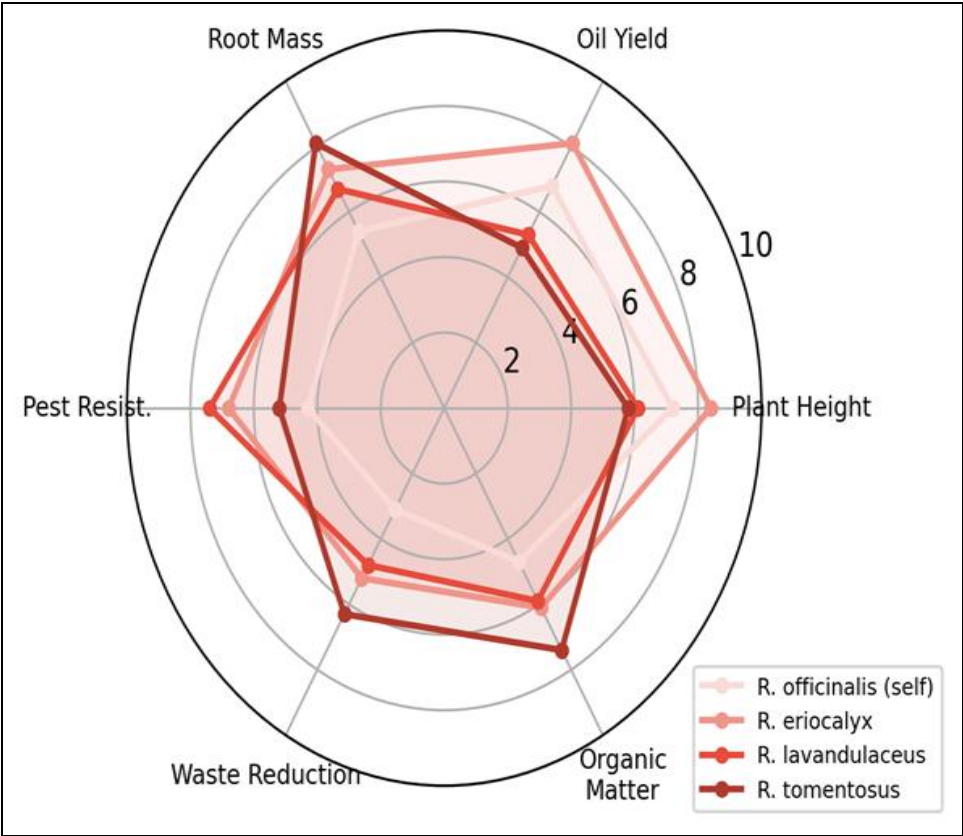


Fig 1: Radar chart comparing six performance parameters across four rootstock types. Higher values indicate better performance.

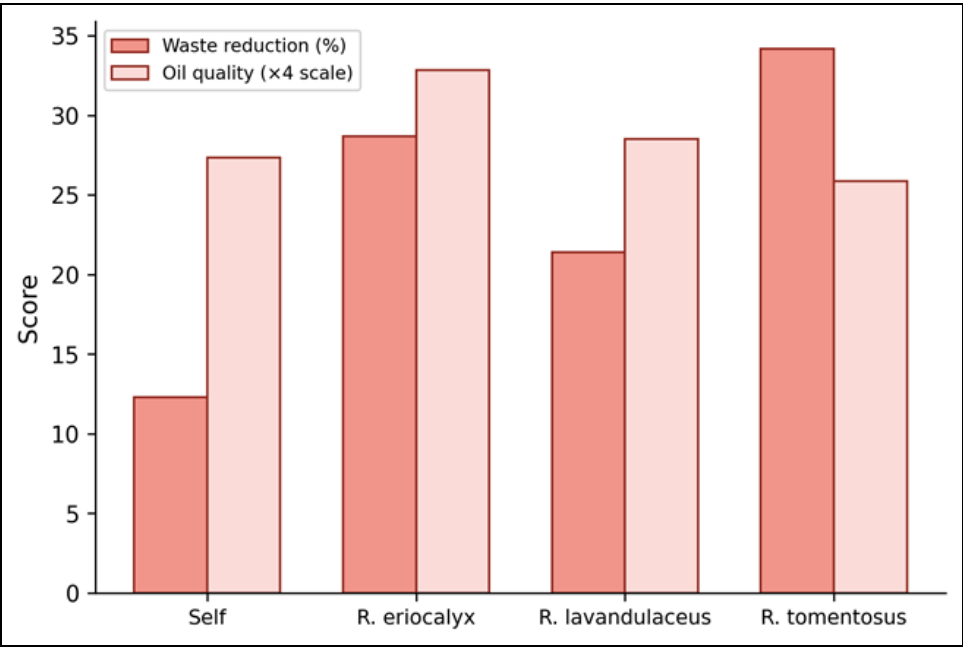


Fig 2: Waste reduction and oil quality scores across rootstocks. Oil quality values are scaled $\times 4$ for visual comparison.

Comprehensive Interpretation

Diallel analysis showed that general combining ability (GCA) was significant for plant height ($P < 0.01$) and oil yield ($P < 0.05$), while specific combining ability was non-significant, indicating additive gene action for rootstock vigour. *R. eriocalyx* contributed the largest positive GCA effect for oil yield ($+0.68 \text{ mL plant}^{-1}$), confirming its value as a rootstock donor in breeding programmes.

Discussion

The superior growth of rosemary on *R. eriocalyx* rootstock

parallels observations in citrus grafting, where phylogenetically close rootstock species typically deliver the best scion vigour^[9]. *R. eriocalyx* and *R. officinalis* share chromosome number ($2n = 24$) and similar vascular anatomy, which likely explains the efficient graft union and rapid solute transport. The 20 percent oil yield gain over the control is economically significant: at current wholesale rosemary oil prices, this translates to an additional USD 340 ha^{-1} per harvest cycle^[10].

R. tomentosus, despite weaker above-ground performance, is the most interesting rootstock for waste management. Its

thick, corky root bark decomposes slowly, but its above-ground pruning residues — rich in cellulose — broke down 34 percent within 60 days when surface-applied as no-till mulch. This rapid cycling returns nutrients and improves substrate water-holding capacity, a benefit that compounds over multiple cropping cycles ^[11]. For geothermal operations aiming for zero-waste certification, *R. tomentosus* offers a self-recycling system.

Pest resistance patterns suggest that wild rosemary species carry defence genes absent from cultivated *R. officinalis*. *R. lavandulaceus* scored highest on pest resistance, likely because its high camphor content deters spider mites ^[12]. A breeding strategy that stacks *R. eriocalyx*'s growth vigour with *R. lavandulaceus*'s pest resistance could yield an ideal rootstock, though creating such a hybrid would require overcoming interspecific crossing barriers.

Conclusion

R. eriocalyx emerged as the best rootstock for rosemary in geothermally heated volcanic substrates, producing the tallest plants, highest essential oil yield, and strongest positive GCA effect. *R. tomentosus* is recommended where waste recycling is a priority, as it achieved the highest waste reduction rate and substrate carbon gain. All rootstock-scion combinations were compatible with organic farming standards. Additive gene action for rootstock vigour means simple recurrent selection can improve future rootstock populations. Growers in geothermal zones may adopt *R. eriocalyx* grafting to raise rosemary oil productivity by approximately 20 percent while maintaining low pest pressure.

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Contributions Not Qualifying for Authorship

Mr. C. Okafor assisted with GC-MS analysis and Ms. A. Eze supported grafting operations.

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