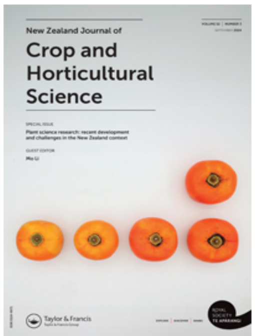

Taylor & Francis
Taylor & Francis Group

New Zealand Journal of Crop and Horticultural Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tnzc20

Comparative evaluation of pumice as a soilless substrate for indoor *Rubus idaeus* L. cultivation

Rui Zhao, Svetla Sofkova-Bobcheva, Donita L. Cartmill, Derrylea Hardy & Anke Zernack

To cite this article: Rui Zhao, Svetla Sofkova-Bobcheva, Donita L. Cartmill, Derrylea Hardy & Anke Zernack (2024) Comparative evaluation of pumice as a soilless substrate for indoor *Rubus idaeus* L. cultivation, New Zealand Journal of Crop and Horticultural Science, 52:3, 280-297, DOI: 10.1080/01140671.2024.2358885

To link to this article: https://doi.org/10.1080/01140671.2024.2358885

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

Published online: 21 Jul 2024.

Submit your article to this journal

Article views: 290

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tnzc20

NEW ZEALAND JOURNAL OF CROP AND HORTICULTURAL SCIENCE
2024, VOL. 52, NO. 3, 280–297
https://doi.org/10.1080/01140671.2024.2358885

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Comparative evaluation of pumice as a soilless substrate for indoor *Rubus idaeus* L. cultivation

Rui Zhao [a], Svetla Sofkova-Bobcheva [a], Donita L. Cartmill[a], Derrylea Hardy[b] and Anke Zernack[a]

[a]School of Agriculture & Environment, Massey University, Palmerston North, New Zealand; [b]School of People, Environment and Planning, Massey University, Palmerston North, New Zealand

ABSTRACT
Pumice is an abundant natural resource in New Zealand and its application in horticulture could save significant costs. To investigate the effect of pumice substrates on raspberry growth and fruit quality, two dwarfing selections (sel.8 and sel.110) were grown hydroponically in (1) coconut coir (control); (2) pumice; (3) pumice/coir (50/50 v/v); (4) pumice/flax (50/50 v/v). Results showed that the addition of pumice to coir significantly increased bulk density, which provided better root anchor support for plants, and also increased the water holding capacity (WHC). Pure pumice had a higher bulk density and lower porosity compared to the other tested substrates, which enhanced fruit quality and yield, although the vegetative growth was slightly lower compared to the control. Mixed pumice/flax substrate had the lowest porosity and poorer WHC, resulting in inferior raspberry growth vigour and productivity. Our results furthermore suggested different substrates could affect the one-year-old cane height, crop yield and fruit characteristics. Pumice was more suitable for sel.8, while the pumice/coir mixture promoted a higher yield for sel.110. In conclusion, pumice and pumice-based mix substrates can be successfully used for hydroponic dwarfing raspberry production without compromising yield and fruit quality.

ARTICLE HISTORY
Received 27 October 2023
Accepted 20 May 2024

HANDLING EDITOR
Mo Li

KEYWORDS
Growing media; hydroponic substrate; pumice; coir; New Zealand flax; harakeke; *Rubus* sp.; vegetative growth; fruit quality; principal component analysis

Introduction

Raspberry (*Rubus idaeus* L.) has been cultivated for nearly 500 years. Currently, raspberries used for processing are mostly cultivated in open fields, while protected hydroponic cultivation often yield higher-quality fruits, which are commonly used for fresh consumption (Stojanov et al. 2019; Balawejder et al. 2023). Compared to traditional planting systems, soilless cultivation reduces the risks associated with the presence of telluric pathogens and replanting, thus driving growers towards hydroponic solutions (Forge et al. 2016). Raspberry soilless systems provide better control of the environment above and below ground, offering greater guarantees of a high quality product

CONTACT Rui Zhao rosianezhao@gmail.com; Svetla Sofkova-Bobcheva S.Sofkova@massey.ac.nz

© 2024 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

(Bignami et al. 2023). The selection of appropriate substrate materials and ratios can have a major impact on the growth and development of greenhouse plants and fruit quality as this provides a stable growing environment that aids root growth and nutrient uptake (Djidonou et al. 2016; Carlen et al. 2019). Coconut coir, a residue of the coconut industry, mainly exported from India and Sri Lanka (Rosairo et al. 2004; Ekambaram and Raja 2014), is widely used in the production of horticultural crops due to its tough structure, suitable properties, excellent hydrophilicity and high biosafety (Blok and Wever 2008; Carlile et al. 2019; Nemati et al. 2021). However, coir gradually decomposes and physically breaks down after a few years of use as a growing medium and subsequently requires responsible disposal or reuse, such as by composting, incineration or as landfill (Lopez-Mondejar et al. 2010; Thomas et al. 2013). To avoid the problem of organic substrate properties changing during the growing process, growers add an inert, stable inorganic component (De Rijck and Schrevens 1998). Pumice, a very porous, lightweight, high-silica, glassy rock produced by explosive volcanic eruptions and found in volcanic areas around the world, has become a good inorganic option for this. However, as the physical properties of pumice vary between volcanic regions and even between different eruptions from the same volcanic centre, the effects of different types of pumice on crop growth need to be taken into consideration (Lenzi et al. 2001; Gizas and Savvas 2007).

In recent years, research into the effects of pumice-based substrates on muskmelons (*Cucumis melo* L.) and tomatoes (*Solanum lycopericum* L.) has demonstrated that pumice significantly enhanced most of the visual and flavour characteristics and total soluble solids content of the fruits (Nishimura et al. 2005; Mitsanis et al. 2021), accelerated flowering, and promoted tomato fruit ripening (Nishimura et al. 2005; Tzortzakis and Economakis 2008). Many studies have also highlighted the advantages of pumice as a substrate for soilless culture in the suppression of pathogens (Nishimura et al. 2005; Van der Gaag and Wever 2005). Furthermore, pumice has been found to support the establishment and antifungal activity of biocontrol agents, making it conducive to disease control (Khalili et al. 2009). These findings collectively indicate that pumice holds significant promise as a substrate for enhancing plant growth and combating pathogens in soilless cultivation systems.

Despite the promising production potential of pumice substrate in soilless culture, its application in raspberry hydroponics is still limited. The central North Island of New Zealand holds abundant pumice resources produced by large caldera-forming eruptions in the Taupō Volcanic Zone over the past 2 million years (Wilson et al. 1995, 2009; Barker et al. 2021). Utilising pumice as an alternative to traditional organic substrates such as coir in soilless culture can significantly reduce production costs arising from purchased and transported materials as well as eliminate supply chain issues associated with importing substrates from overseas. This application has the potential to reduce the carbon footprint and make soilless cultivation more sustainable in New Zealand. Further research is essential to determine the feasibility and benefits of incorporating pumice into soilless cultivation practices for raspberries, thus promoting more efficient and cost-effective horticultural production in the country.

Flax (*Phormium tenax*), commonly known as New Zealand flax or harakeke in Māori, is a species of perennial plant native to New Zealand that was also used as a substrate in this experiment. Flaxes are often used as visually appealing decorative plants in landscaping due to their distinctive long leaves. Additionally, the tough fibres of New Zealand flax can be used to produce rope, woven fabrics or traditional Māori clothing (Joness 2003; Brown 2016). Recently, it has also shown great advantages in reinforcing the properties of composites and multiple uses for flax cellulose (Di Giorgio et al. 2020; Sivasubramanian et al. 2021).

This study was focused on investigating the physical properties of pumice (grade 1–7 mm) and pumice mixed substrates, and comparing the growth vigour and productivity of raspberries grown in the different test substrates. By exploring the production potential of pumice, the results provide recommendations for future substrate development, and offer innovative, environmentally friendly, and cost-saving methods for New Zealand's horticultural systems.

Methods and materials

Experiment setup

Experiments were conducted in a tunnel greenhouse with side and end ventilation at Massey University Plant Growth Unit, Palmerston North, New Zealand, from October 2022 to April 2023. We used primocane-fruiting raspberry canes of two dwarfing raspberry selections labelled as Sel.8 and Sel.110, supplied by Whenua Fruit Limited as experimental material, and the same hydroponic nutrient solution as Whenua Fruits' operations (Level 3 Custom Bathed Nutrition, System Specific, Pure Hydroponics, Rotorua, NZ). The experimental greenhouse was covered with polyethylene plastic film (VisQueen Lumisol Clear Polythene, 180 μm, bpi.visqueen, Rushden, UK) and was tunnel-shaped with sidewall (base) vents that allow good airflow of fresh air. The average maximum and minimum aerial greenhouse temperatures during the test were 38°C and 11°C, respectively. Coconut coir (crush grade, Daltons, Matamata, NZ), 85°C heat sterilised pumice (1–7 mm, Industrial Processors, Ltd., Auckland, NZ), and dried flax fibre (wild source collected near Rotorua, NZ) cut into 2–5 cm-long pieces were used to create four treatments: (1) coir (control), (2) pure pumice (grade 1–7 mm), (3) pumice/flax (V/V 50/50), and (4) pumice/coir (V/V 50/50). Plants were irrigated with a nutrient solution with an EC of 0.8 $mS{\cdot}cm^{-1}$ and a pH of 5.8 during establishment. The laterals and existing substrates were removed as much as possible during the transplanting. The plants were transplanted into 8L containers filled with substrate on 21st Nov. For the experiment, nutrient supply will be dissolved. We used a solution with EC of 1.0 $mS{\cdot}cm^{-1}$ and pH of 5.8 was used for irrigation during the vegetative growth period and a solution with EC of 2.2 $mS{\cdot}cm^{-1}$ and pH of 5.6 for irrigation during the fruiting period. An electronic pump was used to drip irrigate the nutrient solution at regular intervals. Fertiliser was supplied for three minutes every three hours between 6AM and 6PM ($500ml{\cdot}day^{-1}{\cdot}plant^{-1}$). The plants in different substrate treatments were randomised and supplied with nutrients by a drain-to-waste drip irrigation system with the excess nutrient solution drained off and not reused. Each substrate treatment contained 17 plants of sel.8 (total of 68 plants) and 8 plants of sel.110 (total of 32 plants) with each plant as a single replicate. The plants were arranged in 4 bays within the greenhouse (90 m^2) where spacing between plants in each bay was 25 cm and the spacing between the bays was 40 cm with a 100 cm center.

Measurements

Measurements of the physical properties of the substrate were taken with reference to Gessert (1976) and the European Committee for Standardization (2002). Each parameter had three replications (n = 3) per substrate treatment. The cane height (cm), cane diameter (mm), and number of new canes of raspberry plants were measured from the first week up until the 20th week after transplanting. The SPAD was measured with the OPTI-SCIENCES CCM-200plus Chlorophyll Content Meter. The samples were similarly aged, fully expanded leaves and were measured at the same time of the week. Leaves were also collected and measured for fresh weight and dried at 60°C for 24 hours to measure dry weight for leaf dry matter content (%). The measurements were repeated twice for each container. Throughout the fruiting period (27th February 2023 to 17th April 2023), fruits were harvested three times a week. The number and weight of ripe fruits was counted, including broken and overripe fruits, which were recorded as total harvested fruit number and total yield. The weights of all fruits, except for broken, incomplete fruits, was determined and the average fruit weight (g) was calculated. The average number of fruits per raspberry plant was multiplied by the average fruit weight to estimate bulk fruit weight (g). Estimated yield ($kg{\cdot}ha^{-1}$) was calculated based on the area occupied by each raspberry plant (40cm × 25 cm). Crop load was calculated using fruit number and cane diameter, expressed as the number of fruits per unit cane cross-sectional area ($fruit/cm^2$).

Raspberry fruit dimensions and size (fruit diameter, fruit height, fruit shape index, fresh weight per fruit), were calculated by measuring 50 fruits per treatment from different fruiting periods. For fruit quality parameters, 25 fruits from each treatment of the different selections were individually measured. The dry matter was measured by placing the fruits in 60°C oven and dried for 24 hours. The ratio of the dry weight of the fruit to the fresh weight is the dry matter content of the fruits (%). The total soluble solids (TSS) were measured on ground raspberry juice using a digital hand-held pocket refractometer (Model IC-PAL-1, ATAGO CO., Ltd., Tokyo, Japan). Fruit colour was measured using a spectrophotometer (Model cm-700d, Konica Minolta, Inc., Tokyo, Japan). The illumination angle of the instrument was 0°, viewing angle 45° and a standard white calibrated reflector was used. Data were recorded as L* (lightness), C* (chroma), and h° (hue angle). Firmness measurements were taken with reference to Haffner et al. (2002) using a TA-XT Texture Analyser (Texture Technologies, Massachusetts, USA). Each raspberry sample was placed vertically on the bench and the firmness of the fruit was measured using a circular probe. The test mode was selected as compression, the test speed was set to 12 $mm{\cdot}sec^{-1}$ and the compression distance was set to 10 mm. Fruits were juiced and the titratable acid (TA) was measured by electronic titrator (Hanna HI-932-C2-02 Automatic Potentiometric Titration System, Hanna Instruments, Rhode Island, USA). Five fruits were mixed and ground to get a drop of pure juice, and the electronic titrator automatically displayed titration end point. Buffer solutions of pH 4 and pH 7 were used for calibration. After measuring the titratable acid content, the remaining juice was used to measure the Brix using a refractometer and the Brix/acid ratio of individual raspberries was obtained from the ratio of the two to estimate the raspberry flavour.

Statistical analysis

Data were tested for normality, and then subjected to nonparametric test. The Tukey's multiple comparison was applied for the analysis ($p < 0.05$). A generalised linear mixed-effects model (GLIMMIX procedure) was applied to fit the plant height or stem diameter over weeks followed by a Poisson distribution and log function after the model. A generalised linear mixed-effects model was also used to analyse the effects of selection, treatment and their interaction on fruit quality parameters. The significance of the difference in the slopes of the plant growth curves in the lower and upper limits of the 95% confidence intervals (CLs) was analysed. Principal component analysis and comprehensive evaluation were completed using the method of Tian et al. (2015). The data was first standardised and a matrix of correlation coefficients was constructed. The eigenvalues and eigenvectors were then calculated, and the composite score was computed (Tian et al. 2015). Statistical analyses were performed using the IBM SPSS Statistics (SPSS Inc., Chicago, USA).

Results

Substrate properties

The physical properties of substrates have been shown to affect crop growth, water utilisation and disease incidence (Gabriel et al. 2009). Bulk density ($g{\cdot}cm^{-3}$), porosity (%) and water holding capacity (WHC %) are three measurable variables that can be used to evaluate moisture and oxygen supply, and are often applied to assess the quality of the substrate. Bulk density facilitates the development and expansion of the plant root system. Mixing pumice with other organic substrates reduced its bulk density to some extent (Table 1). The volume of pore space in the medium is a key physical property that influences water and nutrient uptake and gas exchange in the root system (Sahin et al. 2002). Percentage and distribution of the pore determine the ability of substrate to contain moisture and oxygen, thus the porosity affects the nutrient uptake and gas exchange of the root system (Nerlich et al. 2022). In the experiments, coconut coir had the highest porosity of 66.1%, promoting better air exchange in the root zone. However, the addition of pumice to coir reduced the porosity to 58%. Pure pumice and mixed flax/pumice were less porous, suggesting a lower ability to supply air to the plant root system, and being more restrictive to root expansion. Water holding capacity (WHC) is the amount of moisture that can be held in the substrate and reflects the capacity to retain water (Nerlich et al. 2022). It is interesting to note that the two mixed substrates had the highest and lowest WHC (Table 1). The mixed coir/pumice had the highest WHC value which was 22.6%, while that of mixed flax/pumice was only 11%. The WHC of pure pumice was 15.5%. Thus, it can be inferred that coir has

Table 1. Physical properties of four substrate types (Showed as Mean ± SEM, n = 4).

Substrate	Bulk density ($g{\cdot}cm^{-3}$)	Porosity (%)	Water Holding Capacity (%)
Coconut Coir (Control)	0.446 ± 0.024	66.05% ± 0.99%	18.31% ± 0.4%
Pumice	0.993 ± 0.04	45.03% ± 0.79%	15.49% ± 0.31%
Flax + Pumice	0.87 ± 0.027	49.53% ± 1.23%	10.95% ± 0.49%
Coconut Coir + Pumice	0.764 ± 0.012	57.95% ± 0.49%	22.55% ± 0.44%

an improving effect on the water holding capacity of pumice, whereas flax does not have such a positive effect.

Plant vegetative growth

The one-year-old cane height of sel.8 and sel.110 were recorded weekly over a period of 20 weeks (Figure 1, Table 2), and the height of the canes increased relatively slowly during the first four weeks after transplanting (21 November–12 December, 2022), as well as after week 15 (27 February, 2023, fruiting stage). For sel.8, plants grown in these two substrates grew significantly faster in height than those grown in pure pumice. In Figure 2 and Table 3, the regression equations for the change in cane diameter in the four substrates were shown for both raspberry selections. For sel.8, the slope of the cane diameter equation was greater for the plants grown in mixed coir/pumice. The plants grown in pure pumice showed the lowest value for the diameter growth equation slope.

The number of secondary laterals in each raspberry plant was counted every two weeks and the number of new laterals per week was counted (laterals/week). The results (Table 4) indicated that all raspberries grew 0.1–0.2 new laterals per week in the containers, which implies that each raspberry would add an average of 1 lateral

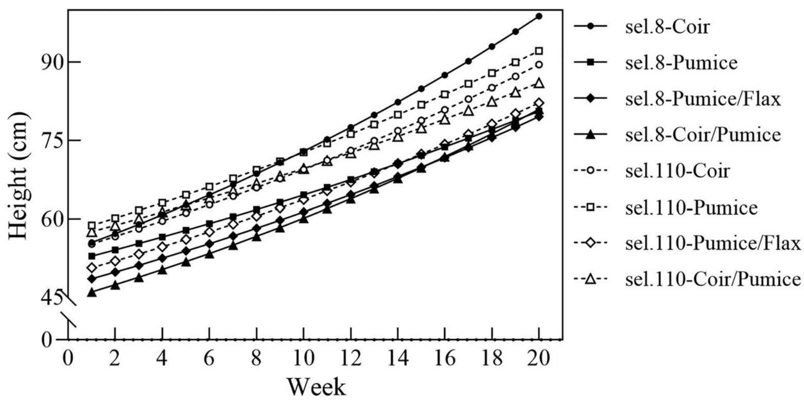

Figure 1. Regression curves of growth rate over time based on the average cane height (mm) of sel.8 and sel.110 in four substrates.

Table 2. Estimated regression equation of plant growth per week (W) based on plant height (cm).

Selection	Treatment	Link Function	Model equation	n	F
sel.8	Coir (Ctrl)	Log	$H = e\wedge(0.02935W + 3.9863)$ [a]	340	593.84
	Pumice	Log	$H = e\wedge(0.02314W + 3.9469)$ [b]	340	399.04
	Pumice/Flax	Log	$H = e\wedge(0.02576W + 3.8568)$ [ab]	340	464.17
	Coir/Pumice	Log	$H = e\wedge(0.02871W + 3.7166)$ [a]	340	516.53
sel.110	Coir (Ctrl)	Log	$H = e\wedge(0.02543W + 3.9863)$ [a]	160	241.38
	Pumice	Log	$H = e\wedge(0.02369W + 4.1085)$ [a]	160	232.57
	Pumice/Flax	Log	$H = e\wedge(0.02548W + 3.8631)$ [a]	160	214.47
	Coir/Pumice	Log	$H = e\wedge(0.02116W + 4.032)$ [a]	160	167.42

n: Number of observations used.
The slopes of regression lines were compared according the 95% CLs.

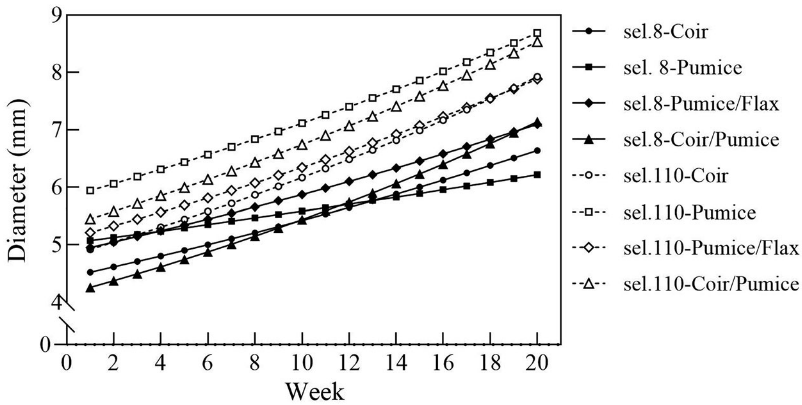

Figure 2. Regression curves of growth rate over time based on the average cane diameter (cm) of sel.8 and sel.110 in four substrates.

per container in 5–10 weeks. For sel.8, plants grown in pure pumice had significantly greater lateral formation when compared to plants grown in mixed pumice and flax. A similar trend can be seen for sel.110. Plants in pure pumice and mixed coir/pumice were similar in their performance, with approximately 0.181 new laterals growing per week and significantly greater than mixed pumice/flax. There were no significant differences between the other treatments. Therefore, it can be assumed that flax inhibited the occurrence of new laterals to a certain extent.

Table 3. Estimated regression equation of plant growth per week (W) based on cane diameter (mm).

Selection	Treatment	Link Function	Model equation	n	F
sel.8	Coir (Control)	Log	D = e^(0.02022W + 1.4889) [a]	644	52.61
	Pumice	Log	D = e^(0.01771W + 1.613) [a]	662	42.7
	Pumice/Flax	Log	D = e^(0.01894W + 1.5811) [a]	680	48.38
	Coir/Pumice	Log	D = e^(0.02623W + 1.4211) [a]	649	89.8
sel.110	Coir (Control)	Log	D = e^(0.02406W + 1.5687) [a]	298	36.64
	Pumice	Log	D = e^(0.02098W + 1.7622) [a]	320	28.16
	Pumice/Flax	Log	D = e^(0.02177W + 1.6298) [a]	303	28.02
	Coir/Pumice	Log	D = e^(0.0236W + 1.6724) [a]	320	36.51

n: Number of observations used.
The slopes of regression lines were compared according the 95% CLs.

Table 4. Lateral formation of two raspberry selections in four substrates.

Selection	Treatment	Lateral formation (Laterals/Week)
sel.8	Coir (Control)	0.147 [ab]
	Pumice	0.168 [a]
	Pumice/Flax	0.126 [b]
	Coir/Pumice	0.153 [ab]
sel.110	Coir (Control)	0.175 [ab]
	Pumice	0.181 [a]
	Pumice/Flax	0.119 [b]
	Coir/Pumice	0.181 [a]

Tukey HSD multiple comparison method was applied for the analysis, and different letter were used to represent significant differences ($p < 0.05$).

Yield

Both selections performed well in pure pumice and control (coir) over the fruiting period (Table 5). The sel.8 plants grown in pumice gave the highest amount of harvestable fruit, bulk fruit weight, and estimated yield, and yielding nearly three times the number of fruits grown in coir/pumice. In contrast, plants grown in mixed pumice/flax were inferior to the control in all yield indicators. Sel.110 also produced the highest number of harvestable fruits in pumice, but due to smaller fruit weights, it did not yield more than the control (coir) and mixed coir/pumice treatment. It was inferred that this was due to the excessive crop load, which is in line with past findings that excessive crop load will come at the expense of fruit size and yield (Delić et al. 2021). In addition, plants of both selections grown in mixed pumice/flax showed smaller fruit size and lower total yield compared to the control.

Correlation analysis

Correlations between vegetative growth parameters and yield were used compared to infer factors affecting yield as well as to explore cultivation management for improved economic efficiency (Figure 3). Plant height and lateral formation were significantly and positively correlated ($p < 0.05$) with the number of fruits per plant, bulk fruit weight and estimated yield. This is similar to the experimental results of Sønsteby et al. (2009), which proved that there is a correlation between plant height and production, thus promoting growth in plant height can increase yield. Our results also illustrate that plants with high lateral formation possess greater productivity.

In addition, as expected, higher crop load had a highly significant negative correlation ($p < 0.01$) with individual fruit fresh weight and a significant positive correlation ($p < 0.05$) with the number of fruits per plant. Therefore, proper regulation of raspberry crop load is helpful in maximising yield. Currently, it is a common practice in some European raspberry productions to retain a large number of laterals to increase raspberry yield without considering the quality of retained flower buds, their position on the canes or their biological potential (Životić et al. 2019). Raspberries grown in a hedgerow system and kept with 80, 100 and 120 well-developed and well-positioned mixed buds per metre

Table 5. Total number of harvested fruits, bulk fruit weight (g), plant crop load of cane cross section and estimated yield (kg·ha^{-1}) of two raspberry selections, sel.8 (n = 17) and sel.110 (n = 8). Data were bulk collected during the fruiting period, from 27 February to 14 April.

Selection	Treatment	Total Harvested Fruit Number	Bulk fruit weight* (g)	Crop Load** (Fruit·cm^{-2})	Estimated Yield*** (kg·ha^{-1})
sel.8	Coir (Ctrl)	268	86.47	6.9	7771.5
	Pumice	325	119.7	7.2	9527.1
	Pumice/Flax	184	65.47	4.17	5763.9
	Coir/Pumice	119	43.24	5.71	3517.92
sel.110	Coir (Ctrl)	313	137.81	8.19	14233.3
	Pumice	324	127.03	9.48	12387.9
	Pumice/Flax	125	71.4	8.30	5460.9
	Coir/Pumice	291	176.4	7.97	14969.7

*Bulk yield: average fruit weight × total fruit number / plant number.
**Crop load: fruit number per plant / cane cross-sectional area.
***Estimated yield: (1 ha × yield per plant) / area of single plant.

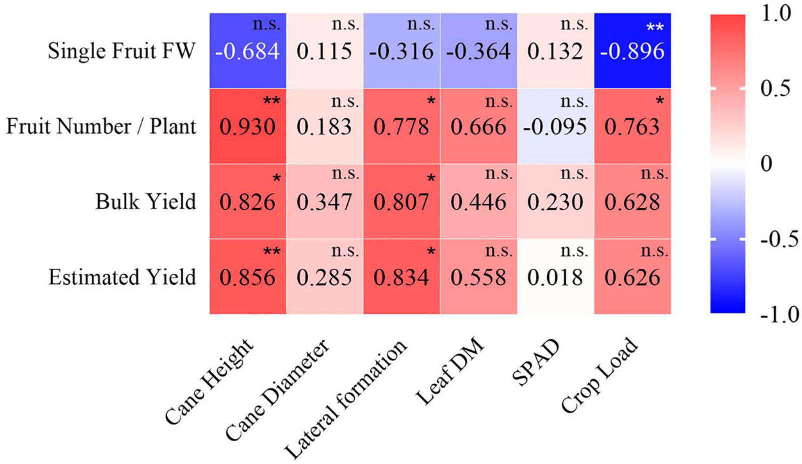

Figure 3. Pearson's correlation analysis of vegetative growth and productivity parameters in raspberry plants. * and ** represent significant correlations at the $p < 0.05$ and $p < 0.01$ levels, respectively (two-tailed). n.s. denotes not significant.

of hedge have been studied, and the findings point to high and stable yields recorded at a moderate load of 100 buds per metre (Životić et al. 2019). Current research on berry crop load is mainly focused on grapes (Helwi et al. 2021; Previtali et al. 2021), and information on raspberries is still limited. As we used dwarfing selections were used in this experiment, so appropriate loads need to be further investigated.

Fruit quality

For sel.8, substrate changes did not significantly affect fruit size and individual fruit weight (Table 6). But the fruit shape index (FSI) of the fruit grown in coir/pumice was significantly lower than that of the control (coir) and pure pumice, suggesting that the width of the raspberry is more prominent compared to its length, giving it a closer to a transversely elliptical or flattened form (Figure 4). For the fruits of sel.110, significant differences in the appearance were found between the four substrates. The fruits from the plants grown in the control (coir) and mixed coir/pumice substrates had significant larger fruit size and single fruit FW. The FSI of the fruits in control substrate was significantly larger than that of the mixed pumice/flax grown plants, which indicates a slender or more vertically elongated fruit shape (Figure 4). The simple and reciprocal effects of the treatment and the selection demonstrated by the generalised linear model, highlighted highly significant differences ($p < 0.01$) in all four morphological parameters between the two selections, i.e. fruit dimensions and individual weight were significantly larger in sel.8 than those in sel.110. There was also a significant interaction effect ($p <$ 0.05) between selections and treatments.

For nutritional and sensory parameters of sel.8 fruits, planting in pumice resulted in a significant increase in fruit TSS by 2% and DM content by 6% compared to the control. In contrast, planting in mixed pumice/flax significantly reduced fruit TA by 0.9 g/mL and hardness by 0.06 N/mm. Although reduced acidity increased fruit sweetness, previous

Table 6. The fruit dimension (mm), fruit shape index (FSI) and average weight of a single fruit FW (g) of two raspberry selections under four treatments. Shown as mean ± SEM.

Selection	Treatment	Fruit Diameter (mm)	Fruit Height (mm)	FSI	FW / Fruit (g)	TSS (%)	TA (g/mL)	DM (%)	Firmness (N/mm)	L*	C*	h°
sel.8	Coir (Ctrl)	22.51 ± 0.36^{b}	23.08 ± 0.36^{a}	1.03 ± 0.012^{a}	4.936 ± 0.143^{a}	8.09% ±0.23%^{b}	2.47 ± 0.09^{a}	12.16% ±0.06%^{c}	0.2576 ± 0.014^{a}	29.54 ± 0.45^{a}	17.08 ± 0.69^{a}	16.07 ± 0.37^{ab}
	Pumice	23.79 ± 0.3^{a}	24.18 ± 0.34^{a}	1.025 ± 0.02^{a}	4.977 ± 0.148^{a}	10.25% ±0.33%^{a}	2.21 ± 0.07^{ab}	18.28% ±0.59%^{a}	0.2373 ± 0.012^{ab}	28.38 ± 0.23^{ab}	15.1 ± 0.66^{ab}	14.73 ± 0.56^{b}
	Pumice/Flax	24.13 ± 0.19^{a}	23.99 ± 0.38^{a}	0.994 ± 0.014^{ab}	5.332 ± 0.13^{a}	8.24% ±0.23%^{b}	2.37 ± 0.09^{a}	15.48% ±0.72%^{b}	0.2343 ± 0.015^{ab}	27.71 ± 0.48^{b}	13.9 ± 0.56^{b}	11.72 ± 1.0^{c}
	Coir/Pumice	24.09 ± 0.3^{a}	23.03 ± 0.46^{a}	0.957 ± 0.018^{b}	5.026 ± 0.167^{a}	8.36% ±0.26%^{b}	1.96 ± 0.07^{b}	17.03% ±0.62%^{ab}	0.1972 ± 0.008^{b}	25.18 ± 0.27^{c}	13.8 ± 0.47^{b}	17.09 ± 0.53^{a}
sel.110	Coir (Ctrl)	20.38 ± 0.24^{a}	21.76 ± 0.29^{a}	1.07 ± 0.013^{a}	3.637 ± 0.104^{ab}	9.22% ±0.19%^{ab}	1.96 ± 0.06^{b}	15.43% ±0.74%^{ab}	0.2759 ± 0.019^{a}	28.81 ± 0.41^{b}	19.44 ± 0.74^{a}	16.99 ± 0.46^{b}
	Pumice	19.09 ± 0.35^{b}	20.17 ± 0.51^{b}	1.055 ± 0.016^{ab}	3.058 ± 0.151^{c}	9.0% ±0.22%^{ab}	2.24 ± 0.08^{ab}	17.17% ±0.41%^{a}	0.288 ± 0.019^{a}	29.66 ± 0.47^{ab}	21.33 ± 0.64^{a}	19.04 ± 0.49^{a}
	Pumice/Flax	20.04 ± 0.29^{ab}	20.17 ± 0.37^{b}	1.008 ± 0.014^{b}	3.497 ± 0.134^{bc}	8.59% ±0.14%^{b}	2.41 ± 0.08^{a}	13.41% ±0.66%^{b}	0.2748 ± 0.02^{a}	29.17 ± 0.33^{b}	20.21 ± 0.54^{a}	16.73 ± 0.51^{b}
	Coir/Pumice	21.07 ± 0.38^{a}	22.16 ± 0.41^{a}	1.058 ± 0.016^{ab}	4.108 ± 0.148^{a}	9.36% ±0.23%^{a}	2.20 ± 0.08^{ab}	18.40% ±0.61%^{a}	0.2503 ± 0.012^{a}	30.96 ± 0.60^{a}	19.82 ± 0.66^{a}	19.09 ± 0.42^{a}
Significance												
p(Selection)		0.000**	0.000**	<0.001**	0.000**	0.037*	0.341^{NS}	0.724^{NS}	<0.001**	<0.001**	0.000**	<0.001**
p(Treatment)		<0.001**	0.412^{NS}	0.003**	<0.001**	<0.001**	<0.001**	<0.001**	0.005**	0.013*	0.01*	<0.001**
p(Selection* Treatment)		<0.001**	<0.001**	0.03*	<0.001**	<0.001**	<0.001**	<0.001**	0.003**	<0.001**	<0.001**	0.024*

Tukey HSD multiple comparison method was applied for the analysis, and different letters were used to represent significant differences ($P < 0.05$).
Generalised linear mixed-effects model was used to analyse the effects of selection, treatment and their interaction. **, * and ^{NS} denote significant differences at the 0.01, 0.05 levels and non-significant difference, respectively.

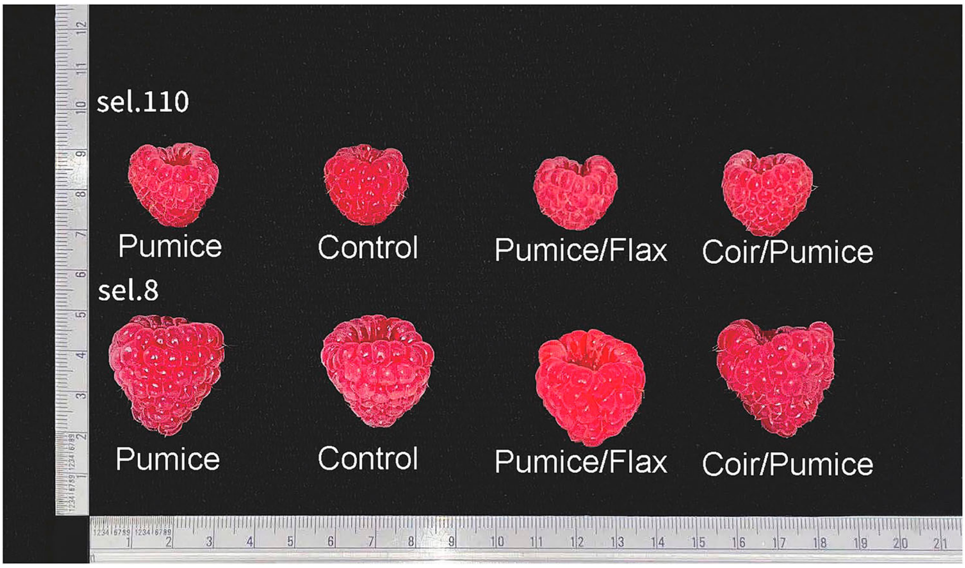

Figure 4. Fruit size and shape of sel.8 and sel.110 grown in four substrates (Control = Coconut coir). Photo was taken on 19 March 2023, with fruit selected for harvest maturity and representative traits for each treatment.

studies have shown that acidity inhibits the growth of some microorganisms and reduces the risk of fruit spoilage, so higher acidity may enhance the antimicrobial properties of fruit and prolong fruit freshness (Cushnie and Lamb 2011; Ousaaid et al. 2021). Besides, fruit grown in both mixed substrates (pumice/flax, coir/pumice) had significantly lower L* and C* values than the control, suggesting lower saturation and vibrancy. Fruit in pumice/flax had significantly lower h° values than control (coir), indicating that the addition of flax to the coir produced redder fruits.

As for the fruits of sel.110, fruit grown in pumice/flax had significantly lower TSS and DM content than fruit grown in coir/pumice, but significantly higher TA content than the control. Firmness of sel.110 fruit did not differ among the treatments. Additionally, the fruits in control and pumice/flax had significantly lower L* and h°, indicating lower brightness and redder colour. However, there were no significant differences between treatments in C* values. Mitsanis et al. (2021) demonstrated that pumice significantly enhanced most of the visual and flavour properties of tomato. This is consistent with the results obtained in this experiment. In addition, fruits with different appearances can be used in different markets. Graham et al. (2007) had demonstrated, larger and brighter fruits are more suitable for fresh marketing. Whereas processed fruits are more sought after for their intense colour and flavour. Therefore sel.8 and sel.110 can be recommended for fresh market and processing, respectively.

Different gene combinations and genetic characteristics of selections directly influence the quality of the fruits (Agrawal 2005). By analysing the quality differences between the two raspberry selections, it was found that the differences in TA and DM content did not reach a significant level ($p > 0.05$). There was a significant difference in TSS content ($p < 0.05$), where it was greater in sel.110 compared to sel.8, and there was a highly significant difference in firmness and L*, C* and h° ($p < 0.01$), where sel.110 had greater firmness, glossiness and brightness comparted to sel.8 while sel.8 was redder in colour. In addition, a highly significant interaction effect ($p < 0.01$) was found for all quality parameters across treatments and selections.

Principal component analysis

Principal Component Analysis (PCA) was performed on 11 quality indicators of raspberries, and three principal components were selected based on the criterion that the cumulative contribution was greater than 85%. Figure 5 shows the proportion of single variance and cumulative contribution rate of each variance. The eigenvalue of three principal components is 5.971, 2.473 and 1.239, and the cumulative contribution rate of the first three components reached 88.024%, which represents the majority of biological information for the 11 quality indicators tested. Each principal component is a linear combination of the original data.

The first principal component reached 54.284%. Among the eigenvectors of the component, the characters with higher eigenvectors are fruit diameter, height and single fruit FW (Figure 6). The biological information this reveals suggests that there is a highly significant positive correlation between these three fruit traits, indicating that the larger the fruit size, the heavier the weight of the individual fruit and the higher the yield. These parameters can be termed as yield factors. The contribution rate of the second principal component is 22.48%, and the cumulative rate of the first and second components reached 77.812%. Among them, DM, TSS content and Brix/Acid are the characters with large eigenvector values, and there is a positive correlation between the three parameters. They are the main source of nutrients in the fruit that directly determine the quality of the raspberries, which can be categorised as nutritional factors. Similar observations were reported by Sehgal et al. (2021) in tomatoes, and the positive contribution demonstrates the importance of these indicators in influencing berry quality. The contribution rate of the third principal component is 11.403%. Characteristics with large

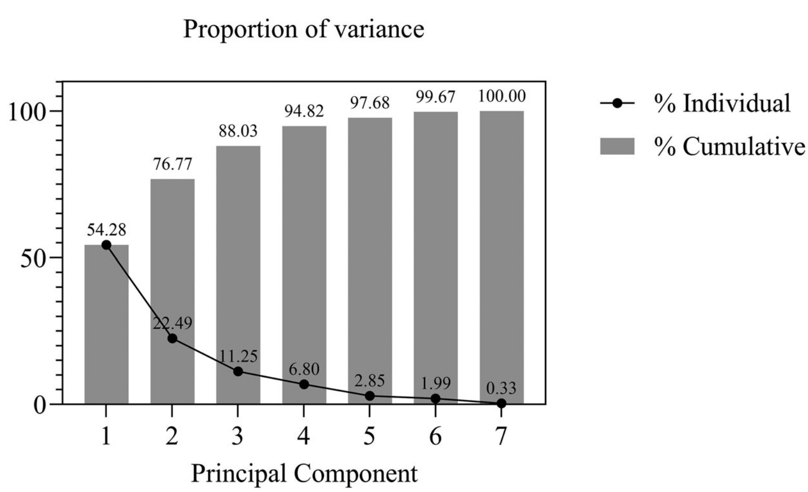

Figure 5. Proportion of variance and the cumulative contribution rate of principal components.

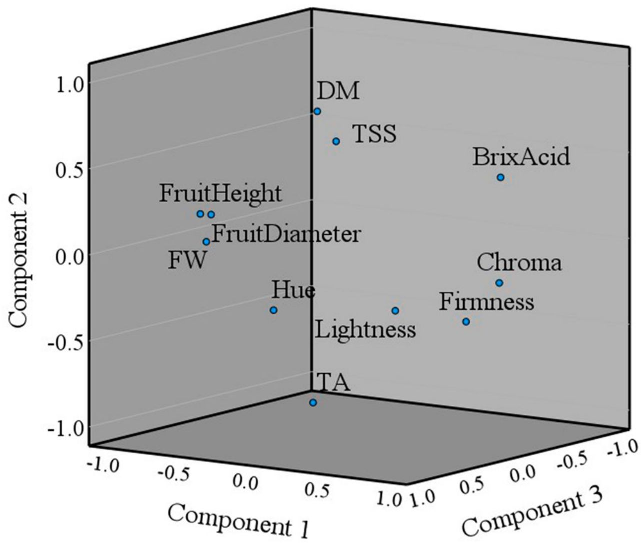

Figure 6. Three-dimensional component plots for 11 quality parameters of raspberries.

eigenvector values include colour parameters, TA content and firmness, which directly affect the flavour and appearance of the fruit and can be termed as sensory factors. The cumulative contribution rate of the first three components reached 88.024%.

Comprehensive evaluation

The simple comparison method cannot consider all the factors comprehensively. Therefore, principal component analysis is used to transform multiple original quality indicators into a smaller number of principal components that are not related to each other, which retains most of the original information and simplifies the process of comprehensive quality evaluation. Based on the contribution rates of the three principal components (Y_1: yield factors, Y_2: nutritional factors, Y_3: sensory factors), a comprehensive evaluation model Z of raspberry fruit quality was established:

$$Z = 0.54284Y_1 + 0.2248Y_2 + 0.1126Y_3$$

This mathematical model was used to evaluate the raspberry fruits of the two selections in the four substrates, to obtain the comprehensive score Z for each treatment combination, and then the Z value was used as a criterion to rank the excellence (Tian et al. 2015). As shown in Table 7, for sel.8, plants grown in coir had an advantage in yield factors, whereas plants grown in pumice performed better in nutritional and sensory factors. In contrast, sel.110 grown in pumice had higher yields, whereas coir and coir/pumice substrates increased the nutritional and sensory factors, respectively. Overall, the fruits of the two selections showed the same response to the different substrates: pure pumice grew the highest quality fruits, followed by the control, while mixed pumice/flax yielded the poorest quality. In addition, sel.110 generally produced higher fruit quality than sel.8. Our experiments showed that pumice improved the quality of fruit compared to those produced by using traditional coconut coir as a substrate.

Table 7. Comprehensive score and ranking according to 11 main quality indicators of the two raspberry selections.

		Principal Component Score				
Selection	Treatment	y1	y2	y3	Comprehensive Score	Rank
sel.8	Coir (Ctrl)	−0.7174	−2.2283	0.0931	−0.8799	2
	Pumice	−1.5756	1.8031	1.5781	−0.2723	1
	Pumice/Flax	−3.3582	−1.5655	0.4449	−2.1248	4
	Coir/Pumice	−2.7602	1.5115	−1.9529	−1.3784	3
sel.110	Coir (Ctrl)	1.8899	0.9516	−0.7998	1.1498	2
	Pumice	3.2483	0.1737	−0.0762	1.7938	1
	Pumice/Flax	2.0914	−1.5911	−0.4375	0.7284	4
	Coir/Pumice	1.1817	0.9451	1.1504	0.9835	3

Discussion

Dwarfing raspberries can be grown indoors hydroponically for more efficient use of space and with reduced labour and harvesting costs. In this experiment, dwarfing selections are easier to manage and maintain in greenhouse due to its compact growth, allowing for better regulation of plant growth and development. Compared to high-bush varieties, they have the advantage of being thornless and requiring no staking or support structure, making them ideal for hydroponic bags or containers. The hydroponic system also provides more precise control of water and nutrient supply. However, with the rising price of shipped products, and disturbed supply chain globally, prompted growers to look for low-cost local soilless cultivation substrates. To assess the horticultural production potential of pumice, flax and coconut coir, their physical properties were measured. Results showed that the addition of pumice to coir significantly increased bulk density, which provided better support for raspberry plants and maximised WHC. Pure pumice (grade 1–9 mm) had a higher bulk density and lower porosity, which contributed to fruit yield, although it slightly inhibited vegetative growth. Mixed pumice/flax had a low porosity and poor WHC, resulting in inferior raspberry growth vigour and productivity. By blending different grades of pumice, the balance of aeration and water retention can be controlled to meet the needs of various crops. Therefore, pumice serves as an excellent hydroponic growing medium that can be easily adjusted based on the type of crop or root system requirements. In addition, for perennials, the durability and stability of the substrate needs to be considered when cultivating. The use of coir as a media may start to decompose after 3 years, thus affecting the growing environment of the crop root system and nutrient supply (Toboso-Chavero et al. 2021). New Zealand boasts abundant natural resources, including pumice, scoria, and zeolite, which theoretically can be used as substrates for many years without breaking down (Bar-Tal et al. 2019), but requiring disinfection between applications for different crops. This offers potential economic benefits, but further research on cost and longevity is needed. Pumice has a longer lifespan as a substrate and will continue to be studied over the next few years.

Our experiment also investigated the effects of selection and substrate on the fruit quality of hydroponically grown raspberries. The results showed significant links between selection and treatment for most of the traits in the used dwarf raspberries sel.8 and sel.110. Specifically, the two selections showed significant changes grown in different substrates. We observed that in sel.8, pure pumice as a substrate inhibited the increase in plant height, but increased yield and fruit nutrient content. However, in sel.110, pure pumice did not significantly affect vegetative growth and enhanced fruit nutrient value, but reduced fruit size. This emphasises the importance of considering multiple factors in similar future studies to accurately understand the impact of a substrate's suitability for raspberry production. Different substrate types and management strategies should be adapted to different raspberry selections to maximise their growth and yield potential. However, despite the initial insights provided in this study, further research is needed to gain a deeper understanding of the complex mechanisms of interactions between selections, treatments, and environments for more precise agricultural management and production practices.

To conclude, compared to coir, pumice as a substrate can positively affect the fruit quality of both raspberry selections. Also, pumice-based mix substrates could be successfully used for hydroponic raspberry production without compromising yield and quality of the fruit.

Acknowledgements

The authors report there are no competing interests to declare. The authors acknowledge the funding support from 'He Whenua Pungapunga – Exploring the sustainable use of Te Arawa's natural pumice resources' MAUX2009 MBIE Te Pūnaha Hihiko: Vision Mātauranga Capability – Connect Scheme to AVZ and Massey University – REaDI funds, School of Agriculture and Environment. We also acknowledge the support and resources provided by Whenua Fruits and Pure Hydroponics Ltd. for this research.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Massey university contract under collaboration related to "He Whenua Pungapunga – Exploring the sustainable use of Te Arawa's natural pumice resources".

ORCID

Rui Zhao http://orcid.org/0009-0000-0271-1373
Svetla Sofkova-Bobcheva http://orcid.org/0000-0002-0121-8445

References

Agrawal AA. 2005. Plant genotype and environment interact to shape a diverse arthropod community on evening primrose (Oenothera biennis). Ecology. 86(4):874–885. doi:10.1890/04-1068.

Balawejder M, Piechowiak T, Matłok N, Szostek M, Kapusta I, Niemiec M, Komorowska M, Wróbel M, Mudryk K, Szeląg-Sikora A, et al. 2023. The modification of substrate in the soilless cultivation of raspberries (*Rubus idaeus* L.) as a factor stimulating the biosynthesis of selected bioactive compounds in fruits. Molecules. 28(1). doi:10.3390/molecules28010118.

Barker SJ, Wilson CJN, Illsley-Kemp F, Leonard GS, Mestel ERH, Mauriohooho K, Charlier BLA. 2021. Taupō: an overview of New Zealand's youngest supervolcano. New Zealand Journal of Geology and Geophysics. 64(2–3):320–346. doi:10.1080/00288306.2020.1792515.

Bar-Tal A, Saha UK, Raviv M, Tuller M. 2019. Inorganic and synthetic organic components of soilless culture and potting mixtures. In: Raviv M, Lieth JH, Bar–Tal A, editors. Soilless culture. 2nd ed. London: Elsevier; p. 259–301.

Bignami C, Reye F, Saccaggi M, Pane C, Zaccardelli M, Ronga D. 2023. Composts from grapevine and hazelnut by-products: a sustainable peat partial replacement for the growth of micropropagated hazelnut and raspberry in containers. Hort. 9(4):481.

Blok C, Wever G. 2008. Experience with selected physical methods to characterize the suitability of growing media for plant growth. Acta Horticulturae. 779:239–250. doi:10.17660/ActaHortic.2008.779.29.

Brown A. 2016. Weaving flowers from New Zealand flax. 4th ed. New Zealand: Browncraft Ltd.

Carlen C, Ançay A, Christ B. 2019. Optimization of the root environment for raspberry production on substrate. In: Proceedings of the XII International Rubus and Ribes Symposium: innovative Rubus and Ribes production for high quality berries in changing, Zürich, Switzerland, 23–28 June 2019. Vol. 1277, 283–286.

Carlile WR, Raviv M, Prasad M. 2019. Organic soilless media components. In: Raviv M, Lieth JH, Bar-Tal A, editors. Soilless culture theory and practice. 2nd ed. London: Elsevier; p. 303–378.

Cushnie TPT, Lamb AJ. 2011. Recent advances in understanding the antibacterial properties of flavonoids. International Journal of Antimicrobial Agents. 38(2):99–107. doi:10.1016/j.ijantimicag.2011.02.014.

Delić M, Behmen F, Matijašević S, Mandal Š, Hamidović S, Murtić S. 2021. Influence of crop load on the yield and grape quality of Merlot and Vranac (Vitis vinifera L.) varieties in Trebinje vineyard. Acta Agriculturae Slovenica. 117(4). doi:10.14720/aas.2021.117.4.1601.

De Rijck G., Schrevens E. 1998. Distribution of nutrients and water in rockwool slabs. Scientia Horticulturae. 72(3-4):277–285.

Djidonou D, Simonne AH, Koch KE, Brecht JK, Zhao X. 2016. Nutritional quality of field-grown tomato fruit as affected by grafting with interspecific hybrid rootstocks. HortScience. 51:1618–1624. doi:10.21273/HORTSCI11275-16.

Ekambaram K, Raja SR. 2014. Export performance of coir and coir products from India. CLEAR IJRCM. 5(7):44–47.

European Committee for Standardization. 2002. Polish standard EN 13041: soil improvers and growing media – determination of physical properties - dry bulk density, air volume, water volume, shrinkage value and total pore space. Brussels, Belgium: European Committee for Standardization.

Forge T, Neilsen D, Neilsen G, Watson T. 2016. Using compost amendments to enhance soil health and replant establishment of tree-fruit crops. Acta Horticulturae. 1146:103–108. doi:10.17660/ActaHortic.2016.1146.13.

Gabriel MZ, Altland JE, Jr O, S J. 2009. The effect of physical and hydraulic properties of peatmoss and pumice on Douglas fir bark based soilless substrates. HortScience. 44(3):874–878. doi:10.21273/HORTSCI.44.3.874.

Gessert G. 1976. Measuring a medium's airspace and water holding capacity. Ornamentals Northwest Archives. 1(8):11–12.

Giorgio D, Salgado L, Dufresne PR, Mauri A, N A. 2020. Nanocelluloses from phormium (*Phormium tenax*) fibers. Cellulose. 27(9):4975–4990. doi:10.1007/s10570-020-03120-x.

Gizas G, Savvas D. 2007. Particle size and hydraulic properties of pumice affect growth and yield of greenhouse crops in soilless culture. HortScience. 42:1274. doi:10.21273/HORTSCI.42.5.1274.

Graham J, Hein I, Powell W. 2007. Chapter 9: Raspberry. In: Kole C, editor. Genome mapping and molecular breeding in plants. Vol 4: Fruits and nuts. Springer-Verlag; p. 207–216.

Haffner K, Rosenfeld HJ, Skrede G, Wang L. 2002. Quality of red raspberry *Rubus idaeus* L. cultivars after storage in controlled and normal atmospheres. Postharvest Biology and Technology. 24(3):279–289. doi:10.1016/S0925-5214(01)00147-8.

Helwi P, Scheiner J, Botezatu A, Essary A, Hillin D. 2021. Effect of pruning and mechanical fruit thinning on crop load and berry and wine composition of Tempranillo in Texas. IVES Technical Reviews.

Joness J. 2003. Harakeke in New Zealand today and into the future. In: Harakeke Flax. The Royal Society of New Zealand; p. 5–6.
Khalili S, Hultberg M, Alsanius BW. 2009. Effects of growing medium on the interactions between biocontrol agents and tomato root pathogens in a closed hydroponic system. The Journal of Horticultural Science and Biotechnology. 84(5):489–494. doi:10.1080/14620316.2009.11512553.
Lenzi A, Oggiano N, Maletta M, Bolaffi A, Tesi R. 2001. Physical and chemical characteristics of substrates made of perlite, pumice, and peat. Italus Hortus. 8:23–31.
Lopez-Mondejar R, Bernal-Vicente A, Tittarelli RM, Canali F, Intrigiolo S, Pascual F, A J. 2010. Utilisation of citrus compost-based growing media amended with *Trichoderma harzianum* T-78 in *Cucumis melo* L. seedling production. Bioresource Technology. 101:3718–3723. doi:10.1016/j.biortech.2009.12.102.
Mitsanis C, Aktsoglou DC, Koukounaras A, Tsouvaltzis P, Koufakis T, Gerasopoulos D, Siomos AS. 2021. Functional, flavor and visual traits of hydroponically produced tomato fruit in relation to substrate, plant training system and harvesting time. Hort. 7(311):311.
Nemati R, Fortin J-P, Craig J, Donald S. 2021. Growing mediums for medical cannabis production in North America. Agronomy. 11:1366. doi:10.3390/agronomy11071366.
Nerlich A, Karlowsky S, Schwarz D, Förster N, Dannehl D. 2022. Soilless tomato production: effects of hemp fiber and rock wool growing media on yield, secondary metabolites, substrate characteristics and greenhouse Gas emissions. Hort. 8(2):272.
Nishimura Y, Fukumoto Y, Shimasaki K. 2005. Effects of reservoir depth at the bottom of bed on plant growth and fruit quality of muskmelon (*Cucumis melo* L.) in pumice substrate. Environment Control in Biology. 43(4):267–274. doi:10.2525/ecb.43.267.
Ousaaid D, Imtara H, Laaroussi H, Lyoussi B, Elarabi I. 2021. An investigation of Moroccan vinegars: their physicochemical properties and antioxidant and antibacterial activities. Journal of Food Quality. 1–8. doi:10.1155/2021/6618444.
Previtali P, Wilkinson KL, Ford CM, Dokoozlian NK, Pan BS. 2021. Crop load and plant water status influence the ripening rate and aroma development in berries of grapevine (*Vitis vinifera* L.) cv. cabernet sauvignon. Journal of Agricultural and Food Chemistry. 69(27):7709–7724. doi:10.1021/acs.jafc.1c01229.
Rosairo HSR, Kawamura T, Peiris TLGS. 2004. The coir fiber industry in Sri Lanka: reasons for its decline and possible turnaround strategies. Agribusiness. 20(4):495–516. doi:10.1002/agr.20071.
Sahin U, Anapali O, Ercisli S. 2002. Physico-chemical and physical properties of some substrates used in horticulture. Gartenbauwissenschaft. 67:55–60.
Sehgal N, Chadha S, Kumar S, Ravita. 2021. Variability and traits association analyses in bacterial wilt resistant F4 progenies of tomato, *Solanum lycopersicum* L., for yield and biochemical traits. Indian J Exp Biol. 59:617–625.
Sivasubramanian P, Kalimuthu M, Murugesan P, Azeez A, Nagarajan R, de Felipe Vannucchi C, Carlo S. 2021. Mechanical properties of Phormium tenax reinforced natural rubber composites. Fibers. 9(11):11.
Sønsteby A, Myrheim U, Heiberg N, Heide OM. 2009. Production of high yielding red raspberry long canes in a Northern climate. Scientia Horticulturae. 121(3):289–297. doi:10.1016/j.scienta.2009.02.016.
Stojanov D, Milošević T, Mašković P, Milošević N, Glišić I, Paunović G. 2019. Influence of organic, organo-mineral and mineral fertilisers on cane traits, productivity and berry quality of red raspberry (*Rubus idaeus* L.). Scientia Horticulturae. 252:370–378. doi:10.1016/j.scienta.2019.04.009.
Thomas GV, Palaniswami C, Prabhu SR, Gopal M, Gupta A. 2013. Co-composting of coconut coir pith with solid poultry manure. Curr Sci. 104(2):245–250.
Tian Z, Yang Y, Wang F. 2015. A comprehensive evaluation of heat tolerance in nine cultivars of marigold. HEAB. 56(6):749–755.
Toboso-Chavero S, Madrid-López C, Villalba G, Gabarrell Durany X, Hückstädt AB, Finkbeiner M, Lehmann A. 2021. Environmental and social life cycle assessment of growing media for urban rooftop farming. The International Journal of Life Cycle Assessment. 26(10):2085–2102. doi:10.1007/s11367-021-01971-5.

Tzortzakis NG, Economakis CD. 2008. Impacts of the substrate medium on tomato yield and fruit quality in soilless cultivation. Horticultural Science. 35(2):83–89. doi:10.17221/642-HORTSCI.

Van der Gaag DJ, Wever G. 2005. Conduciveness of different soilless growing media to Pythium root and crown rot of cucumber under near-commercial conditions. European Journal of Plant Pathology. 112(1):31–41. doi:10.1007/s10658-005-1049-7.

Wilson CJN, Gravley DM, Leonard GS, Rowland JV. 2009. Volcanism in the central Taupo volcanic zone, New Zealand: tempo, styles and controls. In: Thordarson T, Self S, Larsen G, Rowland SK, Hoskuldsson A, editors. Studies in volcanology: The legacy of George Walker. Special Publications of IAVCEI 2; p. 225–247.

Wilson CJN, Houghton BF, McWilliams MO, Lanphere MA, Weaver SD, Briggs RM. 1995. Volcanic and structural evolution of Taupo volcanic zone, New Zealand: a review. Journal of Volcanology and Geothermal Research. 68:1–28. doi:10.1016/0377-0273(95)00006-G.

Životić A, Mićić N, Žabić M, Bosančić B, Cvetković M. 2019. Precision cane meristem management can influence productivity and fruit quality of floricane red raspberry cultivars. Turkish Journal of Agriculture and Forestry. 43(4):405–413. doi:10.3906/tar-1807-15.