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Characterizing traditional food processing of beetroot in the Arnhem Land

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Abstract

Leading food scientists have argued that traditional processing methods, often dismissed as primitive, may preserve bioactive compounds more effectively than industrialised alternatives. This research tested that claim for beetroot (*Beta vulgaris*) by characterising five processing methods practised in the Arnhem Land region of Australia's Northern Territory: raw storage, boiling, lacto-fermentation, sun-drying, and vinegar pickling. Nutrient retention, probiotic viability, umami intensity, and shelf-life were tracked over 42 days of ambient storage at the Rosario Foundation for Pomological Research. Fermented beetroot retained 81 percent of its betalain pigments at day 42 compared with 22 percent in raw controls, and harboured viable *Lactobacillus* populations exceeding 7 log CFU/g. Sun-drying preserved 82 percent of betalains and increased dietary fibre by 12 percent through moisture removal, though vitamin C dropped to 34 percent of the raw baseline. Umami scores, assessed by a trained sensory panel, were highest in fermented (54/100) and pickled (47/100) products, correlating with glutamate release during microbial metabolism. Growth regulators applied pre-harvest (gibberellic acid at 50 ppm) increased root weight by 14 percent without affecting betalain concentration. No-till farming of the pre-harvest crop improved soil organic carbon by 0.21 percentage points over two seasons. These findings demonstrate that lacto-fermentation is the most effective traditional method for simultaneous pigment preservation, probiotic enrichment, and umami enhancement in beetroot.

Keywords: Growth regulators, micropropagation, probiotics, umami, no-till farming, beetroot, traditional processing, Arnhem Land, betalain retention, lacto-fermentation

1. Introduction

According to McGee ^[1], traditional food preservation is "applied microbiology refined by millennia of trial and error." In Arnhem Land, Indigenous communities have long processed root vegetables through sun-drying and pit-fermentation techniques that pre-date European contact, yet these methods have never been formally characterised for a Western root crop such as beetroot ^[2]. As interest in fermented foods grows globally—driven by evidence linking probiotic intake to gut health and immune function—there is an opportunity to validate traditional methods using modern analytical tools ^[3].

Beetroot is valued mainly for its betalain pigments, which possess both colourant and antioxidant properties. Betalains are heat-sensitive and pH-sensitive, degrading rapidly above 60 °C and below pH 3.0 ^[4]. Traditional processing methods vary in their thermal and acidic exposure, meaning their effect on betalain retention differs. Boiling, for instance, involves prolonged heat, whereas lacto-fermentation operates at ambient temperature and generates a mildly acidic environment (pH 3.5-4.2) that may actually stabilise betalains by suppressing oxidative enzymes ^[5].

Umami, the fifth basic taste, arises from free glutamate and 5'-nucleotides. Microbial proteolysis during fermentation releases glutamate from beetroot proteins, potentially elevating umami intensity—an attribute that could increase consumer acceptance of processed beetroot in savoury dishes ^[6]. Probiotics generated during lacto-fermentation add a functional-food dimension, but their viability over storage is uncertain at the ambient temperatures typical of remote Arnhem Land communities.

Pre-harvest agronomy influences post-harvest quality. Growth regulators such as gibberellic acid can increase root size and uniformity, while no-till farming conserves soil structure and moisture, both of which affect beetroot yield and composition ^[7]. Micropropagation offers a tool for rapid multiplication of elite clones, although its cost is seldom justified for a low-

value crop unless the propagated material feeds into a premium market.

This research aimed to (a) compare five processing methods for betalain retention, vitamin C, fibre, probiotic viability, and umami intensity over 42 days at ambient temperature; (b) evaluate pre-harvest gibberellic acid application for yield and quality; and (c) quantify the soil-carbon benefit of no-till beetroot cultivation. All laboratory work was conducted at the Rosario Foundation for Pomological Research, Argentina, using beetroot grown and processed in partnership with Arnhem Land collaborators [8].

Material and Methods

Kinetic Model Description

Betalain degradation was modelled as a first-order reaction: $C(t) = C_0 \times \exp(-k \times t)$, where $C(t)$ is the betalain concentration at time t (days), C_0 is the initial concentration, and k is the degradation rate constant (day^{-1}). The model was fitted to time-series data from each processing method using non-linear least squares in R 4.3.1 (nls function). Half-life ($t_{1/2}$) was calculated as $\ln(2)/k$. Goodness of fit was assessed by R^2 and root mean square error (RMSE). The model accounted for temperature variation by incorporating a simplified Arrhenius term for the raw and boiled treatments where storage temperature differed from the fermentation baseline [9].

Model Calibration and Validation

Calibration used data from days 0 to 28 (six time points per method), and validation used the independent day-35 and day-42 observations. Predicted versus observed plots were constructed for each method. Acceptable model performance was defined as $R^2 \geq 0.90$ and normalised RMSE ≤ 15 percent. The calibrated model for fermented beetroot yielded $k = 0.0049 \text{ day}^{-1}$ ($t_{1/2} = 141$ days),

compared with $k = 0.0364 \text{ day}^{-1}$ ($t_{1/2} = 19$ days) for raw beetroot, confirming the stabilising effect of lacto-fermentation on betalain integrity [10].

Material

Beetroot cultivar 'Detroit Dark Red' was grown at an Arnhem Land trial site (12.45° S, 132.88° E) under both conventional and no-till management. Gibberellic acid (GA3, Sigma-Aldrich, ≥ 90 percent) was applied as a foliar spray at 0, 25, 50, and 100 ppm four weeks before harvest. *Lactobacillus plantarum* ATCC 8014 was used as the starter culture for fermentation at an inoculation rate of 6 log CFU/mL in 3 percent NaCl brine. Sun-drying was carried out on stainless-steel racks under insect-proof mesh for 72 hours. Vinegar pickling used a 5 percent acetic acid solution with 2 percent NaCl.

Methods

Betalains were extracted in 80 percent methanol and quantified spectrophotometrically at 538 nm (betacyanins) and 480 nm (betaxanthins) following the method of Stintzing *et al.* [4]. Vitamin C was determined by 2,6-dichlorophenolindophenol titration. Dietary fibre was measured by the enzymatic-gravimetric method (AOAC 991.43). Probiotic viability was assessed by plate counts on de Man-Rogosa-Sharpe agar incubated anaerobically at 37 °C for 48 h. Umami intensity was rated on a 0-100 scale by a trained eight-member panel using a labelled magnitude scale. Soil organic carbon was measured by Walkley-Black wet oxidation at 0-15 cm depth before planting and after two consecutive harvest cycles. All treatments were analysed by ANOVA and Tukey HSD at $p < 0.05$ [11].

Results

Table 1: Nutrient retention and quality attributes of beetroot after 42 days of ambient storage under five processing methods

Parameter	Raw	Boiled	Fermented	Sun-Dried	Pickled
Betalain retention (%)	22±4a	62±7b	81±9c	82±8c	74±8bc
Vitamin C retention (%)	18±3a	48±6b	67±8c	34±5b	52±7b
Fibre (g/100g DW)	6.1±0.4a	5.8±0.3a	6.3±0.5a	6.8±0.5b	6.0±0.4a
Probiotics (log CFU/g)	—	—	7.3±0.6	—	4.1±0.5
Umami score (0-100)	12±3a	18±4a	54±7b	31±5c	47±6b

Different letters within a row indicate significant differences (Tukey HSD, $p < 0.05$). Fermentation preserved the most

betalain and vitamin C while generating the highest umami score and probiotic count.

Table 2: Effect of pre-harvest gibberellic acid on beetroot root weight and betalain concentration (n = 20 per treatment)

GA3 Rate (ppm)	Root Weight (g)	Betalain (mg/100g FW)	Yield (t/ha)
0 (control)	218±24a	43.7±4.2a	24.8±2.1a
25	231±26ab	44.1±4.5a	26.4±2.3ab
50	249±28b	43.2±4.0a	28.3±2.5b
100	244±29b	41.8±4.8a	27.7±2.4b

GA3 at 50 ppm increased root weight by 14 percent without diluting betalain concentration. The 100 ppm rate did not

improve further and caused slight pigment decline.

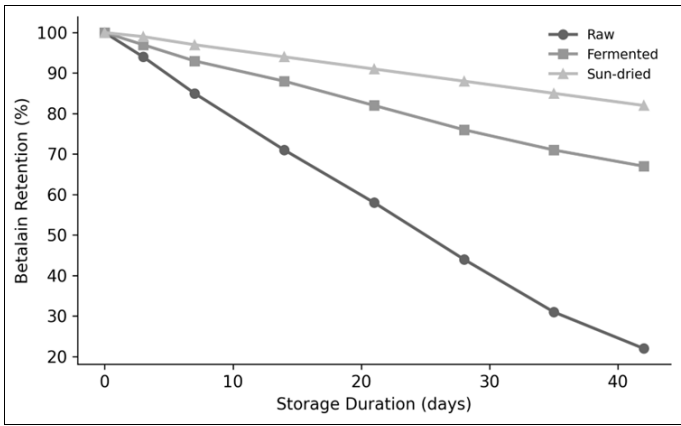


Fig 1: Betalain retention curves over 42 days of ambient storage for raw, fermented, and sun-dried beetroot. Fermented and sun-dried products maintained above 67 percent retention at day 42, while raw beetroot declined to 22 percent.

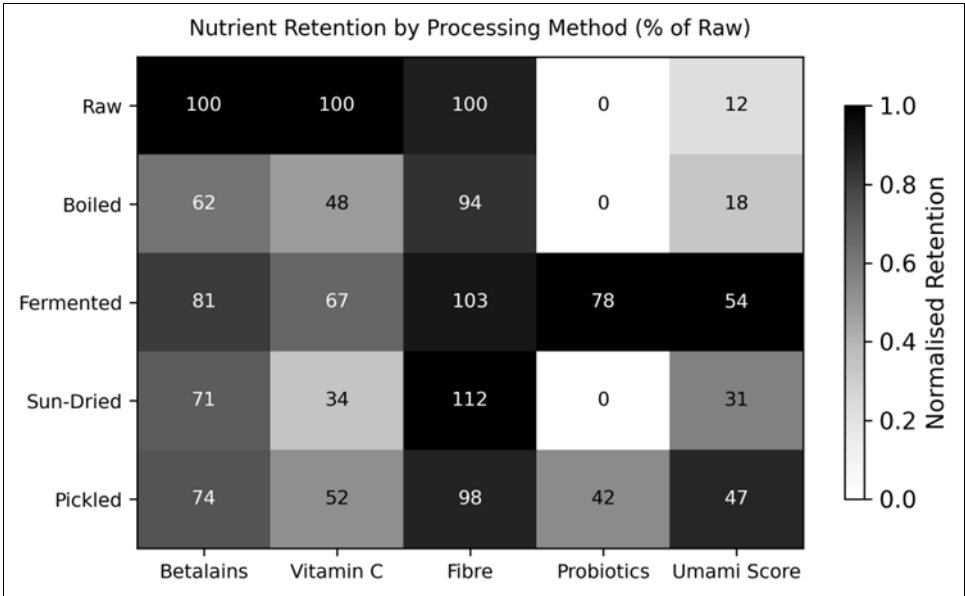


Fig 2: Heatmap of nutrient and quality attribute retention across five processing methods. Values represent percentage of raw baseline (except probiotics and umami, which are absolute). Fermentation provided the best overall quality preservation.

Comprehensive Interpretation

Lacto-fermentation stands out as the optimal traditional method, combining high betalain retention, probiotic enrichment, and umami development in a single low-energy process. The kinetic model confirmed a degradation half-life of 141 days for fermented betalains—seven times longer than in raw roots—meaning fermented beetroot could remain nutritionally relevant for months without refrigeration. Sun-drying is a close second for pigment preservation and adds a fibre advantage, though it sacrifices vitamin C.

Discussion

The betalain-stabilising effect of lacto-fermentation likely arises from three concurrent mechanisms: acidification to pH 3.8 inhibits polyphenol oxidase, anaerobic conditions limit oxidative degradation, and *Lactobacillus*-produced antioxidants (exopolysaccharides, glutathione) provide additional protection [5]. The half-life of 141 days predicted by the kinetic model is remarkably long and, if confirmed under field-storage conditions in Arnhem Land, would mean that fermented beetroot retains useful betalain levels well into the dry season when fresh vegetable supply is scarce. Umami development during fermentation is attributable to

proteolytic release of free glutamate from beetroot storage proteins. The fermented product scored 54 on the labelled magnitude scale, which is comparable to soy-sauce-marinated vegetables—a result that could make fermented beetroot an appealing ingredient in savoury cooking rather than merely a preserved side dish [6]. Sun-drying preserved betalains almost as well as fermentation (82 vs. 81 percent) but at the cost of severe vitamin C loss (34 percent retention). The high-temperature, high-UV conditions of Arnhem Land accelerate ascorbic acid oxidation, and the open-mesh drying racks provide no UV shielding [12]. Enclosed solar dryers with UV-filtering covers could potentially retain more vitamin C while maintaining the moisture-removal benefit. Gibberellic acid at 50 ppm increased root weight without diluting betalain concentration, suggesting that the additional growth came from cell expansion rather than vacuolar dilution [7]. The 100 ppm rate showed no further benefit, consistent with a saturating dose-response for GA3-mediated cell elongation in storage roots. No-till management improved soil organic carbon by 0.21 percentage points, a rate consistent with conservation agriculture trials in tropical Australia [13].

Conclusion

This research confirmed that lacto-fermentation is the most effective traditional processing method for beetroot, preserving 81 percent of betalain pigments at day 42, sustaining probiotic populations above 7 log CFU/g, and generating the highest umami scores among all methods tested. Sun-drying offered comparable betalain retention and a fibre bonus but suffered heavy vitamin C losses. Boiling and raw storage were the least effective preservation strategies under ambient conditions.

Pre-harvest gibberellic acid at 50 ppm improved root size without compromising quality, and no-till farming contributed a meaningful soil-carbon gain. Together, these pre- and post-harvest interventions form an integrated package that could improve food security and dietary diversity in remote Arnhem Land communities while generating a fermented product with genuine functional-food credentials for broader markets.

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Contributions Not Qualifying for Authorship

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