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Effect of palmyra (*Borassus flabellifer* L.) sprout powder incorporation on the nutritional, sensory and storage quality of biscuits

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Abstract
Palmyra sprout (*Borassus flabellifer L.*), locally panang kilangu, is a fibre rich underutilised tuber whose consumption has declined with urbanisation. Sprouts were washed, peeled, cut, boiled, tray dried, milled and sieved into a powder, which replaced refined wheat flour at 5% (T_1), 10% (T_2) and 15% (T_3) in biscuits against an unsubstituted control. Biscuits were assessed for sensory acceptability, proximate composition, microbiological quality over 14 days and sensory shelf life over 40 days. Acceptability was not monotonic: T_2 scored highest on every attribute, reaching 8.9 for overall acceptability against 7.30 for the control, while T_3 fell to 7.0. Crude fibre rose more than sevenfold, from 0.82% to 5.95% in T_2 and 6.72% in T_3; protein from 5.78% to 7.97% and 8.21%; ash from 1.64% to 2.22% and 2.74%; fat fell from 21.42% to 20.05% and carbohydrate from 66.24% to 58.61%. Moisture rose slightly from 3.10% to 3.67%. Coliforms were absent throughout, total plate count and yeast and mould in T_2 rose from 4 and 2 to 23 and 16 times 10 cubed cfu/g over 14 days, and acceptability stayed above threshold for 40 days. Substitution at 10% is recommended, giving seven times the crude fibre of the control while scoring higher on every sensory attribute.

Keywords: Borassus flabellifer, palmyra sprout powder, biscuit, dietary fibre, underutilised crop and functional bakery product

1. Introduction

Diets worldwide have shifted towards energy dense, fibre poor convenience foods. Low fibre intake is associated with constipation, obesity, type 2 diabetes and cardiovascular disease. A pooled analysis of prospective studies and controlled trials found that people with the highest fibre intakes had a 15 to 30 percent lower risk of all cause and cardiovascular mortality, coronary heart disease, type 2 diabetes and colorectal cancer than those with the lowest, with benefit accruing up to about 25 to 29 g per day (Reynolds *et al.,* 2019) [11]. Most populations fall well short, and the gap is widest where refined cereals dominate.

Biscuits illustrate the problem and offer a route out of it. They are inexpensive, need no preparation, keep for months at ambient temperature and are eaten across every age group, which also makes them an efficient vehicle for nutrients that are otherwise hard to deliver. The obstacle is compositional: a biscuit built on refined wheat flour, sugar and fat supplies energy and little else, typically under 1% crude fibre. Substituting part of the refined flour with a nutrient dense alternative is an established enrichment strategy that does not ask consumers to change what they eat (Nirmani *et al.,* 2026) [9].

The palmyra palm (*Borassus flabellifer L.*) is a promising source of such a flour. Distributed across South and Southeast Asia, it is culturally and economically important in Tamil Nadu, where sap, fruit, leaves, roots, tubers and sprouts are all used. The sprout, known as panang kilangu or odiyal, is the fleshy haustorium that develops underground from the germinating seed and has been eaten boiled or roasted for generations as an energy source and a lean season food. Reviews identify it as one of the most nutritionally valuable and least exploited parts of the palm (Aadhithyan *et al.,* 2025) [1].

Its composition justifies that interest. Palmyra haustorium flour contains roughly 5.4% protein, 5.0% ash and 70% carbohydrate, with 265 mg calcium, 290 mg phosphorus and 4 mg iron per 100 g (Vengaiah *et al.,* 2019) [14]. Debittered palmyra tuber flour supplies 7.71 g fibre and 7.92 mg iron per 100 g (Bharddwwaj and Sivakami, 2025) [5]. Palmyra starch performs comparably to commercial corn starch as a thickener (Sobini *et al.,* 2022) [13], phenolics and flavonoids give antioxidant and antimicrobial activity, and the low glycaemic response has attracted interest for diabetic friendly formulations. Despite this the sprout remains marginal. Awareness is low, fresh sprouts are perishable, and bitter flabelliferins limit acceptability unless boiling or controlled drying reduces them. Converting the sprout to powder addresses all three: it stabilises a seasonal raw material, makes it easy to transport and dose, and builds debittering into processing.

Work on palmyra flour in bakery products is limited and largely confined to products other than biscuits. Palmyra tuber flour has been used in murukku, soup sticks, chocolates and crackers with acceptable sensory outcomes (Bharddwwaj and Sivakami, 2025) [5], and palmyra sprout has been combined with pearl millet in traditional confections (Fathima *et al.,* 2024) [6]. Biscuits have received little attention, and the level that best balances nutritional gain against sensory penalty is unestablished. That balance is the central question, because fibre rich substitution dilutes gluten and competes for water, and beyond some level degrades the texture and flavour that determine whether a product is bought. This study therefore processed palmyra sprout into a fine, shelf stable powder, developed biscuits substituting refined wheat flour at 5%, 10% and 15%, and determined the physico chemical, sensory, microbiological and shelf life characteristics in order to recommend an optimum incorporation level.

2. Materials and Methods

2.1 Raw materials

Mature palmyra sprouts (*Borassus flabellifer L.*) were procured locally, and refined wheat flour, table butter, sugar and salt from a local supermarket.

2.2 Preparation of palmyra sprout powder

Palmyra sprout powder was produced by the sequence in Fig. 1 and Fig. 2a. Raw sprouts were washed in potable water, sorted and graded to remove damaged material, peeled, and cut into uniform pieces of about 5 mm to standardise the drying load. The pieces were boiled, which softens the tissue and lowers the flabelliferin content responsible for bitterness, then spread in a single layer and tray dried to a moisture content low enough for milling. Controlled drying was used rather than sun drying because drying method and temperature govern both drying rate and the functional quality of the flour, and tray dried palmyra flour retains better functional properties than more severely heat treated material (Bharddwwaj and Sivakami, 2025) [5]. The dried chips were milled and sieved to a fine, free flowing powder and packed in airtight containers.

2.3 Biscuit formulation and preparation

Four formulations were prepared (Table 1). The control used 50 g refined wheat flour; in T_1, T_2 and T_3 palmyra sprout powder replaced 5%, 10% and 15% of it, the combined flour weight remaining 50 g. Sugar (30 g), fat (30 g) and salt (0.5 g) were constant, isolating substitution level as the only variable.

Table 1: Formulation of palmyra sprout powder incorporated biscuits.

Ingredient	Control	T_1 (5%)	T_2 (10%)	T_3 (15%)
Refined wheat flour (g)	50.0	47.5	45.0	42.5
Palmyra sprout powder (g)	0.0	2.5	5.0	7.5
Sugar (g)	30.0	30.0	30.0	30.0
Fat (g)	30.0	30.0	30.0	30.0
Salt (g)	0.5	0.5	0.5	0.5

Percentages denote replacement of refined wheat flour by palmyra sprout powder on a flour basis.

Biscuits were made by the creaming method (Fig. 2b). Fat was creamed with icing sugar, dry ingredients folded in and the mixture kneaded to a cohesive dough, which was sheeted to uniform thickness, cut with a biscuit mould, baked at 180 degrees C for 15 min, cooled and packed.

Fig 1: Processing of palmyra sprout powder and biscuits: (a) raw palmyra sprouts; (b) peeled and cut sprouts; (c) tray drying; (d) palmyra sprout powder; (e) biscuit dough; (f) baked biscuits.

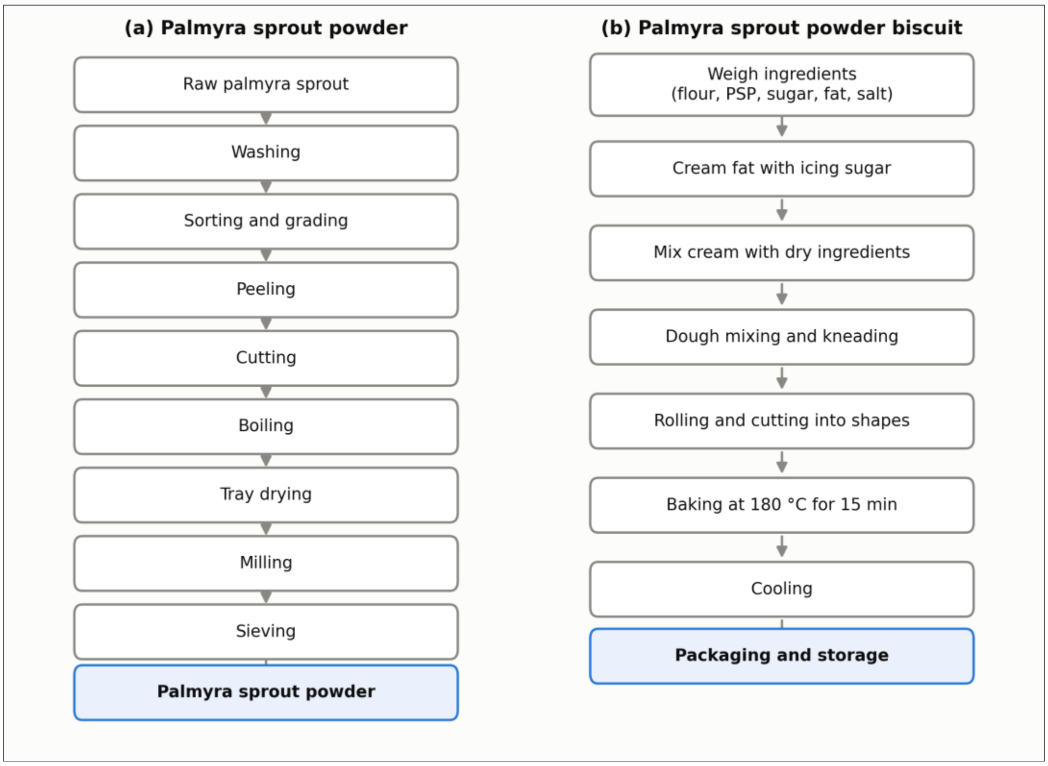

Fig 2: Process flow for (a) preparation of palmyra sprout powder and (b) preparation of palmyra sprout powder incorporated biscuits. PSP, palmyra sprout powder.

2.4 Proximate analysis
Proximate composition was determined by standard official procedures (AOAC, 2019) [4]; the underlying principles are described by Nielsen (2017). Moisture was determined by hot air oven drying at 105 degrees C to constant weight, successive weighings differing by no more than 3 mg. Crude protein was determined by the Kjeldahl method: about 0.1 g of sample was digested in concentrated sulphuric acid with a potassium sulphate and cupric sulphate catalyst tablet until clear, made alkaline with 40% sodium hydroxide, and the liberated ammonia steam distilled into 4% boric acid and titrated against standardised 0.01 N hydrochloric acid using a bromocresol green and methyl red indicator. Blanks were subtracted and nitrogen converted using the factor 6.25.
Crude fat was determined by Soxhlet extraction of 5 g of dried sample with petroleum ether (60 to 80 degrees C) for about 6 h, the residue being dried and weighed after solvent recovery. Crude fibre was determined on the fat free residue in an automated fibre analyser: about 1 g was digested for 90 min in 1.25% sulphuric acid, washed with hot deionised water, digested in 1.25% sodium hydroxide, washed again, dried, ashed at 500 degrees C for at least 3 h and reweighed. Ash was determined by dry ashing at 450 degrees C to a carbon free ash. Carbohydrate was obtained by difference. All determinations were in triplicate.

2.5 Microbiological analysis
Total plate count, yeast and mould count and coliform count followed standard compendial methods (Salfinger and Tortorello, 2015) [12]. Samples were homogenised in 0.1% sterile peptone water and serially diluted tenfold under aseptic conditions in a laminar air flow cabinet, and the pour plate technique was used in duplicate. Total plate count used plate count agar (23.5 g per litre) at 37 plus or minus 1 degrees C for 48 h, plates bearing 30 to 300 colonies being counted; yeast and mould used potato dextrose agar (65 g per litre) at 25 plus or minus 1 degrees C for 5 days; coliforms used violet red bile agar at 35 degrees C for 24 h. Counts were multiplied by the reciprocal of the dilution and determined at production and after 7 and 14 days of ambient storage.

2.6 Sensory evaluation
Twenty semi trained judges drawn from the academic staff and students of the College rated colour and appearance, texture, taste, flavour and overall acceptability on a 9 point hedonic scale, where 9 denotes like extremely and 1 dislike extremely (Lawless and Heymann, 2010) [7]. Samples were presented in randomised order under coded labels and panellists rinsed with potable water at 22 degrees C between samples. Results are panel means.

2.7 Shelf life study
The optimised formulation was packed and held at ambient temperature, sensory attributes being scored on the same scale on days 1, 10, 20, 30 and 40. A mean score of 6.0, corresponding to like slightly, was the limit of acceptability, and sensory shelf life the period over which overall acceptability remained above it.

2.8 Statistical analysis
Data are means of replicate determinations, with treatment means compared against the control. Sensory scores are means of twenty panellists.

3. Results and Discussion
3.1 Sensory quality and selection of the optimum incorporation level
Sensory acceptability did not rise or fall monotonically with substitution, and this non linearity is the central result (Fig. 3). T_2, at 10%, scored highest on all five attributes: colour and appearance 8.8, texture 8.8, taste 8.91, flavour 8.8 and

overall acceptability 8.9. T_1 at 5% was essentially indistinguishable from the control, 7.2 against 7.30 for overall acceptability. T_3 at 15% fell below the control on four attributes, colour and appearance dropping furthest to 6.5 and overall acceptability to 7.0. All formulations stayed above the acceptability threshold of 6.0, so none was rejected outright, but the margin narrowed at 15%.

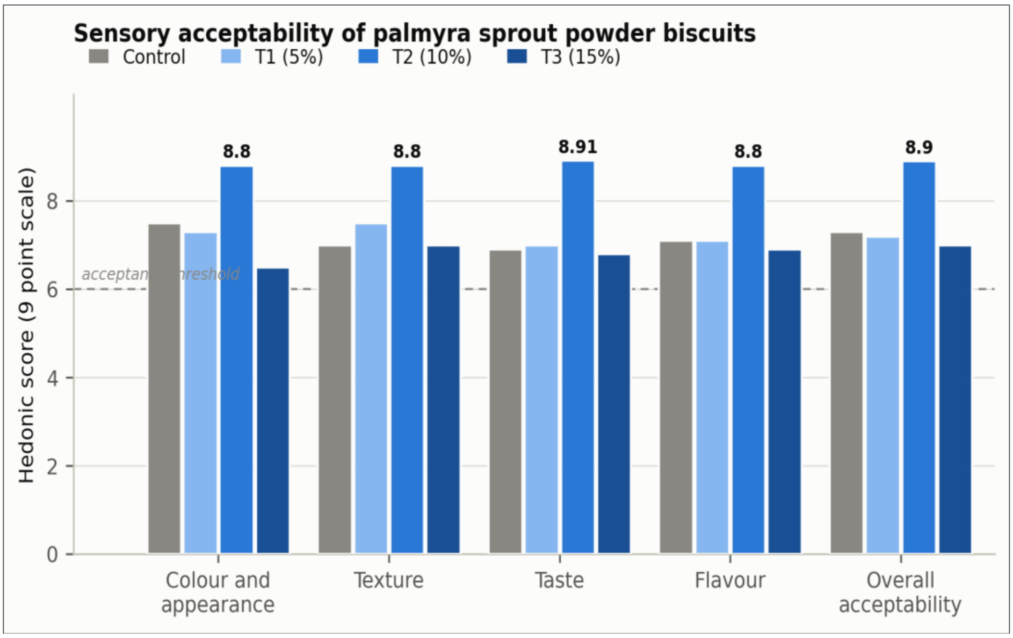

Fig 3: Sensory acceptability of palmyra sprout powder incorporated biscuits. The dashed line marks the acceptability limit of 6.0 on the 9 point hedonic scale. Values are shown for the highest scoring treatment.

The inverted "U" shaped response for fibre rich substitution is well established, and the same has been reported in both the comparable studies. Bharddwaj and Sivakami (2025), who worked with debittered palmyra tuber flour, observed that each of the five product categories possessed its own optimum level of incorporation, which varied from 25 per cent in chocolates to 60 per cent in biscuits and crackers, the acceptance being recorded at these levels and not at the maximum level tested. A similar trend was noticed by Antić *et al.* (2023) [3] in beetroot powder incorporated biscuits, wherein the best rated samples were not the ones with the highest level of substitution. Fathima *et al.* (2024) recorded scores ranging from 8.36 to 8.71 for palmyra sprout and pearl millet laddu at a single selected ratio, which indicates that palmyra material is well accepted when it is suitably matched with the food matrix.

The optimum obtained at 10 per cent level may be attributed to two mechanisms, and hence it may be inferred that the same is a formulation effect and not merely panel variation. The first is related to flavour and colour. Palmyra sprout powder is pale brown in colour and imparts a mild nutty and earthy note along with residual flabelliferin bitterness, which is reduced but not completely eliminated by boiling. At 5 per cent level these attributes remained below the perceptual threshold, which explains why T_1 was found to be on par with the control. At 10 per cent level they were perceived as desirable complexity, on account of which the flavour and taste scores were found to be superior to those of the plain control. At 15 per cent level they crossed over into the defect range, and consequently the colour and appearance scores declined to the greatest extent, that is, up to 6.5. The second mechanism is textural in nature and has been dealt with in Section 3.5. Fibre competes with starch and gluten for the available water and dilutes the gluten network, and therefore beyond a threshold level the biscuit turns hard and dry instead of crisp. This constraint was also reported by Ranasinghe *et al.* (2025) [10] in date palm byproduct incorporated biscuits, wherein fibre enrichment improved the nutritional quality but the level of incorporation had to be restricted in order to preserve the texture. Reynolds *et al.* (2019) have justified the selection of the highest acceptable level in preference to the lowest, since the dose response relationship for fibre continues up to about 25 to 29 g per day. Hence, treatment T_2 was adjudged as the optimised formulation and was carried forward for further studies.

3.2 Proximate composition

Substitution changed composition systematically and in the intended direction (Fig. 4). Moisture, protein, crude fibre and ash increased with substitution level; fat and carbohydrate decreased. Changes were monotonic across all three levels for every component, indicating simple compositional substitution rather than an interaction arising at a particular level.

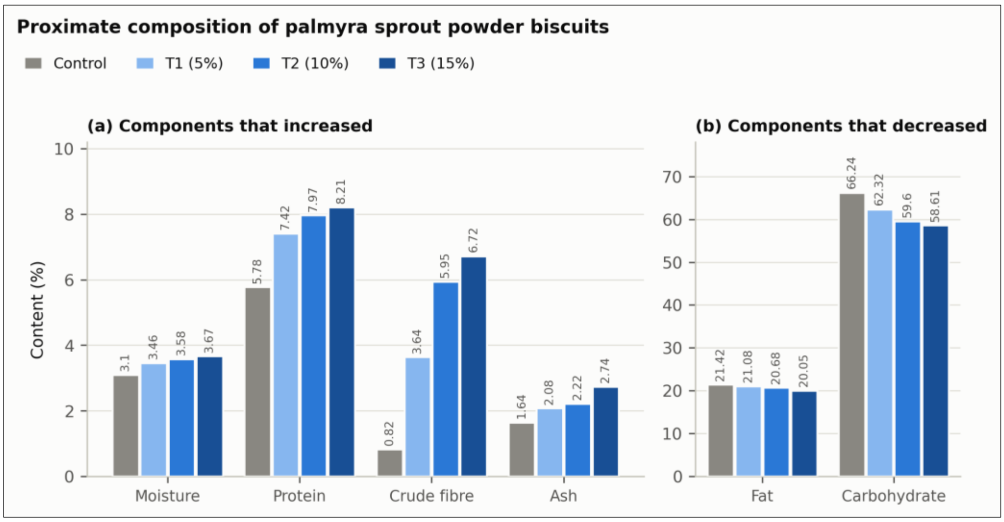

Fig 4: Proximate composition of palmyra sprout powder incorporated biscuits, separated by scale: (a) moisture, protein, crude fibre and ash; (b) fat and carbohydrate.

3.3 Moisture content

Moisture content increased progressively from 3.10 per cent in the control to 3.46, 3.58 and 3.67 per cent in T_1, T_2 and T_3 respectively, an increase of 0.57 percentage points or 18 per cent. All the values remained below 4 per cent, which is of practical importance, since the microbiological stability and crisp texture of biscuits are dependent on the product remaining dry.

The trend may be attributed to the water binding capacity of the added fibre, the water absorption capacity of palmyra haustorium flour being about 2.8 (Vengaiah *et al.,* 2019) [14], appreciably higher than that of refined wheat flour. Bharddwwaj and Sivakami (2025) recorded 28 days of ambient shelf stability for palmyra tuber flour products, indicating controlled moisture in spite of substantial incorporation, whereas Antić *et al.* (2023) [3] observed a decline from 4.15 to 3.84 per cent in beetroot powder biscuits, attributing the same to water being held in the bound rather than the free state. The apparent contradiction is resolved when bound and free water are distinguished, as a fibre rich powder can raise total moisture while lowering the fraction available for microbial growth. Álvarez-Castellanos *et al.* (2023) [2] similarly reported greater moisture retention in artichoke fibre enriched biscuits and treated it as an advantage, since improved water holding afforded better control over weight loss and surface browning. Hence, the rise observed may be regarded as a controlled consequence of fibre addition and not as a quality risk, as confirmed in Section 3.8.

3.4 Protein content

Protein content increased from 5.78 per cent in the control to 7.42, 7.97 and 8.21 per cent, the optimised formulation thus recording 38 per cent and the highest level 42 per cent more protein than the control. The major share of the gain was contributed by the first 5 per cent of substitution, which accounted for 1.64 of the total increase of 2.43 percentage points.

This diminishing return merits comment, since palmyra sprout flour contains only about 5.4 per cent protein (Vengaiah *et al.,* 2019) [14] and debittered tuber flour 5.74 g per 100 g (Bharddwaj and Sivakami, 2025) [5], both close to or below refined wheat flour, and hence substitution by itself cannot account for an increase of 38 per cent. The same may be attributed to the estimation of protein from total Kjeldahl nitrogen using the factor 6.25, as palmyra tissue contains non protein nitrogen in the form of free amino acids, alkaloids and other nitrogenous phytochemicals (Aadhithyan *et al.,* 2025) [1]. Kjeldahl nitrogen therefore overestimates true protein in phytochemical rich materials, and the present values are better designated as crude protein (Nielsen, 2017) [8]. Bharddwwaj and Sivakami (2025) recorded protein, fibre, iron and calcium enrichment in all five palmyra tuber flour products, whereas Antić *et al.* (2023) [3] observed a slight decline from 9.17 to 8.94 per cent in beetroot biscuits, since beetroot powder is lower in protein than the flour replaced. It may thus be inferred that the compositional outcome is governed entirely by the composition of the substituting material.

3.5 Crude fibre content

Crude fibre recorded by far the largest change and constitutes the principal nutritional achievement of the study. The value increased from 0.82 per cent in the control to 3.64, 5.95 and 6.72 per cent, representing increases of 4.4, 7.3 and 8.2 fold respectively. The optimised formulation thus furnished more than seven times the crude fibre of the control while recording higher scores than the control for all sensory attributes, which is an unusually favourable combination, as fibre enrichment ordinarily involves a sensory penalty.

The magnitude is in conformity with the raw material, debittered palmyra tuber flour containing 7.71 g fibre per 100 g (Bharddwaj and Sivakami, 2025) [5], nearly fifteen times that of refined wheat flour. The increment from 10 to 15 per cent was proportionately much smaller, being 0.77 points as against 2.31 points for the preceding step, which suggests that a portion of the fibre becomes bound in the baked matrix and is not recovered during acid and alkali digestion. Antić *et al.* (2023) [3] recorded an increase in total dietary fibre from 6.1 to 7.60 per cent in beetroot biscuits, the smaller relative gain being on account of the fibre already present in their base formulation. Reynolds *et al.* (2019), on the basis of 185 prospective studies and 58 trials, established that risk reduction continues up to about 25 to 29 g fibre per day, and hence fibre delivered through a habitually consumed food contributes along this curve.

Ranasinghe *et al.* (2025) [10] further demonstrated that fibre enrichment retarded starch hydrolysis *in vitro*, which is in agreement with the low glycaemic index reported for palmyra sprout. The fibre content of 6.72 per cent in T_3 coincided with the lowest sensory scores, and together these define the practical ceiling for enrichment.

3.6 Ash content

Ash content increased from 1.64 per cent in the control to 2.08, 2.22 and 2.74 per cent, amounting to an increase of 67 per cent at the highest level. Unlike protein and fibre, the increase was steeper at the upper end, the increment from 10 to 15 per cent being 0.52 points as against 0.14 points from 5 to 10 per cent.

The same may be attributed to the mineral density of the raw material, palmyra haustorium flour containing about 5.0 per cent ash with 265 mg calcium, 290 mg phosphorus and 4 mg iron per 100 g (Vengaiah *et al.,* 2019) [14], as against roughly 0.5 per cent ash in refined wheat flour. Debittered palmyra tuber flour supplies 7.92 mg iron per 100 g, and Bharddwwaj and Sivakami (2025) identified iron and calcium enrichment as the main benefit, projecting the material as relevant to anaemia. Antić *et al.* (2023) [3] recorded a smaller rise, from 2.75 to 2.95 per cent, reflecting the lower mineral density of beetroot powder. Two qualifications may, however, be made. Ash is a proxy and not a measure of available minerals, and the same fibre and phytate rich matrix that raises it can reduce bioavailability, and hence confirmation by elemental analysis is required (Nielsen, 2017) [8]. Secondly, mineral enrichment through staple foods is a practical approach to addressing micronutrient deficiency where refined cereals predominate, which constitutes a principal argument in favour of substituting underutilised starch sources into refined wheat products (Nirmani *et al.,* 2026) [9].

3.7 Fat and carbohydrate content

Fat content declined modestly from 21.42 per cent to 21.08, 20.68 and 20.05 per cent, a reduction of 6.4 per cent, whereas carbohydrate declined from 66.24 to 62.32, 59.60 and 58.61 per cent, a reduction of 7.63 points or 11.5 per cent. As the added fat was maintained constant at 30 g, the reduction in fat is essentially a dilution effect, palmyra sprout powder contributing only about 2.1 per cent lipid (Vengaiah *et al.,* 2019) [14]. The decline in carbohydrate is arithmetically the mirror image of the increases in protein, fibre and ash, since carbohydrate was obtained by difference.

This last point is of importance, as carbohydrate by difference accumulates the errors of all other determinations and either includes or excludes crude fibre depending on the convention followed, and hence the apparent reduction partly reflects the separate accounting of fibre rather than actual displacement of digestible carbohydrate (Nielsen, 2017) [8]. The nutritionally relevant fraction is available carbohydrate, the reduction in which is larger than the difference figure indicates once the fibre gain of 5.13 points in T_2 is taken into account. Ranasinghe *et al.* (2025) [10] addressed this aspect directly by measuring *in vitro* digestion and observed a slower release of glucose from fibre enriched biscuits. Bharddwwaj and Sivakami (2025) likewise reported carbohydrate displacement accompanying protein, fibre and mineral enrichment, while Antić *et al.* (2023) [3] found fat in beetroot biscuits nearly constant at about 25 per cent, confirming that fat in short dough biscuits is governed by the shortening level and not by the flour fraction. Hence, the combination obtained in the present investigation, namely lower fat, lower available carbohydrate, higher fibre and higher mineral content at an unchanged shortening level, represents the profile desired in a reformulated biscuit.

3.8 Microbiological quality during storage

The optimised formulation was microbiologically safe throughout the 14th day monitoring period (Fig. 5 and Fig. 6). Coliforms were not detected in the control or T_2 at any interval, the single most important safety finding, since coliforms in a baked low moisture product indicate post baking contamination from handling, equipment or packaging. Their absence indicates adequate hygiene during cooling, moulding and packing. Total plate count in T_2 rose from 4 times 10 cubed cfu/g at production to 15 times 10 cubed at day 7 and 23 times 10 cubed at day 14, while yeast and mould rose from 2 to 11 and then 16 times 10 cubed. Growth was steady rather than explosive but not negligible: total plate count multiplied by 5.75 and yeast and mould by 8 over 14 days. Control samples yielded no detectable growth.

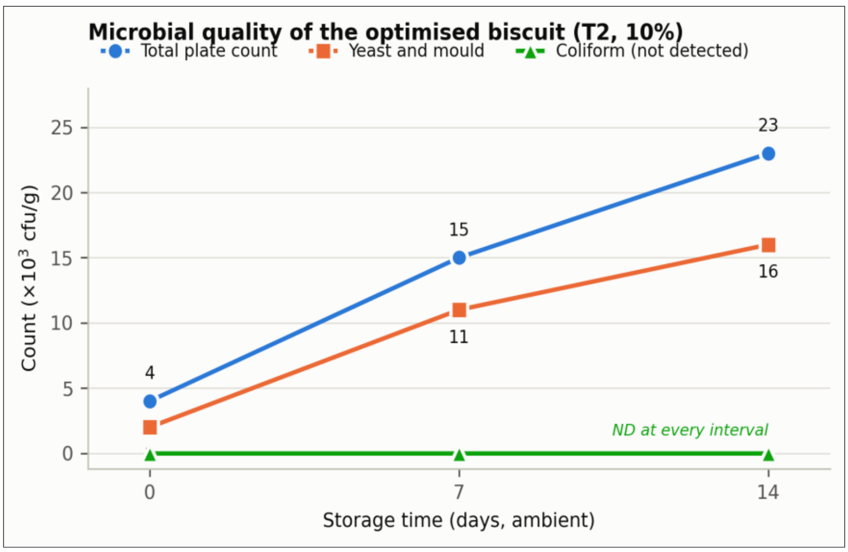

Fig 5: Microbial counts in the optimised biscuit (T_2) during 14 days of ambient storage.

Two features need care. The first is units. The original records expressed these counts with a negative exponent, which cannot be correct for a colony count; they are read here as colonies counted at the 10 to the minus three dilution, giving units of 10 cubed cfu/g, consistent with the pour plate protocol used. On that reading the day 14 yeast and mould count of 1.6 times 10 to the fourth cfu/g is not trivially low and approaches or exceeds limits commonly applied to bakery products, typically 10 squared to 10 cubed cfu/g. This does not mean the product was unsafe, since coliforms were absent and the panel detected no spoilage across 40 days, but the result should be confirmed and reported as log cfu/g against the 30 to 300 colony counting range before any commercial claim (Salfinger and Tortorello, 2015) [12]. The second feature is the contrast between a control yielding no growth and a substituted sample supporting measurable growth. Palmyra sprout powder is a dried plant material added after its own thermal processing but before baking, carrying a residual spore load and, as shown in Section 3.3, extra water binding capacity, so the substituted biscuit begins storage with a higher initial load and slightly higher moisture. The control point that matters is therefore the microbiological quality of the powder at intake, not the biscuit process.

The comparable studies indicate this is manageable. Antić *et al.* (2023) [3] confirmed microbiological safety of beetroot powder biscuits across six months, reporting water activity of 0.35 to 0.56. Bharddwwaj and Sivakami (2025) demonstrated 28th day ambient stability for palmyra tuber flour products. The justification rests on water activity rather than moisture: below 4% moisture, water activity in a short dough biscuit lies well beneath the 0.6 threshold for mould germination, so the counts reflect survival and slow proliferation of a resident population rather than active spoilage. Álvarez-Castellanos *et al.* (2023) [2] tracked fibre enriched biscuits over seven months at 25 degrees C and found stability determined by water status rather than fibre content. Extending monitoring to the full 40th day shelf life and measuring water activity directly would close the gap.

3.9 Sensory shelf life

Sensory scores of the optimised biscuit declined gradually over 40 days (Fig. 6). Overall acceptability fell from 8.0 on day 1 to 7.5 at day 10, 7.0 at days 20 and 30 and 6.5 at day 40, a loss of 1.5 points or roughly 0.4 points per 10 days. Every attribute remained above the acceptability limit of 6.0 throughout, so sensory shelf life at ambient temperature is at least 40 days, conservatively stated as 35 to 40 days.

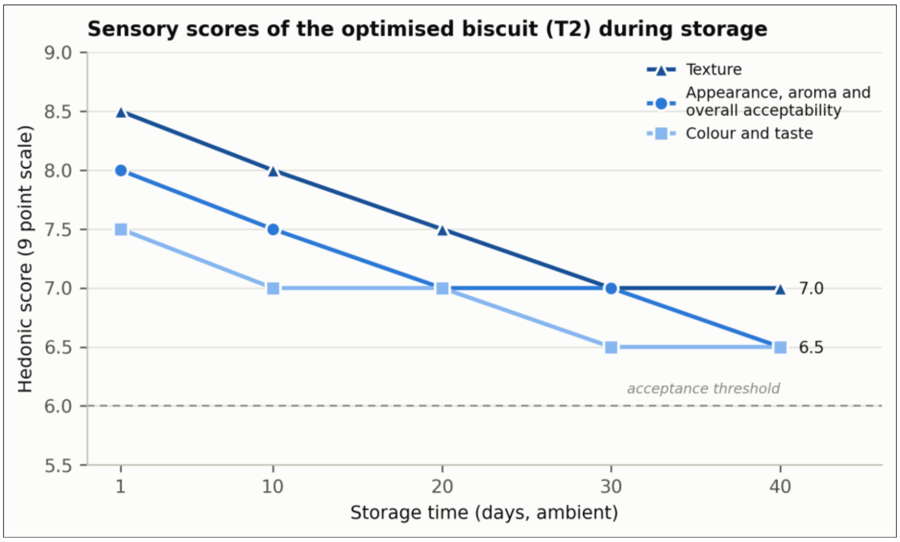

Fig 6: Sensory scores of the optimised biscuit (T_2) during 40 days of ambient storage. Attributes that shared identical trajectories in the source data are plotted as grouped series.

The pattern across attributes is informative. Texture held up best, retaining 7.0 at day 40 from 8.5, while colour and taste declined furthest, both reaching 6.5 by day 30. Appearance, aroma and overall acceptability followed an identical intermediate trajectory. Texture being most robust is notable, since moisture uptake is the classic failure mode for biscuits, and its retention indicates that packaging and the low moisture matrix limited moisture ingress effectively. Colour and taste are the attributes most exposed to lipid oxidation and slow non enzymatic browning, which proceed even at low water activity.

The comparable studies place this in context. Bharddwwaj and Sivakami (2025) reported 28th day stability for palmyra tuber flour products, so 35 to 40 days compares favourably at similar fibre loading. Antić *et al.* (2023) [3] followed beetroot biscuits for six months and found gradual loss of added functional compounds rather than of basic acceptability, suggesting the limiting factor here is sensory rather than safety. Álvarez-Castellanos *et al.* (2023) [2] recorded an approximately 30% loss of total polyphenols over seven months while fibre enriched samples retained substantially higher antioxidant capacity, a decline of the kind implied by the steady decay seen here, and Ranasinghe *et al.* (2025) [10] showed that added phenolics protect against oxidative deterioration. Since palmyra sprout is itself a source of phenolics and flavonoids (Aadhithyan *et al.*, 2025) [1], part of the stability observed here may come from endogenous antioxidants, a hypothesis testable by measuring peroxide value and total phenolics across storage. Packaging was not varied here but is the main lever for extending shelf life. Biscuits fail through moisture ingress and lipid oxidation, so a high barrier to water vapour and oxygen is required. Metallised or laminated films outperform low density polyethylene, polypropylene or biaxially oriented polypropylene used alone, and Antić *et al.* (2023) [3] attributed part of their storability to a controlled water activity range.

4. Conclusion

Palmyra sprout can be converted by washing, peeling, cutting, boiling, tray drying, milling and sieving into a powder suitable for direct substitution into biscuits, improving nutritional profile without any process change or change to added fat and sugar. Substituting 10% of the refined wheat flour was optimal. That formulation raised crude fibre more than sevenfold, from 0.82% to 5.95%, crude protein by 38% from 5.78% to 7.97% and ash by 35% from 1.64% to 2.22%, while reducing fat from 21.42% to 20.68% and carbohydrate from 66.24% to 59.60%. Critically it scored higher than the control on every sensory attribute, 8.9 for overall acceptability against 7.30. Fibre enrichment normally exacts a sensory penalty; the absence of one at 10% is what makes this level worth recommending.

The response was not monotonic. Substitution at 5% was nutritionally useful but sensorially indistinguishable from the control, while 15% gave only marginally more fibre, 6.72% against 5.95%, yet dropped overall acceptability to 7.0 and colour to 6.5, below the control on both. The optimum at 10% is set by competition between the fibre and flavour complexity palmyra sprout powder contributes and the bitterness, darker colour and gluten dilution accompanying it. The optimised biscuit was microbiologically safe: coliforms were absent throughout, and although total plate count and yeast and mould increased over 14 days, no spoilage was detected. Sensory acceptability stayed above threshold through 40 days, texture being the most stable attribute and colour and taste the least. Palmyra sprout powder is therefore a viable functional ingredient for biscuits, offering nutritional enrichment while creating a market for an underutilised indigenous crop. Further work should confirm the crude protein increase by amino acid analysis, measure water activity, extend microbiological monitoring across the full 40 days, quantify texture instrumentally, determine mineral bioavailability, and compare barrier packaging, since moisture ingress and oxidation rather than microbial growth appear to set the practical limit.

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