



RESEARCH COMMUNICATION

Effect of bio-control agents and harvesting time on storage quality of *Colocasia esculenta* (L.) Schott cormels

Dristi Barman¹, Sheriful Alam¹, Dipom Saikia^{1,2}, Tanishka Saikia^{1*}, Munmi Bora¹, Soumitra Goswami¹,
Rinku Moni P³, Ira Sarma¹, Nayanmoni Buragohain¹ & Reemashree Das¹

¹Department of Horticulture, Assam Agricultural University, Jorhat 785 013, Assam, India

²Department of Food Technology, Faculty of Engineering and Technology, Rajiv Gandhi University, Doimukh 791 112, Assam, India

³Horticultural Research Station, Assam Agricultural University, Kahikuchi 781 017, Assam, India

*Correspondence email - tanishka.saikia80@gmail.com

Received: 20 October 2025; Accepted: 21 April 2026; Available online: Version 1.0: 21 June 2026

Cite this article: Dristi B, Sheriful A, Dipom S, Tanishka S, Munmi B, Soumitra G, Rinku MP, Ira S, Nayanmoni B, Reemashree D. Effect of bio-control agents and harvesting time on storage quality of *Colocasia esculenta* (L.) Schott cormels. Plant Science Today. 2026; 13(sp2): 1-9.
<https://doi.org/10.14719/pst.12351>

Abstract

An experiment was conducted to investigate the combined effect of bio-control agents (BCAs) and harvesting time on the post-harvest storage quality of *Colocasia esculenta* (L.) Schott cormels. Cormels of the cultivar 'Ahina' were pre-treated with two BCAs: Biogreen-5 and Bio-veer, followed by planting in early February, 2024, with an untreated control. Harvesting was done in September, October and November of the same year and stored under shade condition ($28 \pm 2^\circ\text{C}$, $85 \pm 2\%$ RH). A factorial randomised block design (FRBD) with nine treatment combinations was used to assess physico-chemical quality changes across storage intervals. Results revealed that harvesting time significantly influenced quality parameters, with November-harvested cormels recorded higher starch content (up to 75.15 %), amylopectin (84.92 %), crude protein (9.11 %) and dry matter content (26.10 %), concomitantly reduced rotting percentage and physiological weight loss. Application of BCA especially Biogreen-5, notably improved storage quality by reducing pathogen-induced spoilage and enhancing nutrient accumulation. A pronounced interaction effect was observed, with the H3B1 treatment (November harvest $\times$ Biogreen-5) performing best across all parameters. Changes in sugar, starch and protein content were observed during storage. Harvesting in November combined with Biogreen-5 treatment improved storage quality and reduced losses under ambient storage conditions.

Introduction

Taro, *Colocasia esculenta* (L.) Schott, a tropical/subtropical tuber crop belonging to the family Araceae and genus *Colocasia*, is grown widely for its edible leaves and corm (1, 2). Taro is often propagated vegetatively using cormels, which are mostly grown in well-drained agricultural systems that are either rain-fed or irrigated (3). Two varieties of *Colocasia* are primarily grown in India: Dasheen or Bunda (*C. esculenta* var. *esculenta*) and Eddoe (*C. esculenta* var. *antiquorum*). Taro is considered a valuable staple and subsistence crop in many developing countries due to its high carbohydrate content, particularly starch, which may constitute approximately 70–80% of the dry matter of the corm (1, 4). In addition to serving as an energy-rich food source, taro is processed into various food products such as flour, paste, chips and fermented preparations, thereby contributing to household food security and rural livelihoods. The crop also possesses potential industrial value owing to the unique physicochemical properties of its starch, which can be exploited in food formulations and other value-added applications (5).

Globally, Taro is cultivated on about 1.9 M ha with an annual production of 12.39 Mt (6). In India, it occupies 40000 ha with a

production of 0.606 Mt, highlighting its importance as a tuber crop (7). Taro is typically harvested 6-13 months after planting, with most of the crop occurring in March and April. After harvesting, the corms are placed in the shade for natural drying. For planting in the next season, growers often choose healthy cormels between October and December and store them for 3–4 months (8). Sometimes they are kept in pits; however, the cormels degrade because of a lack of airflow, rodent attacks and microbial growth. Like other tuber crops, lack of appropriate storage techniques leads to significant post-harvest losses. In a storage period of 2–5 months, losses of roughly 50–90 % have been documented (8). Physical damage, such as punctures, cuts and abrasions sustained during harvest, is mostly to blame for these losses, as it accelerates moisture loss and increases cormel degradation. Stored tuber sprouting and tissue breakdown further contribute to post-harvest losses (9).

Soil-borne post-harvest pathogenic fungi such as *Fusarium solani*, *Botryodiplodia theobromae*, *Rhizopus stolonifera*, *Aspergillus niger* and *Sclerotium rolfsii*, well establish themselves on corms and cormels at the time of harvest, causing spoilage through wound infection (10). Therefore, controlling these pathogens by using bio-control agents such as *Trichoderma viride*, *Trichoderma harzianum*, *Pseudomonas fluorescens*, *Bacillus subtilis*, etc., may enhance the

shelf life of the taro cormels. A bio-control agent (BCA) is a living organism or a combination of such organisms, viz., fungus, bacterium, virus, nematode, insect, etc., that suppresses, reduces, or manages the population of harmful pests and pathogens in agriculture or natural ecosystems (11–13).

Previous literature has documented post-harvest losses in taro and the individual application of biological control agents (BCAs) for improving crop health and productivity (14, 15). Nonetheless, information regarding the combined influence of cultivation practices and post-harvest management strategies on the storage performance of *Colocasia* cormels remains sporadic. In particular, the potential interaction between harvesting time and pre-plant BCA treatment and its implications for storage stability has not been sufficiently explored. Therefore, the present study examined this interaction to determine the most effective strategy for shelf-life extension. In addition, changes in key physicochemical and quality attributes across the storage period were evaluated to better understand deterioration patterns. Such information may contribute to the development of improved management strategies aimed at minimising post-harvest losses and enhancing the storage potential of taro.

Materials and Methods

Raw materials and geographical location

The planting material was procured from the Experimental Farm, Department of Horticulture, Assam Agricultural University, Jorhat-13. The experimental site was located at 26°47' N latitude and 94° 122' E Longitude, at an elevation of 86.9 m above mean sea level. The topography of the land was uniform. Jorhat falls within the upper Brahmaputra valley agro-climatic zone of Assam. The climatic condition is humid and sub-tropical, having hot summers and mild winters with high relative humidity (> 80 %). The total rainfall is about 2200 mm, but unevenly distributed throughout the year. The intensity of rainfall is highest in the monsoon season, which normally begins from the first week of June; however, pre-monsoon rainfall is received in March/April. The intensity of the rainfall decreases from August onwards and lasts up to October. During November to March, scanty rainfall occurs. The maximum temperature ranges from 34–37 °C and the minimum from 8–11 °C. The experiment was conducted during 2024–2025 using the variety Ahina. The Ahina cultivar, often referred to as the eddoe type, is primarily grown as a kharif crop. It is a member of the botanical group of tubers known as *C. esculenta* var. *antiquorum*. There are a few dry scales on the smooth tubers and the flesh is white. These tubers are spherical, small and top shaped.

Soil condition

The soil texture at the experimental site was classified as sandy loam, with a pH of 5.1, bulk density of 1.22 g cm⁻³ and water holding capacity of 15.66 %. The soil was rich in organic matter, including organic carbon (0.64 %) and soil microbial biomass carbon (254.62 µg C g⁻¹) and exhibited adequate levels of nitrogen (215.58 kg ha⁻¹), phosphorus (35.74 kg ha⁻¹) and potassium (106.85 kg ha⁻¹).

Planting and storage

Before planting, the field was prepared by one ploughing and two subsequent harrowing. Well-decomposed farm yard manure (FYM) was applied before the final harrowing and levelling was done uniformly. 30 cm deep pits were dug at a spacing of 90 cm × 75 cm.

Simultaneously, the bio-formulations were prepared by mixing 5 kg of each BCA with 50 kg of well-decomposed FYM, followed by storing them in a cool and dry place covered with gunny bags, to facilitate the growth of beneficial microbes, for about a week. Disease-free and uniform-sized cormels weighing 40–50 g were selected for planting.

Planting was carried out during the first week of February 2024 in 27 experimental plots covering a total net area of 682 m², with 30 plants established per plot. Planting pits were first filled with rice stubble and straw, followed by the application of 100 g of bio-formulation (Biogreen-5 or Bioveer) to enhance early establishment and protection against soil-borne pathogens. Subsequently, one cormel was placed in each pit and finally covered with paddy straw to help maintain adequate soil moisture, thereby facilitating rapid sprouting, root establishment and improved plant vigour. Manual weeding was done to keep the plot weed-free throughout the crops' growing period. To facilitate proper aeration and cormel growth, earthing up and hoeing were carried out at regular intervals.

Harvesting was done in the 1st week of September, October and November, 2024, respectively, by uprooting the plants with the help of a spade. After harvesting, taro cormels were thoroughly cleaned and washed to remove adhering soil and debris. The cleaned cormels were then cured under ambient conditions (28 ± 2 °C, 85 ± 2 % RH) to allow surface drying and healing of minor injuries. Following curing, the cormels were separately stored in well-ventilated crates under a shade, to facilitate proper aeration and minimise post-harvest deterioration during the storage period, i.e., from harvesting till January (Fig. 1–6). Each treatment consisted of approximately 250 nos. of cormels (divided into 3 replications), with each replication weighing 5 kg (approximately 65 nos.).

Description of treatment combinations

The study was laid out using a Factorial randomised block design (FRBD) with two factors, each having three levels, constituting 9 treatments, that were replicated three times. Treatment combinations are represented in Table 1. Biogreen-5 and Bioveer are the talc-based microbial bio-formulations developed under the DBT-NECAB and Assam Agricultural University framework. Biogreen-5 is designed to control both pests and diseases, containing a mixture of five beneficial microorganisms, viz. *T. viride*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Bacillus thuringiensis* and *P. fluorescens*. It works by suppressing pathogenic fungi, controlling insect pests through entomopathogenic microbes and enhancing pro-microbial populations in the rhizosphere. Bio-veer, on the other hand, contains the fungus *T. viride* (strain WP-391). It works by suppressing fungal pathogens through mycoparasitism and producing antifungal

Table 1. Treatment combinations

Treatments	Factor A - harvesting time	Factor B - biocontrol agents (BCA)	Treatment combinations
T ₁	H ₁ - September	B ₁ - Biogreen	H ₁ B ₁ (September biogreen)
T ₂		B ₂ - Bioveer	H ₁ B ₂ (September bioveer)
T ₃		B ₃ - No BA	H ₁ B ₃ (September No BA)
T ₄	H ₂ - October	B ₁ - Biogreen	H ₂ B ₁ (October biogreen)
T ₅		B ₂ - Bioveer	H ₂ B ₂ (October bioveer)
T ₆		B ₃ - No BA	H ₂ B ₃ (October No BA)
T ₇	H ₃ - November	B ₁ - Biogreen	H ₃ B ₁ (November biogreen)
T ₈		B ₂ - Bioveer	H ₃ B ₂ (November bioveer)
T ₉		B ₃ - No BA	H ₃ B ₃ (November No BA)



Fig. 1. Cormels harvested in October at the initial day of storage.

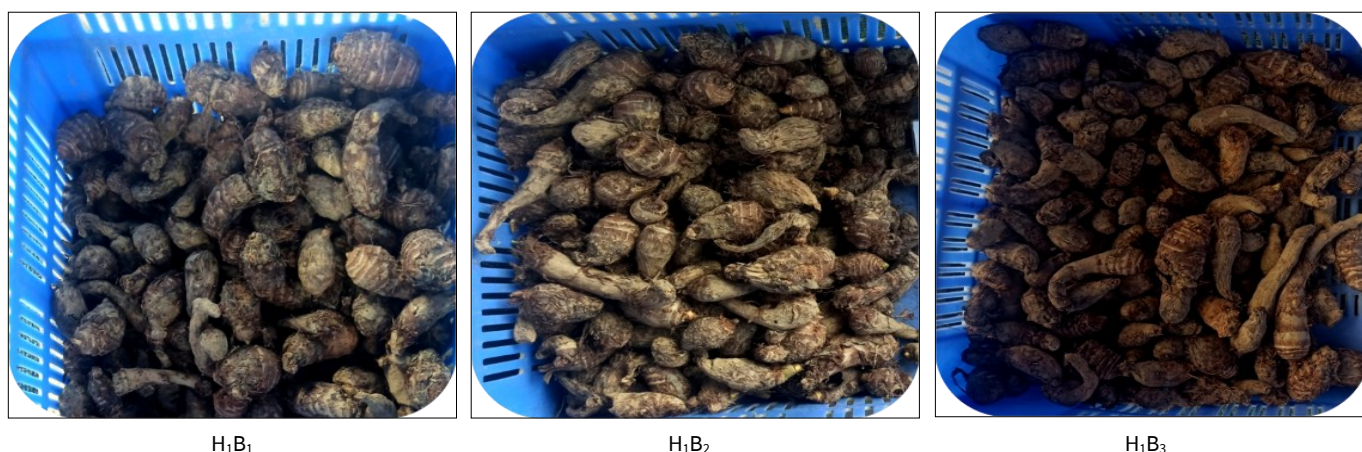


Fig. 2. Cormels harvested in October at the initial day of storage.



Fig. 3. Cormels harvested in November at the initial day of storage.



Fig. 4. Cormels harvested in September at the initial day of storage.

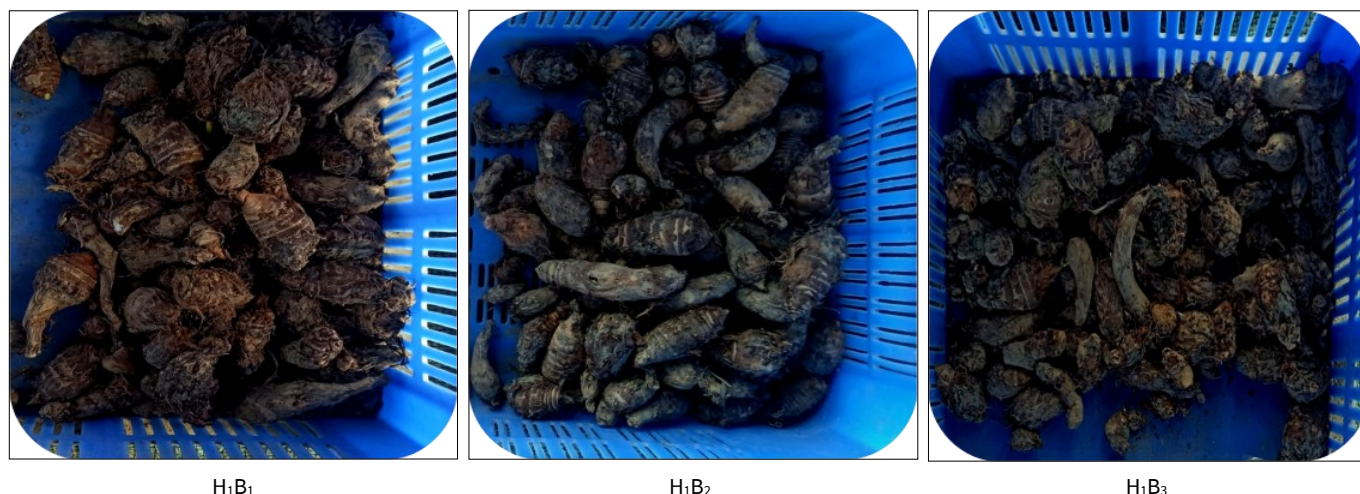


Fig. 5. Cormels harvested in October at the final day of storage.

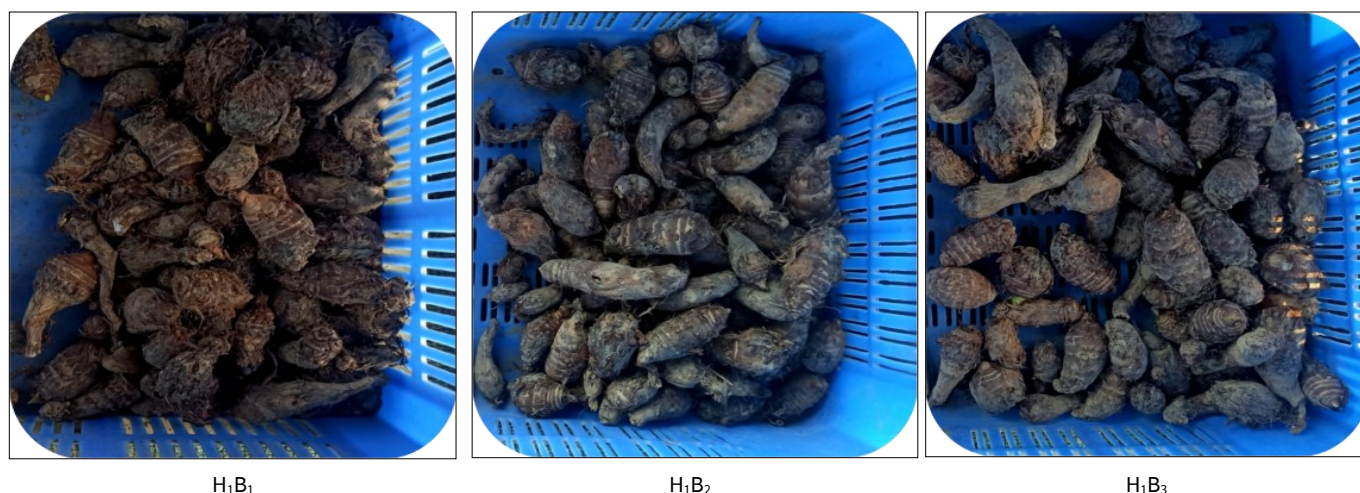


Fig. 6. Cormels harvested in November at the final day of storage.

compounds.

Determination of physicochemical attributes

The physico-chemical attributes of the cormels were recorded in 3 replications and observed first at the time of harvest, i.e., 0th day after storage (DAS) and second from November 2024 to January 2025, at an interval of 30 days irrespective of the time of harvest, as represented in Table 2 and 3. For the storage study, all harvested cormels were cured and subsequently stored under identical ambient conditions (28 ± 2 °C, 85 ± 2 % RH). To maintain consistency in storage duration across treatment, observations were recorded starting from November 2024 and thereafter at 30 days interval until January 2025, irrespective of the original harvest date. Thus, the measurements correspond to comparable storage

periods across treatments.

Total starch content of taro dry matter was determined according to AACC Method 76.13 (16) with slight modifications. Following incubation, the reaction mixtures were centrifuged and 1 mL of the supernatant was diluted with 2 mL of distilled water. Glucose concentration was measured using a YSI 2700 Biochemistry analyser (Yellow Springs, OH, USA). Control samples without enzyme treatment were included to determine free glucose and maize starch was used as a standard to verify enzyme activity. Starch content was calculated using Equation 1:

$$\text{Starch content} = 0.9 \times (\text{glucose after incubation} - \text{blank glucose}) \quad (\text{Eqn. 1})$$

Table 2. Starch, amylose, amylopectin, crude protein, dry matter, total sugar and No. of cormels at harvest (0th day)

Harvesting time	Biocontrol agents	Starch (%)	Amylose (%)	Amylopectin (%)	Crude protein (%)	Dry matter (%)	Total sugar (%)	No. of cormels
H ₁	B ₁	69.24	20.09	79.91	7.17	18.24	5.11	196.67
	B ₂	69.20	20.05	79.95	7.15	18.18	5.08	208.00
	B ₃	68.07	19.09	80.91	7.07	17.45	5.06	209.00
H ₂	B ₁	72.12	18.12	81.88	8.17	21.16	4.12	152.33
	B ₂	72.10	18.05	81.95	8.10	21.11	4.10	163.67
	B ₃	71.09	17.11	82.89	8.03	20.40	4.08	177.33
H ₃	B ₁	75.15	16.07	83.93	9.11	26.10	3.13	81.00
	B ₂	75.11	16.01	83.99	9.09	26.09	3.11	99.67
H ₃	B ₃	74.07	15.08	84.92	9.03	25.37	3.07	107.33
Factors		C.D. (0.05 %)						
Harvesting time - H		0.201	0.158	0.158	0.189	0.301	0.180	35.903
Biocontrol agents - B		0.201	0.158	0.158	NS	0.301	NS	NS
H × B		NS	NS	NS	NS	NS	NS	NS

*Values are mean of 3 replications; CD: Critical difference; NS: Non-significant.

Table 3. Starch, amylose, amylopectin, total sugar, crude protein, dry matter content, PLW, rotting percentage, no. of cormels at different storage duration

Treatment combination	Storage life (DAS)	Starch (%)	Amylose (%)	Amylopectin (%)	Total sugar (%)	Crude protein (%)	Dry matter (%)	PLW (%)	Rotting percentage (%)	No. of cormels
H ₁ B ₁	90	61.13	17.10	82.90	7.27	5.13	23.18	34.55	25.42	146.67
H ₁ B ₂	90	61.10	17.08	82.92	7.08	5.12	23.08	36.63	29.35	147.00
H ₁ B ₃	90	60.06	16.14	83.86	7.02	5.01	22.35	40.50	33.89	138.33
H ₂ B ₁	60	69.14	16.13	83.87	5.13	6.19	25.11	21.18	14.63	130.33
H ₂ B ₂	60	69.10	16.08	83.92	5.07	6.10	25.09	22.35	18.08	135.33
H ₂ B ₃	60	68.10	15.16	84.84	5.05	6.06	24.36	28.09	21.70	139.33
H ₃ B ₁	30	73.12	15.14	84.86	4.12	8.20	28.15	10.27	2.86	78.67
H ₃ B ₂	30	73.04	15.11	84.89	4.10	8.10	28.12	11.09	4.03	95.67
H ₃ B ₃	30	72.06	14.10	85.90	4.07	8.07	27.36	11.23	5.41	101.33
H ₁ B ₁	120	58.12	16.05	83.95	8.12	4.15	25.16	19.89	35.87	131.33
H ₁ B ₂	120	58.09	16.03	83.97	8.10	4.13	25.14	19.96	40.64	130.33
H ₁ B ₃	120	57.03	15.08	84.92	8.03	4.08	24.40	23.37	46.5	121.00
H ₂ B ₁	90	66.12	15.12	84.88	6.16	5.17	27.18	17.49	23.39	118.67
H ₂ B ₂	90	66.10	15.11	84.89	6.13	5.15	27.13	18.38	27.05	123.33
H ₂ B ₃	90	65.11	14.06	85.94	6.04	5.10	26.41	22.99	34.04	122.33
H ₃ B ₁	60	71.15	14.13	85.87	5.21	7.17	30.12	12.92	7.06	75.33
H ₃ B ₂	60	71.12	14.08	85.92	5.10	7.09	30.10	13.59	9.30	81.33
H ₃ B ₃	60	70.09	13.15	86.85	5.04	7.04	29.41	14.58	12.46	94.67
H ₁ B ₁	150	55.09	15.04	84.96	9.17	3.14	28.11	24.03	49.82	113.00
H ₁ B ₂	150	55.07	15.01	84.99	9.11	3.11	28.07	23.79	53.43	113.67
H ₁ B ₃	150	54.04	14.74	85.26	9.04	3.10	27.36	28.35	60.95	103.67
H ₂ B ₁	120	64.16	14.10	85.90	7.25	4.16	30.15	21.06	32.95	107.33
H ₂ B ₂	120	64.11	14.05	85.95	7.17	4.10	30.11	22.04	37.23	110.33
H ₂ B ₃	120	63.08	13.10	86.90	7.09	4.05	29.73	27.46	47.18	106.33
H ₃ B ₁	90	69.13	13.18	86.82	6.15	6.16	33.15	16.54	13.24	70.67
H ₃ B ₂	90	69.10	13.10	86.90	6.12	6.12	33.10	17.48	16.95	75.00
H ₃ B ₃	90	68.04	12.15	87.85	6.05	6.10	32.43	18.46	21.79	85.67
Factors		C.D. (0.05 %)								
ST		0.000	0.000	0.000	0.000	0.000	0.000	0.149	0.000	0.000
HT		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BA		0.000	0.000	0.000	0.103	0.103	0.000	0.004	0.030	0.751
HT × BA		1.000	0.927	0.927	0.993	0.993	0.983	0.541	0.983	0.562

*Values are mean of three replications; DAS : Days after storage; PLW : Physiological loss in weight; CD : Critical difference.

All analyses were performed in triplicate and results are reported as mean values. Amylose and amylopectin contents of taro cormels were determined following the method (17). Approximately 50 mg of sample was gelatinised and subsequently debranched using isoamylase at 50 °C for 2 h. An aliquot (1 mL) of the debranched solution was analysed using a PL-GPC 120 GPC/SEC system (Polymer Laboratories Ltd., Church Stretton, UK) equipped with a 7.8 mm × 300 mm Ultrahydrogel™ TM250 column (Waters, Milford, MA, USA), a guard column (Phenomenex Inc., Lane Cove, Australia) and a refractive index detector maintained at 60 °C. The injection temperature was 40 °C and 0.05 M ammonium acetate (pH 4.75) was used as the mobile phase at a flow rate of 0.5 mL min⁻¹. Amylose and amylopectin fractions were identified from the chromatographic profile based on characteristic peak patterns for taro samples. Following baseline correction and normalisation of detector response, the areas under the peaks corresponding to starch, amylose and amylopectin fractions were calculated to estimate their respective contents.

Total sugars were determined using the phenol-sulfuric acid colourimetric method (18). The wavelength of maximum absorbance (λ_{max}) was first identified by reacting a D-glucose standard solution with 5 % phenol and concentrated H₂SO₄ and scanning the absorbance between 400–800 nm using a UV-Vis spectrophotometer, with a reagent blank prepared similarly without glucose. For analysis, sugar extracts obtained from the sample were appropriately diluted and 1 mL of the diluted solution was reacted with 1 mL of 5 % phenol and 5 mL of concentrated H₂SO₄. After incubation and cooling, absorbance was measured at λ_{max} and total sugar content was quantified spectrophotometrically against the blank.

Using the Kjeldahl method, crude protein was calculated by multiplying the total nitrogen content by a factor of 6.25. Initially, digestion of the sample was done at 400 °C with concentrated sulfuric acid in the presence of copper sulfate and potassium sulfate (1 : 1 w/w) as catalysts (19). The organic nitrogen was converted into an inorganic form of ammonium sulphate. The formed ammonium sulphate was then distilled with a strong alkali (40 % NaOH), leading to release of ammonia, which was then collected in a solution of 4 % boric acid as ammonium borate. Finally, it was titrated against standard hydrochloric acid (0.1N).

Total nitrogen (%) =

$$\frac{(\text{mL of titrant} - \text{mL of blank}) \times N \times 14 \times 100}{(\text{Weight of sample (g)} \times 1000)} \quad (\text{Eqn. 3})$$

where N is the normality of hydrochloric acid used.

$$\text{Protein (\%)} = \text{Nitrogen (\%)} \times 6.25 \quad (\text{Eqn. 4})$$

Dry matter content was quantified by a simple drying method. Fresh mass of cormel was mashed in a chilled mortar-pestle to obtain a uniform extract. The sample was then dried in a hot-air oven (KGUD-121, Spector Litt, Ambala Cantt, Haryana, India) at 55 °C for 48 hr until a constant weight was achieved. The dry matter (DM) content was calculated using Equation 5:

$$\text{DM (\%)} = \left\{ \frac{\text{weight of the oven-dried sample (g)}}{\text{weight of the fresh sample (g)}} \right\} \times 100 \quad (\text{Eqn. 5})$$

Physiological loss in weight (PLW%) was calculated by Equation 6.

$$\text{PLW (\%)} = \frac{(\text{Final weight (g)} - \text{Initial weight (g)})}{\text{Initial weight (g)}} \times 100 \quad (\text{Eqn. 6})$$

Cornel numbers were recorded after discarding the rotten cornels at harvest time and at each observation interval.

Rotting percentage (%) was determined by Equation 7.

$$\text{Rotting \%} = (\text{No. of rotted cornels} / \text{total No. of cornels}) \times 100 \quad (\text{Eqn. 7})$$

Statistical analysis

The experiment was laid out using a FRBD consisting of two factors - harvesting time (three levels) and bio-control treatment (three levels); a two-way analysis of variance (ANOVA) was performed at harvesting to evaluate the main and interaction effects of the factors and analysis of covariance (ANCOVA) was performed for the storage period to compare the means of harvesting time and treatment as the fixed factors and storage duration as the covariate. The significance among the treatments was further determined using least significant difference (LSD) analysis. Each sample was analysed in triplicate and the results are presented as mean values. The data were evaluated statistically using 'R software' with appropriate packages (stats; car; emmeans; agricolae) (version 4.5.1), to find out critical difference within 95 % confidence interval ($p \leq 0.05$).

Results and Discussion

Starch content

Starch content gradually increased with the delay in harvesting time and recorded a maximum in November (H_3) harvested cornels (74.07–75.15 %), which was complemented by the application of Biogreen-5 (B_1). During the early stages of development, carbohydrates are used for vegetative growth and as the plant matures, the growth rate decreases, resulting in the conversion of carbohydrates into starch for storage. Higher starch content in Biogreen-5-treated cornels may be associated with improved plant growth and reduced pathogen incidence (20, 21). Increased nutrient uptake leads to higher chlorophyll levels and a faster rate of photosynthesis, which causes more carbohydrate accumulation in the form of starch (Table 2). The activity of hydrolysis of starch to simpler sugars by alpha-amylase was recorded as low at harvest and rose significantly to higher levels across storage (22) (Table 3).

Amylose and Amylopectin content

Amylose content was found to be highest (19.09–20.09 %) in early harvested cornels (September- H_1), while amylopectin content was found to be maximum (83.93–84.92 %) in the later harvested cornels (November- H_3). During the growth and maturation of taro cornels, the composition of starch structure (amylose-amylopectin ratio) changes from linear chain amylose to branched amylopectin, resulting in a lower amylose-amylopectin ratio. Furthermore, the application of bio-control agent significantly ($p > 0.05$) affected the same. The maximum (16.07–20.09 %) amylose content was found in B_1 (Biogreen-5) and the minimum (15.08–19.09 %) was in B_3 (No Bio-control agent). However, higher amylopectin content (80.91–84.92 %) was found in B_3 and the lower (79.91–83.93 %) in B_1 (Table 2). BCAs may modulate starch biosynthetic enzymes, through plant growth-promoting microorganisms, by enhancing starch synthase activity while suppressing starch branching enzyme activity, thus favouring linear glucan formation, reducing amylopectin synthesis and altering the amylose-amylopectin ratio via phytohormone signalling and carbon partitioning (23–28). The decline in amylose

content and increase in amylopectin content in response to prolonging storage duration might be due to the enzymatic conversion of starch to sugar and amylose being linear, more accessible to enzymatic breakdown, thereby resulting in amylose content reduction (29).

Total sugar content

Total sugar content was recorded as maximum (5.06–5.11 %) in September-harvested cornels (H_1) and minimum (3.07–3.13 %) in November-harvested cornels (H_3). Due to active photosynthesis, during tuber initiation, immature cornels tend to accumulate more simple sugars, because the rate of translocation of sugars from the leaves to the cornels exceeds the rate of conversion of the same to starch. However, when the tuber reaches physiological maturity (November-harvested), a maximum of starch and a minimum of sugar accumulation occur, as shown in Table 2 (30). Due to starch hydrolysis, the amount of sugar content might have increased with the advancement of the storage period, as shown in Table 3 (31).

Crude protein content

In the early stages of physiological development, the taro plants prioritise vegetative growth, where the majority of the plants' nitrogen resources are directed towards the rapidly developing plant parts, which is reflected in the lesser content (7.07–7.17 %) of crude protein in the early September-harvested crop- H_1 (Table 2). The primary function of the mature cornels is to act as a metabolic sink, where carbohydrates and, to a lesser extent, proteins are accumulated for future use (32, 33). This process of significant storage deposition intensifies as the cornels reach maturity, as reflected in the November-harvested crop, H_3 (9.03–9.11 %). Enzymatic activity and microbial degradation break down crude protein into its monomeric units (amino acids) and the loss of moisture reduces the available soluble protein during storage (34) (Table 3).

Dry matter content

Matured cornels (November- H_3) contained significantly higher dry matter content (25.37–26.10 %). During maturation, simple sugars are converted into complex carbohydrates like starch, complemented by gradual moisture loss, which is reflected in increased dry matter content (Table 2). Correspondingly, the application of BCAs might have increased the metabolism or synthesis of phyto-hormones (auxin and gibberellins), which could have led to the solubilisation of minerals and fixation of atmospheric N_2 by plant growth-promoting rhizobacteria (*P. fluorescens*), thus augmenting plant growth. (20, 21). An upward trajectory was recorded in the dry matter content of cornels across the storage period. This might be primarily attributed to respiration, transpiration and tuber sprouting, which resulted in significant moisture reduction; moisture is inversely proportional to dry matter content. Similar literature has been reported in potato and Colocasia tubers (35–37).

Physiological loss in weight

Surface morphology of the cornels plays a significant role in the rate of respiration and transpiration, affecting physiological loss in weight (PLW), facilitated by high temperature and low atmospheric humidity (38). As the cornels matured (November- H_3), the structural characteristics of their outer skin became thicker, preventing any moisture and weight loss. Additionally, the use of BCAs protects the cornels from pathogen-induced tissue degradation, reducing moisture loss and PLW. However, sprouting of cornels during storage caused a prominent decrease in

physiological weight (39).

Number of cormels

The size and weight of cormels increased with the delay in harvesting time. Therefore, for a definite weight of treatment, November-harvested cormels (H_3) accommodated fewer units than September-harvested cormels (H_1) due to the larger size of the former harvested cormels (Table 2 and 3).

Rotting percentage

Trichoderma viride present in BCAs limit the growth of naturally present microorganisms on the tubers' surface, thereby reducing the rotting percentage in the B_1 -treated cormels, followed by the treatment B_2 (Table 3), in contrast to cormels with no BCA treatment (B_3) (40). Across storage, higher moisture levels in the immature cormels (September- H_1) along with increased breakdown of starch to sugar favoured pathogenic growth, resulting in a higher rotting percentage (Fig. 7). However, higher starch content reduced the water activity of the matured cormels



Fig. 7. Rotting of cormels during storage. (a) Rotting in stored cormels; (b) advanced rotting in cormels.

(November- H_3), eliminating the growth of pathogenic microorganisms and consequently reducing the rotting percentage (37).

Conclusion

Harvesting time and bio-control agents significantly influenced the storage quality of *Colocasia esculenta* cormels. The selected samples experienced rapid degradation in quality parameters during storage. Bio-control agent treatment reduced storage losses compared to untreated cormels, although these differences were less pronounced in certain parameters. As evidenced in this experiment, the November-harvested cormels (H_3) were the best harvesting time, while Biogreen-5 (B_1) was the best BCA, followed by Bio-veer (B_2). Among the treatment combinations, H_3B_1 (Biogreen-5 treated November harvest) retained the highest quality parameters with reduced spoilage of cormels across storage. Harvesting in November, combined with Biogreen-5 treatment, is

recommended for improving storage quality and shelf life. This finding may help farmers improve storage management and reduce post-harvest losses.

Acknowledgements

The authors acknowledge the Department of Horticulture, Assam Agricultural University, Jorhat, 785 013, Assam, India, for providing support throughout the research.

Authors' contributions

DB carried out the experiment, performed formal analysis and drafted the original manuscript. DS contributed to statistical analysis, writing and refinement of the final manuscript. TS participated in the design of the study and performed the editing of the manuscript. MB performed the plagiarism check and ensured the originality of the content. SA conceptualised the research, administered the project and supervised. SG provided valuable guidance and supervision during the experimental work. IS participated in the design and coordination. NB and RMP supported the research process. RD assisted in laboratory analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Ferdaus MJ, Chukwu-Munsen E, Foguel A, da Silva RC. Taro roots: An underexploited root crop. *Nutrients*. 2023;15(15):3337. <https://doi.org/10.3390/nu15153337>
2. Ahmed I, Lockhart PJ, Agoo EM, Naing KW, Nguyen DV, Medhi DK, et al. Evolutionary origins of taro (*Colocasia esculenta*) in Southeast Asia. *Ecol Evol*. 2020;10(23):13530–43. <https://doi.org/10.1002/ece3.6958>
3. Ahmed I. Evolutionary dynamics in taro (*Colocasia esculenta* L.). PhD [dissertation]. Palmerston North (NZ): Massey University; 2014.
4. Alcantara RM. The nutritional value and phytochemical components of taro [*Colocasia esculenta* (L.) Schott] powder and its selected processed foods. *J Nutr Food Sci*. 2013;3:207. <https://doi.org/10.4172/2155-9600.1000207>
5. Nagar CK, Dash SK, Rayaguru K, Pal US, Nedunchezhiyan M. Isolation, characterization, modification and uses of taro starch: A review. *Int J Biol Macromol*. 2021;192:574–89. <https://doi.org/10.1016/j.ijbiomac.2021.10.041>
6. Food and Agriculture Organization of the United Nations (FAO). World food and agriculture-statistical yearbook: agricultural production of primary crops. Rome: FAO; 2023.
7. Sunitha S, Laxminarayana K, Veena SS, Jyothi AN, Santhosh Mithra VS, et al. Taro. Technical Bulletin No. 96. Thiruvananthapuram (Kerala, India): ICAR-Central Tuber Crops Research Institute; 2023:42.
8. Modi AT. Effect of indigenous storage method on performance of taro [*Colocasia esculenta* (L.) Schott] under field conditions in a warm subtropical area. *S Afr J Plant Soil*. 2007;24(4):214–9. <https://doi.org/10.1080/02571862.2007.10634812>
9. Becerra-Sanchez F, Taylor G. Reducing post-harvest losses and improving quality in sweet corn (*Zea mays* L.): challenges and

- solutions for less food waste and improved food security. Food Energy Secur. 2021;10(3):e277. <https://doi.org/10.1002/fes3.277>
10. Gyasi E, Akrofi S, Adongo BA, Osafo EA, Kotey DA, Mohammed A. Fungi associated with sweet potato tuber rot at CSIR-PGRRI, Bunso, Eastern Region, Ghana. Ghana J Agric Sci. 2022;57(1):106–12. <https://doi.org/10.4314/gjas.v57i1.8>
 11. Heimpel GE, Mills NJ. Biological control: ecology and applications. Cambridge: Cambridge University Press; 2017. <https://doi.org/10.1017/9781139029117>
 12. Hernández-Rosas F, Figueroa-Rodríguez KA, García-Pacheco LA, Velasco-Velasco J, Sangerman-Jarquín DM. Microorganisms and biological pest control: an analysis based on a bibliometric review. Agronomy. 2020;10(11):1808. <https://doi.org/10.3390/agronomy10111808>
 13. Jaiswal DK, Gawande SJ, Soumia PS, Krishna R, Vaishnav A, Ade AB. Biocontrol strategies: an eco-smart tool for integrated pest and diseases management. BMC Microbiol. 2022;22(1):324. <https://doi.org/10.1186/s12866-022-02744-2>
 14. Himeda M, Njintang YN, Gaiani C, Nguimbou RM, Scher J, Facho B, et al. Physicochemical and thermal properties of taro (*Colocasia esculenta* sp) powders as affected by state of maturity and drying method. J Food Sci Technol. 2014;51(9):1857–65. <https://doi.org/10.1007/s13197-012-0697-9>
 15. Dong X, Fang L, Ye Z, Zhu G, Lai Q, Liu S. Screening of biocontrol bacteria against soft rot disease of *Colocasia esculenta* (L.) Schott and its field application. PLoS One. 2021;16(7):e0254070. <https://doi.org/10.1371/journal.pone.0254070>
 16. AACCC. Approved methods. 10th ed. St. Paul (MN): American Association of Cereal Chemists; 2000.
 17. Xie LH, Tang SQ, Wei XJ, Sheng ZH, Shao GN, Jiao GA, et al. Simultaneous determination of apparent amylose, amylose and amylopectin content and classification of waxy rice using near-infrared spectroscopy (NIRS). Food Chem. 2022;388:132944. <https://doi.org/10.1016/j.foodchem.2022.132944>
 18. Lam HH, Dinh TH, Dang-Bao T. Quantification of total sugars and reducing sugars of dragon fruit-derived sugar samples by UV-Vis spectrophotometric method. IOP Conf Ser Earth Environ Sci. 2021;947(1):012041. <https://doi.org/10.1088/1755-1315/947/1/012041>
 19. Kjeldahl J. Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. Z Anal Chem. 1883;22:366–82. <https://doi.org/10.1007/BF01338151>
 20. Vij S, Sharma N, Sharma M, Mohanta TK, Kaushik P. Application of *Trichoderma viride* and *Pseudomonas fluorescens* to cabbage (*Brassica oleracea* L.) improves both its seedling quality and field performance. Sustainability. 2022;14(13):7583. <https://doi.org/10.3390/su14137583>
 21. Awad-Allah EF, Shams AH, Helaly AA, Ragheb EI. Effective applications of *Trichoderma* spp. as biofertilizers and biocontrol agents mitigate tomato Fusarium wilt disease. Agriculture. 2022;12(11):1950. <https://doi.org/10.3390/agriculture12111950>
 22. Zhang Z, Wheatley CC, Corke H. Biochemical changes during storage of sweet potato roots differing in dry matter content. Postharvest Biol Technol. 2002;24(3):317–25. [https://doi.org/10.1016/S0925-5214\(01\)00149-1](https://doi.org/10.1016/S0925-5214(01)00149-1)
 23. Varghese S, Awana M, Mondal D, Rubiya MH, Melethil K, Singh A, et al. Amylose-amylopectin ratio: comprehensive understanding of structure, physicochemical attributes and applications of starch. In: Thomas S, Ajitha AR, Chirayil CJ, Bejoy Thomas Handbook of biopolymers. Singapore: Springer; 2022:1–30. https://doi.org/10.1007/978-981-16-6603-2_48-1
 24. Chowdhury SP, Hartmann A, Gao X, Borriss R. Biocontrol mechanism by root-associated *Bacillus amyloliquefaciens* FZB42-a review. Front Microbiol. 2015;6:780. <https://doi.org/10.3389/fmicb.2015.00780>
 25. Cao T, Wang S, Ali A, Shan N, Sun J, Chen X, et al. Transcriptome and metabolome analysis reveals the potential mechanism of tuber dynamic development in yam (*Dioscorea polystachya* Turcz.). LWT Food Sci Technol. 2023;181:114764. <https://doi.org/10.1016/j.lwt.2023.114764>
 26. Abdulsalami HA, Lim Y, Cho H. Genetic elements controlling starch biosynthesis and secondary growth in root and tuber crops. J Plant Biotechnol. 2024;51(1):111–20. <https://doi.org/10.5010/JPB.2024.51.012.111>
 27. Vanacore MF, Sartori M, Giordanino F, Barros G, Nesci A, García D. Physiological effects of microbial biocontrol agents in the maize phyllosphere. Plants. 2023;12(24):4082. <https://doi.org/10.3390/plants12244082>
 28. Tyagi A, Lama Tamang T, Kashtoh H, Mir RA, Mir ZA, Manzoor S, et al. A review on biocontrol agents as sustainable approach for crop disease management: applications, production and future perspectives. Horticulturae. 2024;10(8):805. <https://doi.org/10.3390/horticulturae10080805>
 29. Zhu D, Li M, Fang C, Yu J, Zhu Z, Yu Y, et al. Effects of storage on the starch fine structure and physicochemical properties of different rice variety types. Carbohydr Polym. 2023;120273. <https://doi.org/10.1016/j.carbpol.2022.120273>
 30. Singh A, Chaurasiya A, Mitra S. Assessment of nutritional composition in elephant foot yam (*Amorphophallus paeoniifolius* Dennst-Nicolson) cultivars. Int J Food Stud. 2016;5(2):146–57. <https://doi.org/10.7455/ijfs.5.2.2016.a3>
 31. Abreu-Naranjo R, Lucero Yupangui JE, Guardado Yordi E, Lara-Fiallos M, Pais-Chanfrau JM, Pérez Martínez A. Evaluation of taro (*Colocasia esculenta*) as a raw material for bioethanol production through ultrasound-assisted enzymatic hydrolysis. Fermentation. 2025;11(2):102. <https://doi.org/10.3390/fermentation11020102>
 32. Talang H, Mawlong GT, Kjam L, Devi MB, Gurung B, Biswakarma N, et al. Assessment of nutritional quality of taro (*Colocasia esculenta* L. Schott.) genotypes of the Eastern Himalaya, India. Front Nutr. 2025;12:1567829. <https://doi.org/10.3389/fnut.2025.1567829>
 33. Van LN, Binh PT, Sam VK. Changes in physicochemical, nutritional and sensory indicators of taro tubers at different harvest times. Food Sci Technol. 2023;43:e7823. <https://doi.org/10.5327/fst.7823>
 34. David-Chukwu N, Aji RU, Ndukwe KO, Odom TC, Chukwu MN. Production, proximate compositions and dry matters of stored achicha and mpoto-cocoyam based products. Int J Nutr Food Sci. 2021;10(6):144–52. <https://doi.org/10.11648/j.ijnfs.20211006.14>
 35. Bročić Z, Dolijanović Ž, Poštić D, Milošević D, Savić J. Yield, tuber quality and weight losses during storage of ten potato cultivars grown at three sites in Serbia. Potato Res. 2016;59(1):21–34. <https://doi.org/10.1007/s11540-015-9311-7>
 36. Mehta A, Singh SP. Biochemical composition and chipping quality of potato tubers during storage as influenced by fertilizer application. J Food Sci Technol Mys. 2004;41(5):542–7.
 37. Diaguna R, Santosa E, Budiman C. The effect of the taro corm type and storage on morphophysiological deterioration and early growth in the field. Int J Agron. 2023;2023:3280339. <https://doi.org/10.1155/2023/3280339>
 38. Ezeocha CV, Ironkwe AG. Effect of storage methods and period on the physiological and nutrient components of livingstone potato (*Plectranthus esculentus*) in Abia State, Nigeria. Open Agric. 2017;2(1):213–9. <https://doi.org/10.1515/opag-2017-0022>
 39. Singh A, Wadhwa N. Biochemical characterization and thermal inactivation of polyphenol oxidase from elephant foot yam (*Amorphophallus paeoniifolius*). J Food Sci Technol. 2017;54(7):2085–93. <https://doi.org/10.1007/s13197-017-2647-z>
 40. Okigbo RN, Ikediugwu FE. Studies on biological control of postharvest rot in yams (*Dioscorea* spp.) using *Trichoderma viride*. J

Phytopathol. 2000;148(6):351–5. <https://doi.org/10.1111/j.1439-0434.2000.tb04786.x>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.