



RESEARCH ARTICLE

A novel bioorganic calcium enhancement for the germination and physical growth of fodder grass, *Cenchrus ciliaris* L.

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Abstract

Global agricultural crop production relies on organic fertilisers for safer food production and ecosystem sustainability. Huge quantities of residues from eggs, the cases, are discarded day-to-day all around the world, posing a severe threat to the environment. The enormous wastage could be made beneficial to the plants as an effective calcium supplement. *Cenchrus ciliaris* L. is a perennial grass, cultivated for its palatable foliage as fodder. With an attempt to reuse the egg leftovers, a greenhouse experiment was conducted by utilising the powdered form of egg case as an organic fertiliser and a source of calcium to assess the germination potential and physical performance of *C. ciliaris*. Five diverse rates of the egg case powder, viz., 4, 8, 12, 16 and 20 g, were mixed with the potting mixture for the investigation. A chemical fertiliser, calcium nitrate and an organic chemical source, bone meal, were used for comparison along with an untreated control. The results revealed an outstanding germination potential and further plant physical growth with the egg cases acting as a calcium source for *C. ciliaris* plants. A hundred per cent germination and higher rates of growth parameters viz., leaf length, leaf breadth, leaf area, leaf production, shoot and root height were noticed in the highest dose investigated (20 g). The subsequent doses (16, 12 and 8 g) produced immense results as well. The fresh and dried biomass of *C. ciliaris* plants also yielded the highest amount for the highest dose of egg case-supplemented plants. The lowest dose (4 g) produced concordant results with the standard chemical fertiliser, calcium nitrate. Consequently, it is determined that calcium-rich egg cases can enhance the germination rates and physical performance of *C. ciliaris* plants.

Keywords: agricultural residues; bonemeal; calcium; calcium nitrate; *Cenchrus ciliaris*; egg cases; germination; organic fertiliser

Introduction

Cenchrus ciliaris L. is a highly treasured forage crop owing to its nutritive values, yield potential and ability to tolerate water deficit in arid regions and desert ecosystems (1–5). The grass is also known as buffel grass in some regions and “Subat” grass in some other parts of the world (Fig. 1). The fodder is utilised as livestock feed, while the seeds are used for bread making and are consumed by village folks in certain parts of the world (6, 7). The grass is highly palatable to livestock with high protein and nutrients, with good digestibility (8). It is tolerant of grazing and trampling, serving as ideal grass for extensive production in the form of fresh grass or as hay (9, 10). The plant is said to possess medicinal properties, anti-cancer, anti-fungal, anti-bacterial, anthelmintic and anti-amoebic activities and is broadly used to heal pain, inflammation, urinary infections and tumours (11–15). The grass is best adapted to arid and semiarid regions and widely used for erosion control and land rehabilitation programmes (16, 17) (Fig. 1).

Soil infertility is the foremost barrier affecting the productivity of any crop. Fertile soil is the base for sustainable crop production; low soil fertility may jeopardise crop establishment and productivity, threatening the food security of any region (18, 19). Chemical fertilisers are used to supply the required nutrients in the infertile soils; however, their excessive usage has given rise to environmental pollution. In addition, artificial fertilisers pose the burden of monetary

costs for their procurement. The use of organic fertilisers has been revived globally due to the need to lower the cost of fertilising crops using renewable energy sources (20). Organic fertilisers are natural substances used to improve soil fertility, providing the required nutrition for the crop. Natural plant nourishment has a major role in increasing soil fertility and is a crucial part of soil sustainability. Utilising organic fertilisers has the benefits of being inexpensive, enhancing soil aeration, structure and texture, boosting nutrient uptake and soil water retention capacity, with additional benefits of reduced erosion and soil compaction (21, 22).



Fig. 1. *Cenchrus ciliaris*.

The recycling of agricultural residues as an inexpensive organic fertiliser is widely adopted across the globe in an effort of “green ecosystem without pollution”, which has provided constructive effects on plant growth and productivity by improving

soil health and its biota (23). The strategy also enhances the ecological balance of the crop production system, promoting the restoration of ecosystems and soil biodiversity (24).

One of the agricultural residues of interest viz. remains from eggs is an incredible food left over. EU (European Union) regulations consider egg case residues as a noxious residue and dispose them in hundreds of thousands of tonnes in landfills, posing environmental pollution (25–28). A mass quantity of chicken egg cases can be easily gathered from homes, restaurants, food outlets, hatcheries, poultry farms and cake bakers (29). Calcium, as a chief component of egg cases, has a great deal of mechanical strength and is an essential dietary component for adults. Egg cases are a possible raw material for diverse applications due to the presence of elements such as boron, copper, iron, molybdenum, sulphur, silicon and zinc (30). According to reports, approximately 70 million tonnes of eggs were produced in 2014, leading to 8 million tonnes of waste from egg cases (31). China accounted for roughly 42.88 % of the world's total egg production in 2019, which experienced an increase from 73.9 million metric tonnes in 2016 to 82.17 million metric tonnes in 2019. Together, China, the US, India, Indonesia and Brazil accounted for 66.67 % of the world's egg production in 2019 (32). The average global egg consumption per person was 9.6 kg in 2015, which is expected to increase by 10.3 kg in 2030 (33). Disposal of this huge quantity of egg case residues is a lethal environmental issue (34–36). The disposal of this massive quantity of eggshell waste generated worldwide each year is challenging, since, typically, the material is dumped in landfills that produce odours and support microbial development (37). However, it can be perceived as a novel calcium source for sustained plant growth. Eggshells can be a powerful component to fertilise a crop, due to their high levels of calcium.

The egg cases can be used as an organic fertiliser for plants to accelerate their calcium requirement (38). Calcium is the major component of egg cases; they are 95–97 % calcium carbonate crystals, which are stabilised by a protein matrix, along with several other chemical components (39–41) (Table 1). The addition of egg residues in the soil improves calcium availability to plants, along with other nutrients contained in them (42–45). Calcium is a structural component of plant cell walls, regulates cell homeostasis and ion absorption and activates plant enzymes (46).

Table 1. Chemical composition of egg residues (39)

Chemical Name	Percentage (%)
Calcium carbonate	95
Calcium chloride	0.63
Sulphur trioxide	0.6
Disodium monoxide	0.3
Silicon dioxide	0.08
Aluminium dioxide	0.04
Ferric oxide	0.02
Magnesium oxide	0.01
Strontium oxide	0.013
Phosphorus oxide	0.24

Cenchrus ciliaris requires major nutrients, viz., N, P and Ca, in addition to other minor nutrients, which are needed for their performance from germination to forage production (47). The nutrients should be supplemented at the appropriate time and in the right quantities for proper growth and reproduction (48). Calcium is an essential plant nutrient required for cell wall fortification, growth and development. Symptoms of calcium deficiency in grasses are interveinal chlorosis and necrosis of the younger leaves and tissues, which reduce cell stability and integrity

and inhibit growth (49, 50). Serration and curling of the leaf tip, with the tips showing light green or whitish spots, is another symptom of calcium deficiency in grasses. Thus, calcium supplementation aid in the performance of plants.

Cenchrus ciliaris is a calcium-responsive plant that grows best in soils with high calcium content. Adequate calcium in *C. ciliaris* forage supports livestock, though deficiencies might occur, necessitating fertilisation for plant health and animal intake. For better calcium levels in *C. ciliaris* forage, ensuring fertile soils and potentially using fertilisers is recommended. The organic egg cases with high calcium content serve as a calcium supplement for *C. ciliaris* plants, to accumulate them in the foliage, for the benefit of livestock. The soil of Kuwait contains 10.4 g/kg of Calcium (1).

Considering the above, the present investigation was aimed at evaluating the bio-efficacy of egg case residues in enhancing the calcium nutrition of a native grass of Kuwait, *C. ciliaris* by assessing its germination potential and physical performance.

Materials and Methods

A greenhouse experiment was conducted at Kuwait Institute for Scientific Research's (KISR) Station for Research and Innovation (KSRI) in Kabd, Kuwait (29.09° N, 47.41° E, Kuwait, in randomised block design (RBD) to evaluate the effects of egg cases, as a calcium supplement, on the germination and growth performance of *C. ciliaris*.

Collection of residues from eggs

Discarded chicken egg cases were collected from a food restaurant in Kuwait daily (Al-Taj Restaurant, Fintas) as a base source for the experiment. The collected cases were washed thoroughly in running water several times to remove all stains; air-dried, oven-dried at 70 °C for 6 hr, crushed and powdered to examine their efficacy as an organic calcium supplement (Fig. 2) (51, 52).



Fig. 2. Powdered egg cases.

Treatments: The powdered egg cases were mixed with potting mixture in 5 various doses: 4, 8, 12, 16 and 20 g (Fig. 3). Two standard checks were maintained with an organic (bone meal) and chemical fertiliser (Calcium nitrate). Besides, control without supplementation of any fertiliser was maintained. The treatment details were as follows:

1. Bioorganic calcium supplement from egg cases (BCS) - 4 g mixed with potting soil
2. Bioorganic calcium supplement from egg cases (BCS) - 8 g mixed with potting soil
3. Bioorganic calcium supplement from egg cases (BCS) - 12 g mixed with potting soil
4. Bioorganic calcium supplement from egg cases (BCS) - 16 g mixed with potting soil

5. Bioorganic calcium supplement from egg cases (BCS) - 20 g mixed with potting soil
6. Organic fertiliser, bone meal - 12 g mixed with potting soil
7. Chemical fertiliser, calcium nitrate -12 g mixed with potting soil
8. Control with potting soil alone

The treatments were replicated 4 times.



Fig. 3. Mixing bioorganic calcium supplement with the potting soil.

Germination study

The potting mixture comprising sand (700 g), perlite (100 g) and peat moss (200 g), with the respective rate of bioorganic egg case calcium supplement, was filled in 3 L capacity pots. The sand in the potting soil contains minimal calcium content, perlite as low as 0.5 % and peat moss 0.1 %. Five healthy *C. ciliaris* seeds were placed in each pot and their germination rates were recorded daily. The germination percentage was calculated using the following formula:

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

Impact of bioorganic calcium supplement on growth performance of *Cenchrus ciliaris* under protected conditions

The growth performance of the *C. ciliaris* seedlings was measured by recording the length, breadth and eventually the area of the leaves and the number of leaves produced per plant. The fresh and dried plant biomass was calculated by weighing the fresh and dried shoots and roots. The plant biomass was dried in the oven. An average of five leaves was considered for the data on the leaf area measurement and 5 plants for the parameters for growth performance of *C. ciliaris* plants.

Leaf length: Leaf length was measured for each experimental plant with a measuring scale.

Leaf breadth: Leaf breadth was measured for each experimental plant with a measuring scale.

Leaf area: Leaf area was calculated by the following formula

$$\text{Leaf area} = K \times \text{leaf length} \times \text{leaf breadth}$$

Where K = Kemp's constant (monocot leaves = 0.75) (53)

Number of leaves per plant: The number of leaves per plant was calculated by manual counting of the leaves from five plants in a treatment.

Shoot length: The total height of the shoots was measured using a measuring scale by holding the plant in an upright position.

Root length: The plants were carefully uprooted from the pots,

cleaned to remove the soil residues and prepared for measurements; the length of the main long root of each plant in each pot was measured using a measuring scale after straightening the roots.

Shoot fresh biomass: The shoots were cut from ground level and were weighed using a weighing balance.

Root fresh biomass: The cleaned roots, free of residues were weighed using a weighing balance.

Dry biomass: The shoots and roots were dried in an oven at 70 °C and the dried samples were weighed using a weighing balance.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) and presented as the mean \pm standard deviation. The data on the efficacy of the novel bioorganic calcium supplement with egg cases, on germination and plant performance of *C. ciliaris*, were subjected to square root transformation and transformed to $\sqrt{x} + 0.5$ before the ANOVA calculation. The mean values of the experiment were compared using Duncan's Multiple Range Test (DMRT) ($p \leq 0.05$) using SPSS software and were found to be statistically significant at $p < 0.05$.

Results

Germination study

The outcome of the germination study exhibited an excellent impact of powdered egg cases on the radicle emergence (Table 2). A 100 % germination was noticed in the highest dose of the bioorganic powder, followed by subsequent dosages respectively (Fig. 4). A meagre germination rate of 75 % was recorded in the control treatments. Nevertheless, the standard chemical, calcium nitrate, produced 87 % germination, while the organic calcium source, bone meal, made 85 % germination (Fig. 5).

Table 2. Influence of bioorganic calcium supplement powder from egg cases on germination potential of *C. ciliaris* under protected conditions

	Treatments	Germination percentage (%)
T1	BCS from egg case - 4 g	86 \pm 1.12 ^c
T2	BCS from egg case - 8 g	90 \pm 0.85 ^{bc}
T3	BCS from egg case - 12 g	93 \pm 1.52 ^b
T4	BCS from egg case - 16 g	96 \pm 1.45 ^{ab}
T5	BCS from egg case - 20 g	100 \pm 0.00 ^a
T6	Bone meal - 12 g	85 \pm 1.61 ^c
T7	Calcium nitrate -12 g	87 \pm 1.15 ^c
T8	Control	75 \pm 1.45 ^d

Each value is the mean of four replications. In a column, means followed by common letter (s) is / are not significantly different by DMRT at $p = 0.05$.



Fig. 4. Germinated *Cenchrus ciliaris* sprouts.

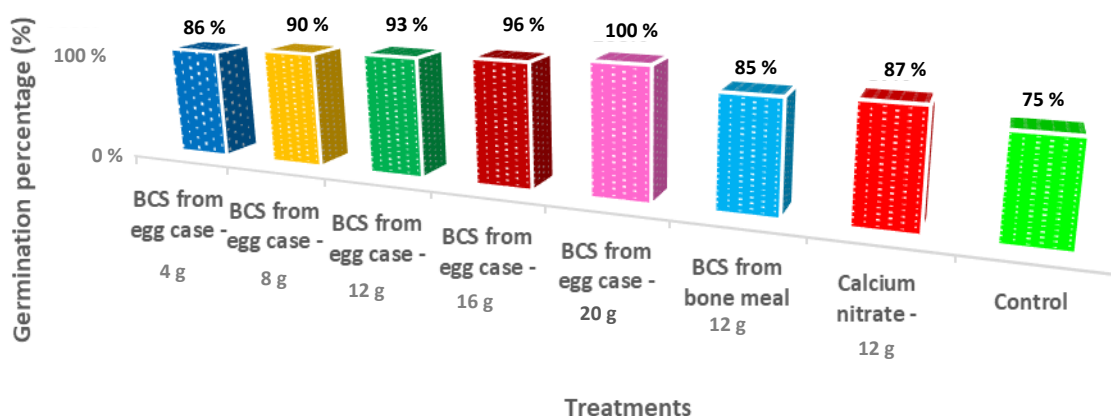


Fig. 5. Germination percentage of *Cenchrus ciliaris* seeds with bioorganic egg case powder supplementation as a calcium source.

Impact of bioorganic egg case powder supplementation on the physical performance of *Cenchrus ciliaris* under greenhouse conditions

Leaf length: The egg cases utilised as a fertiliser in powder form exhibited a very good impact on the length of the produced leaves. The longest leaf recorded was 46.18 cm, obtained from plants treated with the highest dose of bioorganic egg case calcium supplement (20 g). Subsequently, better leaf lengths were noticed in *C. ciliaris* plants treated with 16, 12 and 8 g of the bioorganic egg case calcium powder. The least dose (4 g) treated plants were on par with chemical standards (Calcium nitrate) and organic fertiliser (bone meal) treated plants respectively. However, the untreated control recorded the *C. ciliaris* plants with the least leaf length (Fig. 6, Table 3).

Leaf breadth: The powdered egg case, as a calcium supplement, influenced positively concerning the leaf breadth of *C. ciliaris* as well. The widest leaf was noticed in the highest dosage, trailed by the subsequent lower doses. The lower dosage (4 g) supplemented leaves produced with breadth on par with the calcium nitrate supplemented plants, witnessing 0.42 and 0.46 cm leaf breadth respectively. The organic bone meal applied plants produced leaves with a 0.34 cm breadth and the least recorded leaf breadth (0.28 cm) was with untreated control *C. ciliaris* plants (Fig. 6, Table 3).

Leaf area: The leaf area of *C. ciliaris* plants was calculated using their length and breadth and the largest area was witnessed by *C. ciliaris* plants applied with the highest dosage of bioorganic egg case supplement and the least area for the untreated control plants. As

the dose of the bioorganic egg case calcium supplementation rates declined, so did the leaf area as well. The calcium nitrate and the lowest dose (4 g) of bioorganic egg case powder applied to *C. ciliaris* plants responded similarly, recording 12.89 and 12.10 cm² area respectively. However, the organic bone meal applied plants exhibited 9.26 cm² leaf area, which is the least effective calcium supplement regarding leaf area (Fig. 6, Table 3).

Number of leaves per plant: The novel bioorganic calcium-supplemented *C. ciliaris* plants produced 5–8 leaves on average, whereas the untreated control plants produced only 4–5 leaves per plant. The maximum number of leaves was produced in the highest dosage of bioorganic egg case calcium-supplemented plants. With the decline in the calcium supplementation rates, the number of leaves produced also declined gradually. The chemical and organic calcium-supplemented plants with calcium nitrate and bone meal portrayed similar trends in the number of leaves per plant (Fig. 7, Table 3).

Shoot length: The shoot length of *C. ciliaris* plants showed a positive increment with egg cases as fertiliser. The highest dosage treated plants displayed a maximum length of 62.19 cm, whereas the control plants only averaged 39.76 cm height. The subsequent doses of bioorganic supplementation fall next in the order. The calcium nitrate check showed subsequent better shoot length, trailed by the lowest dosages of egg case supplements. The organic check with bone meal had a lower average shoot length (41.01 cm) than all treatments excluding the control (Fig. 7, Table 4).

Table 3. Impact of bioorganic egg case powder supplementation on growth performance of *Cenchrus ciliaris* under greenhouse conditions

Sl. No.	Treatments	Leaf length (cm)	Leaf breadth (cm)	Leaf area (cm ²)	Number of leaves per plant (No)	Shoot length (cm)	Root length (cm)	Total plant height (cm)
T1	BCS from egg case - 4 g	38.42±1.48 ^{bc}	0.42±0.11 ^e	12.10±3.00 ^e	5.7±0.79 ^d	44.26±1.34 ^e	6.32±0.49 ^b	50.58±4.41 ^e
T2	BCS from egg case - 8 g	40.81±1.34 ^b	0.51±0.09 ^d	15.61±2.44 ^d	6.0±1.34 ^{cd}	47.54±1.02 ^d	6.53±0.31 ^{ab}	54.07±1.07 ^d
T3	BCS from egg case - 12 g	42.17±2.29 ^{ab}	0.62±0.08 ^c	19.61±2.41 ^c	6.4±0.72 ^c	51.29±1.19 ^c	6.78±0.43 ^{ab}	58.07±1.38 ^c
T4	BCS from egg case - 16 g	44.37±2.75 ^a	0.71±0.13 ^b	23.63±3.97 ^b	7.1±1.04 ^b	57.49±1.79 ^b	6.92±0.39 ^{ab}	64.41±1.82 ^b
T5	BCS from egg case - 20 g	46.18±4.38 ^a	0.82±0.21 ^a	28.40±6.09 ^a	7.9±0.85 ^a	62.19±1.66 ^a	7.2±0.27 ^a	69.39±3.54 ^a
T6	Bone meal - 12 g	36.3±2.06 ^{bc}	0.34±0.09 ^f	9.26±2.02 ^d	5.1±0.64 ^d	41.04±1.22 ^e	5.9±0.47 ^c	46.94±1.69 ^e
T7	Calcium nitrate -12 g	37.36±2.96 ^{bc}	0.46±0.01 ^d	12.89±2.80 ^e	5.9±0.55 ^{cd}	46.29±1.60 ^d	6.39±0.41 ^b	52.68±1.74 ^d
T8	Control	33.13±1.09 ^d	0.28±0.08 ^g	6.96±2.64 ^f	4.7±0.61 ^e	39.76±1.47 ^f	5.43±0.31 ^d	45.19±1.54 ^e

Each value is the mean of 4 replications.

In a column, means followed by common letter (s) is / are not significantly different by DMRT at $p = 0.05$.

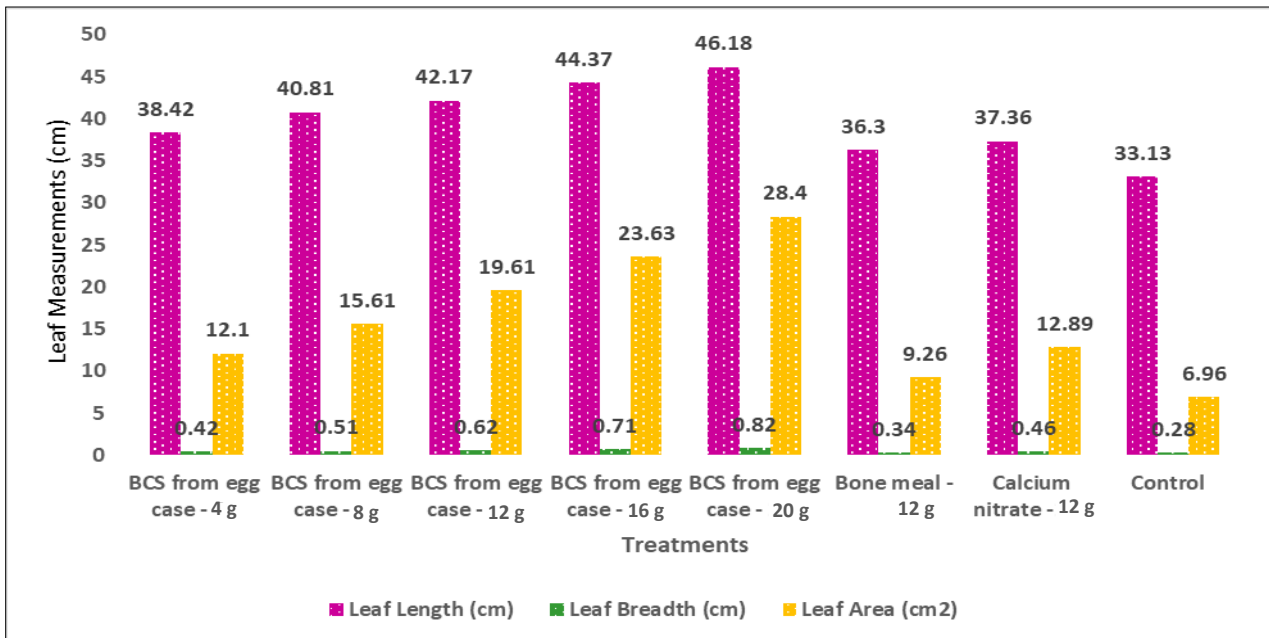


Fig. 6. Impact of bioorganic egg case powder supplementation as a calcium source on leaf parameters of *Cenchrus ciliaris*.

Root length: The root lengths of *C. ciliaris* plants perceived an optimistic result with organic egg case calcium supplementation. The highest egg case dosage 20 g offered the highest average root length of 7.2 cm, while the average was 5.43 cm in untreated control. The length of the roots gradually declined, as the dosage of egg case supplementation was reduced. The lowest dose (4 g) and the calcium nitrate check produced a similar root length portraying 6.53 and 6.39 cm, respectively. The organic check, bone meal posted the lowest root length, excluding the untreated control (Fig. 7, Table 4).

Total plant height: The shoot and root length were summed up to get the total height of *C. ciliaris* plants. The tallest *C. ciliaris* plants were observed in the highest bioorganic egg case powder supplemented plants, averaging 69.39 cm, trailed by the next doses. The standard calcium nitrate supplemented plants were equally tall as the lower doses of egg cases (8 and 4 g) supplemented *C. ciliaris* plants. The organic bone meal-supplemented *C. ciliaris* plants were on par with the untreated control plants (Fig. 8).

Shoot fresh weight: The shoot biomass of *C. ciliaris* plants produced a constructive response to bioorganic egg case powder supplementation. The fresh shoot biomass was highest for the higher doses of 20 g and 16 g, with an average mass of 46.71 g and 43.56 g. The subsequent dose, 12 g, supplied plants produced a biomass equivalent to the standard chemical, calcium nitrate-treated plants exhibiting 38.4 g and 38.27 g. The following doses at 8 g and 4 g recorded 37.29 g and 35.79 g biomass. The

organic fertiliser, bone meal-treated *C. ciliaris* plants and untreated control plots registered the lowest biomass of 34.49 g and 33.84 g biomass (Fig. 8).

Root fresh weight: The root fresh weight of *C. ciliaris* plants produced similar results as the shoot fresh weight, with the highest average weight being 8.03 g for the highest investigated rate of bioorganic egg case calcium supplement 20 g, followed by 7.06 g for the next dose, 16 g. The following dose of bioorganic calcium supplement, 12 g treated plants produced a corresponding biomass with the chemical standard, calcium nitrate treated plants with an average weight of 6.60 and 6.17 g, respectively. The subsequent doses at 8 g and 4 g recorded 5.54 g and 4.51 g, respectively. The lowest biomass was recorded in organic bone meal-treated plants and the untreated check recording 4.79 g and 3.71 g respectively (Fig. 8).

Total fresh biomass: The fresh shoot and fresh root biomass were added together to estimate the total fresh biomass of *C. ciliaris* plants. The highest average weight of total fresh biomass was exhibited by the highest dosage of bioorganic egg case supplemented plants (20 g), followed by the succeeding dose (16 g), recording 54.75 g and 50.62 g respectively. The trend was further trailed by the ensuing doses of egg case powder (12 g), recording 45.0 g, which was equivalent to the calcium nitrate-treated *C. ciliaris* plants, recording 44.44 g, respectively. The scenario declines with egg case powder at 8 g and 4 g, organic bone meal and the least with

Table 4. Impact of bioorganic egg case powder supplementation on biomass of *Cenchrus ciliaris* under greenhouse conditions

Sl.No	Treatments	Shoot fresh weight (g)	Root fresh weight (g)	Total fresh biomass (g)	Shoot dry weight (g)	Root dry weight (g)	Total dry plant biomass (g)
T1	BCS from egg case - 4 g	35.79 ± 1.67 ^d	4.51 ± 0.30 ^e	40.33 ± 1.76 ^d	14.51 ± 0.30 ^e	4.61 ± 0.41 ^f	19.12 ± 0.11 ^e
T2	BCS from egg case - 8 g	37.29 ± 1.55 ^{cd}	5.54 ± 0.24 ^d	42.83 ± 1.12 ^{cd}	17.14 ± 0.98 ^d	5.05 ± 0.37 ^e	22.19 ± 0.41 ^d
T3	BCS from egg case - 12 g	38.4 ± 1.08 ^c	6.60 ± 0.25 ^c	45.0 ± 1.50 ^c	19.7 ± 1.68 ^c	5.76 ± 0.37 ^d	25.46 ± 0.96 ^c
T4	BCS from egg case - 16 g	43.56 ± 1.48 ^b	7.06 ± 0.39 ^b	50.62 ± 0.48 ^b	21.2 ± 1.99 ^b	6.48 ± 0.24 ^b	27.68 ± 0.48 ^b
T5	BCS from egg case - 20 g	46.71 ± 1.64 ^a	8.03 ± 0.60 ^a	54.75 ± 1.09 ^a	23.33 ± 2.11 ^a	7.12 ± 0.71 ^a	30.45 ± 1.43 ^a
T6	Bone meal - 12 g	34.49 ± 1.37 ^{de}	4.79 ± 0.18 ^e	39.28 ± 0.30 ^{de}	14.79 ± 0.18 ^e	4.55 ± 0.26 ^f	19.34 ± 0.12 ^e
T7	Calcium nitrate -12 g	38.27 ± 1.29 ^c	6.17 ± 0.58 ^c	44.44 ± 0.54 ^c	16.17 ± 0.66 ^d	6.27 ± 0.48 ^c	22.44 ± 0.34 ^d
T8	Control	33.84 ± 0.95 ^f	3.71 ± 1.00 ^f	37.55 ± 0.63 ^e	13.01 ± 0.49 ^f	3.57 ± 0.18 ^g	16.58 ± 0.28 ^f

Each value is the mean of 4 replications.

In a column, means followed by common letter (s) is / are not significantly different by DMRT at $p = 0.05$.

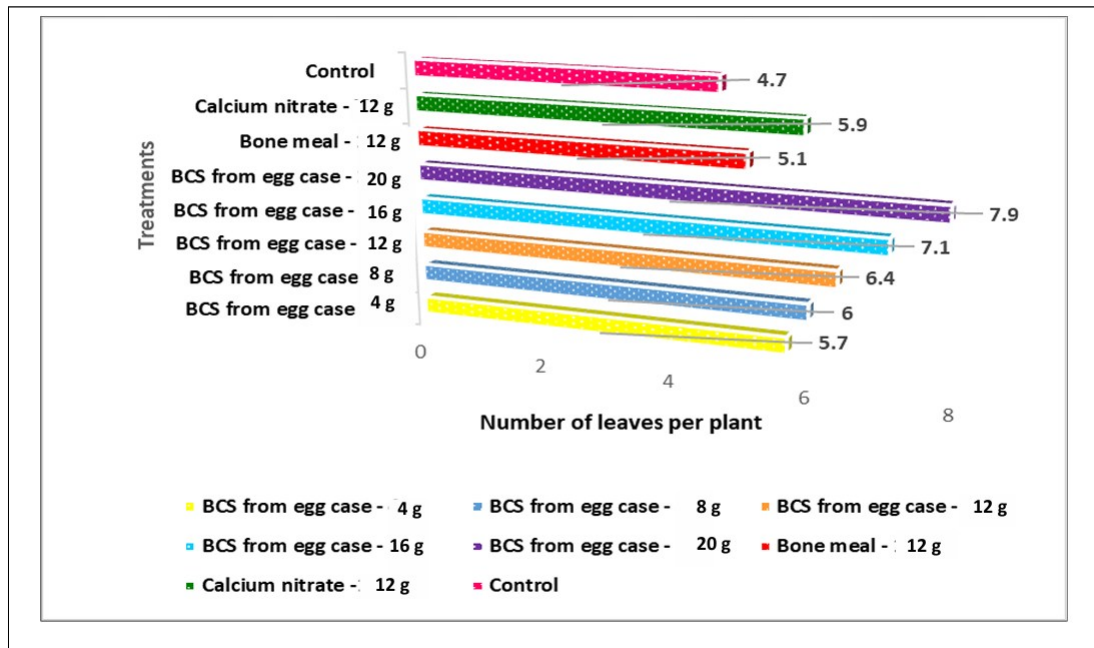


Fig. 7. Effect of bioorganic egg case powder supplementation on leaf production of *Cenchrus ciliaris*.

untreated control, reporting 42.83, 40.33, 39.28 and 37.55 g, respectively (Fig. 8).

Shoot dry biomass: The trend for dried shoot biomass declared an accelerated physical performance of *C. ciliaris* plant mass, the highest with bioorganic egg case powder supplementation on its maximum measure of 20 g, followed by the lower doses. The standard calcium nitrate-treated plants produced 16.17 g of dried *C. ciliaris* plants. The organic bone treatment and the lowest dose of egg cases (4 g) treatment yield concordant results. However, the *C. ciliaris* plants grown without any fertiliser supplementation portrayed the lowest dried biomass of 13.01 g (Fig. 8).

Root dry biomass: The results for root dry biomass of *C. ciliaris* were similar to the shoot dry biomass of the investigated *C. ciliaris* plants. The highest average values were recorded for higher doses of bioorganic egg case calcium powder, which was concordant with calcium nitrate treated plants. The subsequent doses at 12, 8 and 4 g recorded declining dried biomass of 5.76, 5.05 and 4.61 g,

respectively. The organic bone meal and untreated control produced the least root biomass of 4.55 and 3.57 g, respectively (Fig. 8).

Total dry plant biomass: The dried shoot and root biomass were summed up together to estimate the total dried biomass of *C. ciliaris* plants and the trend remained similar to dried shoot and root biomass observations. The highest average total dry biomass was recorded for higher doses of bioorganic egg case calcium supplementation. The subsequent dose (8 g) was in concordance with standard calcium nitrate plants and organic bone meal-treated *C. ciliaris* plants. Nevertheless, the untreated control recorded the lowest dried *C. ciliaris* plant biomass (Fig. 9).

Discussion

Advancements in food security and environmental sustainability in the agricultural farming system demand an integrated soil fertility management approach that accelerates crop productivity and



Fig. 8. Effect of bioorganic egg case powder supplementation on height parameters of *Cenchrus ciliaris*.

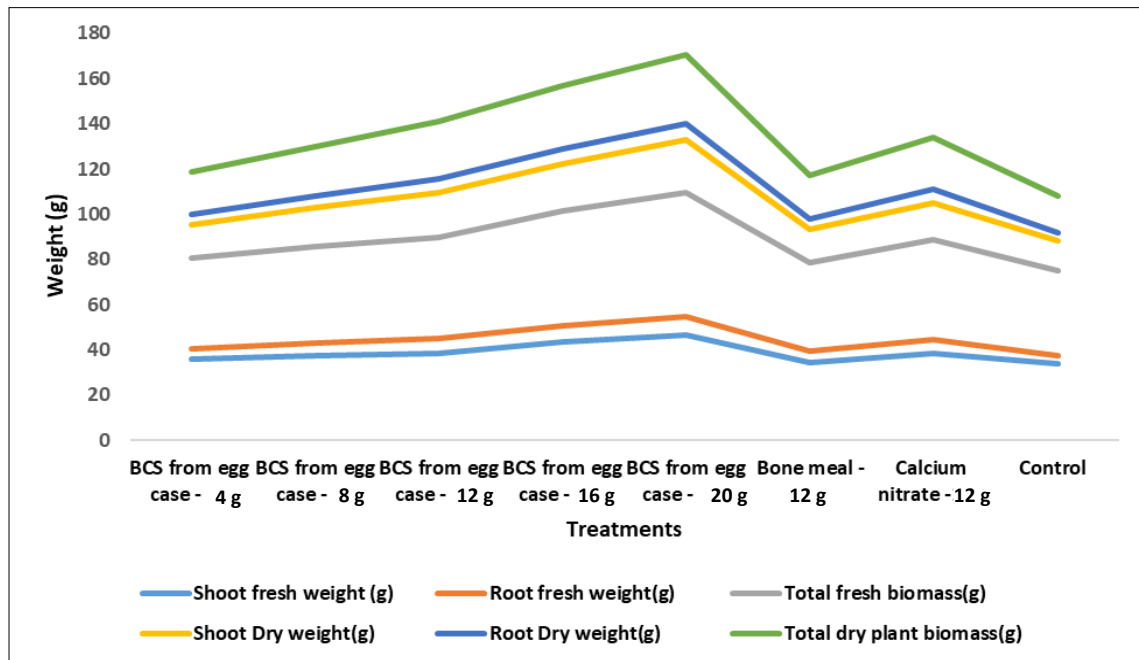


Fig. 9. Impact of bioorganic egg case powder supplementation on biomass production of *Cenchrus ciliaris*.

lessens the deterioration of soil physical and chemical attributes. The fertility management practices include several factors, of which organic inputs, recycled from residues, receive major attention. Food discards are becoming a major issue that affects the waste management system from collection to disposal (54). Chicken egg cases are the most common food residues produced by households, restaurants and other food processing outlets that constitute an environmental nuisance and end up discarded at the dumping site with no consideration of further usage (55). Given that approximately 11 % of eggs' weight comprises the egg cases, yearly, approximately 7.2 million tonnes of eggshell debris is produced; most of them end up in landfills, burdening the environment (56). However, considering their chemical composition, it is a valuable raw material for the production of a variety of high-value-added products (57). The household-derived organic residue, egg cases, is of recent research interest, as they serve as an excellent calcium reserve, possessing 2.22 g of calcium which makes them worth being a bioorganic fertiliser (22, 58, 59). The concept is more oriented towards a 'zero-waste' model of utilising the discards of chicken eggs without any wastage (58, 60).

Any biological residues can be transformed into organic fertilisers, of which egg cases are organic wastes with no economic value, posing harm to the environment. They are an abundant source of calcium in the form of calcium carbonate, with the potential to be used as an organic source. In addition, it also possesses nutrients such as phosphorus, magnesium, sodium, potassium, zinc, manganese, iron and copper. The calcium content in egg cases will stimulate the development and establishment of roots, strengthen stems and seed attributes (61). These discarded residues from eggs as a fertiliser, consequently, have enough capability to enrich the soil and plants with calcium and other required nutrients and can have market value. In addition, they augment the activities of soil microbes.

The research outcomes revealed an affirmative retort in the germination of *C. ciliaris* seeds, with 100 % germination for the highest dose of egg cases of 20 g. The subsequent dosages of egg case powder at the rates of 16, 12, 8 and 4 g portrayed an excellent

response of 96, 93, 90 and 86 % respectively. The current findings are in accordance with previous researchers, who recorded 90 % germination with 10 g of egg cases in an analogous pot culture experiment (62). Earlier studies reported similar results with egg case as an organic fertiliser (63). The highest per cent germination of *C. ciliaris* seeds with calcium supplementation substantiates the role of calcium as a rooting agent.

The physical performance of *C. ciliaris* seedlings regarding leaf parameters, viz., leaf length, leaf width and leaf area were greater for the soil mixed with egg residues. The investigated leaf parameters posed superior values for the highest dose of the bioorganic calcium supplement, followed by the subsequent doses. The standard calcium nitrate check produced equivalent results with the lowest dosage of egg residues, making the bioorganic chemical supplement an effective fertiliser compared to synthetic chemical supplementation. Correspondingly, the present findings are in accordance with previous researchers, who reported that the efficacy of egg residues in cowpea plants with leaf length, width and area was higher for cowpea plants treated with egg residues (62). Calcium is a secondary nutrient that plays a major role in plant tissue production through the formation of cell walls and cell membranes. Generally, roots take up available calcium in the soil and transport it to the new growing parts (64). The calcium supplemented through egg cases energised the *C. ciliaris* plants for healthy formation of leaves, with good length, width and area. Moreover, the production of leaves (number of leaves) was also found to be higher in novel calcium-supplemented *C. cilairis* plants, which is again in agreement with previous studies in cowpea plants (63) and in money plant and wheat grass (63). In addition, the performance of *C. ciliaris* seedlings regarding the plant height (shoot height, root height and total height) was higher in the bioorganic calcium-supplemented plants, which was in line with earlier reports in cowpea plants (62). The *C. ciliaris* biomass harvested after 2 months and weighted as fresh was higher for the higher dosage of bioorganic calcium supplement from egg cases, which was justified previously in cowpea (62) and in cayenne pepper (65). Calcium acts as an agent and serves as a messenger for growth signals such as auxin production and stress

responses, ensuring proper cell division, expansion and nutrient uptake (66).

Calcium plays an important biochemical function and supports several metabolic processes by activating several enzymatic systems, thereby contributing to plant development (67). Calcium also plays an important role in cell integrity and stability (68). Among all the plant parts, calcium accumulates more in leaves due to the formation of calcium pectate in the middle lamella of cells. Calcium is associated with the transport of nitrogen and interaction with potassium and phosphorus (69). The novel bioorganic calcium supplement from egg cases encloses greater levels of calcium in the form of calcium carbonate, which increases its potential as an organic fertiliser. The current finding is in line with previous studies stating that the powdered form of egg residues could be an alternate source of supply of calcium in groundnut, which is reflected in terms of pod yield (70, 71). Apart from calcium supplementation, egg cases enhance the magnesium level (Mg^{2+}) of the plants, which is a vital plant macronutrient, central to chlorophyll, enabling photosynthesis and energy production, activating enzymes for metabolism and aiding carbohydrate transport for growth. Egg cases as soil amendment improve P availability to the plants as well. Therefore, egg case is capable to provide required nutrients, in addition to calcium, enriching the plant biomass. As *C. ciliaris* is a major crop cultivated for its fodder, eggshell is a valuable organic source for *C. ciliaris* production. In addition, eggshells rich in calcium carbonate raise the soil pH that benefits *C. ciliaris* plants by improving calcium absorption. Increased soil pH aids the plants to absorb required nutrients from the soil. Furthermore, egg case supplement as an organic source significantly improves the soil texture that boosts drainage and aeration, which aids *C. ciliaris*' physical performance (72). Consequently, the present study utilises the ignored and discarded household residue, egg cases, as a novel bioorganic calcium supplement for *C. ciliaris* production. It exhibited a promising impact on *C. ciliaris* germination and plant physical performance by its Ca^{2+} , Mg^{2+} , P and other nutrient availability to plants by improving their pH and texture.

Conclusion

Recycling agricultural residues to a fruitful agricultural solution is a recent trend to utilise every resource without any wastage, which lowers the cost of production with higher productivity. The daily wastage from households and food industries, the egg cases were attempted as a novel bioorganic calcium supplement for a common fodder crop, *Cenchrus ciliaris* and many productive outcomes were obtained in terms of its germination and physical growth. The highest investigated rate, 20 g mixed with the potting soil, provided 100 % germination and was superior in all other growth parameters viz, leaf length, leaf breadth, leaf area, number of leaves per plant, shoot length, root length, total plant height, shoot fresh biomass, shoot dry biomass, total plant fresh biomass, shoot dry biomass, root dry biomass and total plant dry biomass. The subsequent doses, 16 and 12 g, were also superior in performance compared to chemical fertiliser, calcium nitrate. However, the dose of 8 g portrayed similar performance as the calcium nitrate treatment. Accordingly, it could be concluded that the novel bioorganic egg case calcium supplement at the dosage of 8 g per pot produced equal outcomes as chemical fertiliser and as the dosage rate increases, the plant performance escalates. Hence, using bioorganic

calcium supplements could potentially lower the cost and reliance on synthetic fertiliser.

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Authors' contributions

MKD contributed to conceptualisation, methodology, software, formal analysis, resources, writing original draft preparation, visualisation and supervision. TAM contributed to methodology, validation, investigation, data curation, writing review and editing and project administration. Both authors read and approved the final manuscript.

Compliance with ethical standards

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

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