Research Square

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Effect of dried Eichhornia crassipes (water hyacinth) supplemented diet on growing Bonsmara steers calves.

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Abstract

Reducing feed costs while maintaining profitable beef production continues to challenge farmers, increasing the need to identify alternative feed resources. *Eichhornia crassipes* (water hyacinth; WH), an invasive aquatic plant, has potential as a ruminant feed ingredient; however, its ability to accumulate pollutants raises food-safety concerns. This study evaluated the nutritive value of dried WH in iso-nitrogenous feedlot diets and assessed the presence of heavy metals in tissues of cattle consuming WH. Four diets containing 0%, 25%, 35%, or 45% WH were formulated and fed to weaner cattle. Average daily gain decreased significantly with increasing WH inclusion ($P < 0.001$), with cattle in the control group achieving 1.60 kg/day compared with 0.83, 0.70, and 0.30 kg/day in the 25%, 35%, and 45% WH treatments, respectively. Feed intake showed a similar declining pattern, and feed conversion ratio worsened at higher levels of WH inclusion. Heavy metals were not detected in liver or muscle samples, although copper concentrations decreased numerically as dietary WH increased. The absence of detectable heavy metal residues is encouraging; however, routine screening of WH-fed livestock products remains advisable due to the plant's capacity to absorb environmental contaminants. Further research is needed to identify post-drying additives or processing strategies that improve the palatability and intake of WH to enhance its value as a cost-effective feed resource for beef cattle.

Introduction

Livestock production in Sub-Saharan Africa (SSA) contributes approximately 20–25% of global output; however, productivity across the region remains low due to inconsistent feed availability and limited access to quality fodder resources (Erdaw, 2023). Scarcity of improved pastures, insufficient land for fodder cultivation, and the high cost of concentrate feeds further constrain growth of the livestock sector (Tulu et al., 2023). Seasonal fluctuations in forage supply exacerbate these limitations, resulting in inadequate nutrient intake and depressed animal performance. Consequently, livestock product output is projected to remain insufficient despite rapidly increasing consumer demand, with estimates indicating that the region will require up to two-thirds more animal-source foods by 2050 (Salvage, 2011). Reliance on imported livestock products is economically unsustainable, underscoring the need to intensify production systems. Such intensification, however, depends fundamentally on identifying affordable, non-conventional feed resources that do not compete with human food supply.

Eichhornia crassipes (water hyacinth; WH) is an invasive, free-floating aquatic plant widely regarded as one of the most problematic weeds in tropical and subtropical regions (Fouzi and Deepani, 2018). Its rapid proliferation alters aquatic ecosystems by reducing dissolved oxygen, modifying water chemistry, and disrupting native flora (Hossain et al., 2015). Despite these negative ecological impacts, WH has been explored for various uses, including fertilizer, fibre, and phytoremediation, and more recently as a potential livestock feed ingredient (Fouzi and Deepani, 2018). Nutrient composition of WH varies with plant age and environment but reports generally indicate moderate to high crude protein content and appreciable fibre and energy values on a dry-matter basis (Ndimele et al., 2011; Men et al., 2006; Hossain et al., 2015). WH leaf meal has also shown promise as a protein supplement in aquaculture diets

(Mahmood et al., 2018; Saha and Ray, 2011). Several studies have confirmed that its nutrients are accessible to ruminants (Teye et al., 2019; Indulekha et al., 2019).

Although WH is abundant and incurs no production cost, it presents potential risks due to its capacity to accumulate heavy metals such as cadmium, chromium, lead, and metalloids including arsenic (Zhou et al., 2005; Shi and Zhao, 2007). Research evaluating both its nutritive value and food-safety implications for ruminant production remains limited, particularly in South Africa where chemical characterisation of locally sourced WH is scarce. Earlier work suggested that WH could supply substantial mineral quantities to cattle diets and may be best utilised as hay or silage (Bagnall et al., 1973; Masifwa et al., 2001; Brendonck, 2003). Its integration into ruminant feeding systems has been recommended for developing countries as a strategy to alleviate feed shortages (Jafari, 2010), especially when combined with energy-dense concentrates to enhance digestibility (Aderibigebe and Brown, 1993; Ojeifo et al., 2000).

Given the growing demand for affordable feed resources and the need to mitigate environmental impacts of WH invasion, this study aimed to evaluate the effect of dried water hyacinth as a dietary protein source on growth performance, carcass characteristics, and potential heavy metal residues in beef cattle.

Material and methods.

Water hyacinth (*Eichhornia crassipes*) was harvested from Hartbeespoort Dam, Northwest Province, South Africa. The water hyacinth was dried and chemically analysed (Table 1). Additional feed ingredients including hominy chop, wheat bran, molasses meal, cottonseed oilcake meal, feed lime, feed-grade urea, salt, and mineral - vitamin premix were procured from Obaro (Pretoria, South Africa). *Eragrostis curvula* hay and lucerne were obtained from the Agricultural Research Council (ARC), Roodeplaat, Gauteng Province.

All feed ingredients were analysed for proximate composition following standard AOAC procedures (AOAC, 2006), while fibre fractions, mineral content, and heavy metal concentrations were determined using AOAC (2015) methods.

Diet formulation.

Experimental diets were formulated to meet nutrient requirements for fattening cattle according to the National Research Council (NRC, 1996). Four iso-nitrogenous diets were prepared with increasing levels of dried water hyacinth:

Treatment 1 (T1): 0 g kg^{-1} DM

Treatment 2 (T2): 25 g kg^{-1} DM

Treatment 3 (T3): 35 g kg^{-1} DM

Treatment 4 (T4): 45 g kg^{-1} DM

Animal management and experimental design.

The study was conducted at the ARC - Animal Production Institute, Irene Campus (Feedlot Section). Ethical approval was granted by the ARC-AP Animal Ethics Committee (APAEC 18/18). Thirty-four Bonsmara weaner cattle (18 steers and 16 heifers), aged 6–8 months and averaging 180 kg liveweight, were used in the study.

All animals were implanted with growth promoters (Revalor-S for steers; Revalor-H for heifers) and treated for viral diseases (Maxitect III), bacterial diseases (Covexin®), internal parasites (Dectomax®), and external parasites (Delete-All®) according to manufacturer recommendations (MSD, Isando, South Africa).

Weaners were individually housed in stanchions and offered one of the four experimental diets (0%, 25%, 35%, or 45% WH) (Table 2) in a completely randomized block design. Each treatment consisted of four to five steers and four heifers (Table 3). The feeding trial was conducted over 98 days.

Table 1
Chemical composition of *Eichhornia crassipes* (water hyacinth).

Parameters	Mean ± SD
Proximate	
Dry matter	95.91 ± 0.202
Crude protein	16.06 ± 0.119
Ash	15.96 ± 0.148
Gross Energy	15.00 ± 0.417
Fiber fractions	
Neutral detergent fiber	47.07 ± 0.627
Acid detergent fiber	26.66 ± 0.747
Acid detergent lignin	6.30 ± 0.502
Toxic metals (mg/kg)	
Arsenic	0.75 ± 0.033
Cadmium	< 0.5 ± 0.000
Copper	11.0 ± 0.963
Iron	2073 ± 35.670
Lead	2.06 ± 0.264
Mercury	< 0.1 ± 0.000

Table 2
Ration composition and estimated nutrient values (%, dry matter basis) of the treatments.

Ingredient	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Hominy chop	56.6	42.2	37.4	32.5
Wheat bran	15	5	5	0
Molasse meal	10	10	10	10
Eichhorniacrassipes (WH)	0	25	35	45
Agrostis curvula	5	5	5	5
Lucerne	5	5	0	0
Cotton OCM[1]	5	5	5	5
Feed lime	1.7	1.5	1.5	1.5
Feed grade urea	1.2	0.8	0.6	0.5
Feed salt	0.5	0.5	0.5	0.5
Premix	0.1	0.1	0.1	0.1
Nutrients				
Crude Protein (%)	16.2	15.8	15.5	15.4
Ether Extract (%)	5.8	4.7	4.4	4.0
Crude Fibre (%)	11.3	14.8	15.1	16.4
Neutral Detergent Fibre (%)	21.9	27.2	28.9	30.8
Gross Energy (MJ/kg DM)	18.1	17.4	17.3	17.0
Calcium (Ca %)	0.9	1.1	1.1	1.2
Phosphorus (P %)	0.6	0.6	0.6	0.6
Copper (Cu, mg/kg)	5.0	6.0	6.5	6.8
Iron (Fe, mg/kg)	69	562	766	962

[1] Oil cake meal, solvent extruded.

Table 3
Animal allocation to the 4 treatment diets with graded levels of *Eichhornia crassipes*

Gender	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Male	5	4	5	4
Female	4	4	4	4

Data collection.

Body weight was recorded at the start of the trial and subsequently at two-week intervals. Daily feed intake (FI) was calculated as the difference between feed offered and orts. Feeding levels were adjusted based on refusals: a 10% reduction was applied when excessive leftovers occurred, whereas a 10% increase was applied when minimal or no refusals were observed. Average daily gain (ADG) was determined as the change in body weight between weighing periods, and feed conversion ratio (FCR) was calculated as weight gain per unit of feed consumed. Manure consistency was scored daily using a 5-point scale, where 1 represented dry faeces with concentric rings and 5 indicated watery diarrhoea with blood.

At the end of the feeding period, animals were slaughtered at a Grade D, low-throughput experimental abattoir at ARC-API, Irene (Gauteng Province), following South African Meat Safety Act 40 of 2000 regulations and procedures described by Hoffman (2014). Carcass traits and classification scores were recorded immediately prior to evisceration. The presence of liver abscesses was assessed for each animal.

For heavy metal analysis, meat samples were collected from the *longissimus dorsi* muscle between the 12th and 13th ribs. Four or five steers and four heifers per treatment were randomly selected for sampling. Concentrations of iron (Fe), copper (Cu), arsenic (As), cadmium (Cd), and lead (Pb) were analysed in both liver and muscle tissues.

Data analysis.

Data on ADG, feed intake, feed conversion ratio, and heavy metal concentrations were analysed using analysis of variance (ANOVA) under the General Linear Model (GLM) procedure of SAS (2020). Treatment means were separated using Fisher's Least Significant Difference (LSD) test, with significance declared at $p < 0.05$. Manure score data were analysed using the chi-square test.

Results

Table 1 shows the chemical composition (proximate, fiber fraction and toxic elements) of the *Eichhornia crassipes* (water hyacinth), while treatment diets nutritive value is illustrated in Table 2. Although not analysed statistically, the values show that in terms of proximate, crude protein (CP), ether extract (EE)

and gross energy (GE) were higher in treatments 1 and 2 compared to their counterparts. Treatments 3 and 4 had higher crude fibre (CF) and neutral detergent fibre (NDF) than other treatments. Minerals (calcium, copper, and iron) increased as level of WH increased, except for phosphorus, which was similar across the treatments.

Table 4
Effect of dried water hyacinth-based diet on growth performance of Bonsmara steers (n = 8 or 9).

Treatment	n	Average daily gain	Feed intake	Feed conversion ratio
1	9	1.60^{a}	9.52^{a}	5.98^{c}
2	8	0.82^{b}	6.07^{b}	7.57^{b}
3	9	0.70^{b}	5.85^{b}	8.36^{b}
4	8	0.30^{c}	4.44^{c}	14.28^{a}
SEM		0.02	0.58	1.28
LSD		0.13	0.76	1.15
P-value		< 0.0001	< 0.0001	< 0.0001

Means within a column with different letters in subscript differs significantly ($P < 0.05$). LSD – Least squared difference, SEM – Standard error of the mean

Effect of dried WH at different inclusion levels in fattening diets on growth performance of Bonsmara is presented in Table 4. Feed intake (FI), average daily gain (ADG) and feed conversion ratio (FCR) of the steers differed ($P < 0.05$) significantly across the treatments. Average daily gain was significantly higher ($P < 0.05$) in treatment 1 and lower ($P < 0.05$) in treatment 4 than other treatments. Treatments 2 and 3 showed moderate gains (0.82 and 0.70 kg/day), statistically similar ($P > 0.05$) to each other. Feed intake followed the same trend as (ADG), which was highest ($P < 0.05$) in treatment 1 and lowest in treatment 4. Treatment 1 had the lowest ($P < 0.05$) FCR, while treatment 4 had the highest FCR value of 14.28.

Table 5
Effect of dietary inclusion levels of dried water hyacinth on Bonsmara steers manure (Chi^2 test = 0.94).

TMT	Week1	Week2	Week3	Week4	Week5	Week6
1	1.89	2.10	1.76	1.33	1.24	1.11
2	1.64	1.61	1.18	0.89	1.04	1.04
3	1.62	1.75	1.40	1.02	1.17	1.17
4	1.64	1.36	1.32	0.95	1.05	1.05

Effect of water hyacinth-based diets on steers manure is shown in Table 5. A scale of 1 to 5 was used to score the manure. Across all treatments, manure scores remained low (between 1.1 and 2.1), indicating firm to slightly soft faeces throughout the feeding period. No diarrhoea (scores ≥ 4) was observed in any treatment. In Treatment 1, scores were slightly soft during the first two weeks (1.89 to 2.10) but declined progressively to firmer faeces by Week 6 (1.11). Treatments 2 and 4 showed consistently firm to slightly dry manure (0.89 to 1.64), with the lowest scores occurring from Week 4 onwards. Treatment 3 followed a similar pattern, with initial soft faeces (1.62 to 1.75) that stabilised to firm scores (1.02 to 1.17) thereafter.

Average weight gain (AWG) of the steers varied significantly among treatments over the 14-week feeding period (Fig. 1). Steers in the treatment 1 consistently showed the highest AWG, with a peak of approximately 3.5 kg/day in week 8. Treatments 2 and 3 showed moderate and relatively stable gains of approximately 0.5 to 1.4 kg/day, with both peaking around weeks 8 to 10. In contrast, steers in treatment 4 had the lowest AWG across all weeks, including a negative gain around week 6.

Figure 2 shows feed intake (FI) by steers fed graded levels of water hyacinth-based diets over the 14-week feeding period. Feed intake differed markedly among treatments during the 14-week feeding period. Steers receiving the control diet (treatment 1) consistently recorded the highest FI, increasing from approximately 6.0 kg/day in week 2 to over 11.0 kg/day by week 14. Treatments 2 and 3 showed intermediate and relatively comparable intake patterns, with FI rising from about 4.0 to 4.5 kg/day in week 2 to peaks of 7.5 to 8.0 kg/day in week 14. In contrast, steers fed the highest WH inclusion (45%; Treatment 4) exhibited significantly lower FI across all weeks, starting at approximately 2.5 kg/day in week 2 and reaching only 5.5 kg/day by week 14.

Table 6
Effect of heavy metals in graded levels of dried water hyacinth-based diets on liver and meat samples (wet weight) from Bonsmara steers.

TMT	Cu	Fe	% moist	As	Cd	Pb
1	25.56a	21.75a	71.5b	ND	ND	ND
2	14.76ab	24.7a	72.6b	ND	ND	ND
3	6.882ab	39.02a	73.1b	ND	ND	ND
4	3.897b	31.96a	75.48a	ND	ND	ND
LSD	18.96	17.37	2.18	ND	ND	ND
F-prob	0.81	0.2	0.24	ND	ND	ND
SEM	2.55	2.33	0.293	ND	ND	ND

Means within a column with different letters in subscript differs significantly ($P < 0.05$). LSD – Least squared difference, SEM – Standard error of the mean. ND – Not detected.

Dietary inclusion of dried water hyacinth had no detectable effect on the presence of arsenic (As), cadmium (Cd), or lead (Pb), as all samples tested negative for these elements across treatments (Table 6). Copper (Cu) significantly differed ($P < 0.05$) between T1 vs T3 and T4, Iron (Fe) concentrations did not differ ($P > 0.05$) among treatments, although numerically higher in T3 and to lesser extent in T4. Moisture content was significantly higher ($P < 0.05$) in T4 compared to other treatments. Overall, no heavy metal contamination was detected, and mineral levels remained within expected biological ranges regardless of dietary WH level.

Table 7
Effect of heavy metals on liver and meat samples (wet weight) from Bonsmara steers fed graded levels of dried water hyacinth-based diets regardless of treatment.

	Cu	Fe	%moist
Liver	28.46a	48.46a	69.54b
Muscle	0.77a	13.1b	75.72a
LSD	28.46	20.929	1.11
F-prob	0.05	< **0.001**	0.002
SEM	1.079	0.988	0.124

Means within a column with different letters in subscript differs significantly ($P < 0.05$). LSD – Least squared difference, SEM – Standard error of the mean. ND – Not detected.

The collected data for the toxicology (arsenic, cadmium, and lead) was limited and no statistical analysis could be done for liver and meat samples per treatment. Copper concentration and iron concentration was higher (Cu: $P = 0.05$, Fe: $P < 0.001$, Table 7) in liver than meat, but moisture content was higher ($P = 0.002$) in meat than in liver.

Discussion

Unavailability of quality fodder and shortage of improved fodder or pasture have been identified as major causes for low meat production (Wimalarathne and Perera, 2019). Water hyacinth has been utilized successfully as livestock feed for ruminants, swine, ducks, geese, and fish due to its high crude protein content and progressive growth. With proper inclusion level to the main ration, WH can be a feasible alternative low-quality roughage such as rice straw, legume straw, hay, and grasses. The WH inhabits freshwater bodies such as tanks, canals, marshes, ponds, rivers, and dams. There is a greater opportunity of utilizing this plant to reduce the feed shortage in the South African livestock feed industry. Utilizing WH as livestock feed is another way of controlling the growth of this plant, apart from biological, chemical, and mechanical control methods.

Water hyacinth used in this study was harvested from Hartbeespoort dam. The dam is fed by a few rivers, which are considered highly polluted from human waste and with agricultural affluent (Auchterlonie et al., 2021). The chemical composition of WH is shown in Table 1. The percentage of dry matter, crude protein, ash, and gross energy of the WH was 95.91 ± 0.20, 16.06 ± 0.12, 15.96 ± 0.15 and 15.00 ± 0.42, respectively. Ndimele et al (2011), reported 23–25% of protein-related matter in dried WH. A study by Men et al. (2006) showed that percentage of crude protein and ash content of WH were 18.6 ± 0.71 and 16.7 ± 1.95, respectively. The fibre fractions of WH in this study were 47.07 ± 0.63 for neutral detergent fiber, 26.66 ± 0.75 for acid detergent fiber and 6.30 ± 0.50 for acid detergent lignin. Crude fibre content of WH was reported by Men et al. (2006) as 21.4 ± 0.85. A study by Hossain et al. (2015), showed that fresh WH had a range of 8.7–9.8, 10.1–11.2, 26.1–27.4, 12.3–12.4 and 1.1–1.8 of dry matter, crude protein, crude fibre, ash, and ether extract, respectively. While Men et al. (2006) indicated that higher proportion of protein can be found in immature leaves and petioles of the WH than in mature plants, several studies revealed that the chemical composition of the WH varies with season, habitat, and fraction of the weed (Tucker et al., 1981 and Abdelhamid, 1991). Nevertheless, researchers have promoted the use of WH as animal feed as its high water and mineral content, which suggest that the nutritional value may be appropriate for certain animals (Llo et al., 2020). Due to the high levels of cellulose and hemicellulose, Murkherjee and Nandi (2004) recommended the possibility of using WH as feed for ruminants. The minimum amount of crude protein content in fodder for ruminants should be 9%. Now the crude protein contained in either dry or fresh WH is ideal to be utilised for growing cattle feed.

Although WH is a good potential for livestock feed owing to its nutrient value, however, the fodder may contain toxic materials from the source of biomass. The heavy metals like cadmium (Cd), lead (Pb), mercury (Hg), and metalloids such as arsenic (As) and fluorine can be absorbed by WH due to greater absorbing capacity (Shi and Zhao, 2007). This study shows that the tested WH had As, Cd, Copper (Cu), Iron (Fe), Pd and Hg concentration of 0.75, < 0.5, 11.0, 2073, 2.06 and < 0.1%. When feeding livestock, what is imperative in terms of nutrition and feed safety, is that concentration of the metalloids should not be traceable. If they do, it should not be above the normal threshold.

Maximum tolerable level for copper in cattle feeds is estimated at 40 mg/kg, but results vary (NRC 2016). As indicated by NRC 2016, levels of 5 mg/kg or slightly above seem ideal. Dietary estimated concentration for treatments 2, 3 and 5 are higher than the recommended concentration of 5 mg/kg, but do not reach the maximum (40 mg/kg) concentration (Table 2). The calculated Fe concentration in the treatment diets (treatments 2, 3 and 4) were above the maximum tolerable concentrations (500 mg/kg, NRC 2016). The Fe content in the rations increased as WH level increased (Table 2). The high Fe concentrations can interfere with Cu absorption and lead to Cu deficiency (Bremner et al., 1987). This Fe interference with Cu can be observed in the decreasing Cu concentration in the liver, whilst Fe concentration increases (Table 6).

The present study evaluated the effects of graded levels of dried WH on growth performance, feed utilisation, manure consistency and heavy-metal residues in Bonsmara steers. Overall, the inclusion of WH at 25 to 45% of the diets (treatment 2 to 4) had a clear depressive effect on average daily gain (ADG),

feed intake (FI), and feed conversion efficiency/ratio (FCR) (Table 4). Steers fed the control diet (treatment) showed performance values consistent with reported growth rates for intensively fed beef weaners (Strydom, 2016), while WH inclusion progressively reduced ADG, with the lowest gains observed in steers fed treatment 4. This decline aligns with studies indicating that WH has limitations as a major component in ruminant diets due to its high fibre fraction, low energy density, and poor palatability (Masifwa et al., 2001; Hossain et al., 2015). Reduced FI in the WH diets provides a direct explanation for the poorer growth performance. Low acceptability of WH, likely due to its fibrous structure and potential presence of secondary metabolites, has been noted in previous studies on cattle and buffaloes (Aderibigbe & Brown, 1993; Teye et al., 2019). A contributing to the decrease in performance may be the low level of Cu in the liver. Copper levels on a wet weight basis should exceed 25 ppm (Miranda et al., 2006). Levels below this will affect performance negatively, and with the increase in Fe (Table 7), Cu availability will be depressed further.

Across the 14-week feeding period, the average weight gain (AWG) patterns further illustrate the negative impact of increasing water hyacinth inclusion on growth performance (Fig. 1). The control group (treatment 1) consistently outperformed all WH-based treatments, showing higher and more stable gains throughout the trial, including a marked peak around Week 8, coinciding with the period of highest feed intake. In contrast, steers on WH diets displayed reduced and more variable AWG, with steers fed treatment 4 experiencing a pronounced drop below zero around week 6, reflecting insufficient nutrient supply relative to growth requirements. Although all WH treatments showed temporary improvements around weeks 8–10, their gains remained well below the control group, indicating that WH could not sustain optimal growth even when short-term intake was adequate.

Feed intake patterns across the 14-week feeding period further demonstrated a consistent reduction in voluntary FI with each increase in WH inclusion (Fig. 2). This is consistent with Mahmood et al. (2018), who observed similar intake depression in fish diets containing WH leaf meal, suggesting that WH may impart reduced palatability or slower ruminal degradation rates. The reduced intake is likely the major contributing factor to the decreased ADG and the elevated FCRs observed in higher WH treatments (treatments 2 to 4). In ruminants, diets with high structural fibre and low soluble carbohydrate content typically reduce digestible energy intake, which can limit microbial protein synthesis and consequently depress growth (Van Soest, 1994; NRC, 1996). Thus, the inferior performance of steers at higher WH inclusion levels is consistent with established rumen physiology.

Manure scoring remained within acceptable ranges for all treatments, with no evidence of diarrhoea or digestive disturbances (Table 5). Slightly softer faecal scores in WH treatments during some weeks may reflect differences in fibre digestibility or moisture content of the diets, but the absence of severe changes suggests that WH did not negatively affect gut health. Similar findings were reported by Indulekha et al. (2019), who noted stable faecal consistency in goats fed WH-based rations, indicating good ruminal tolerance despite lower intake.

A key concern with WH utilisation in livestock diets is its propensity to accumulate heavy metals, particularly in polluted water systems (Zhou et al., 2005; Shi & Zhao, 2007). However, the present study showed that As, Cd and Pb were not detected in any meat or liver samples, indicating that WH collected from Hartbeespoort Dam did not contribute hazardous residue levels (Table 6). This is consistent with Ndimele et al. (2011), who reported variable but often low heavy-metal accumulation in WH depending on the degree of water contamination. Copper concentrations decreased numerically with higher WH inclusion, but with statistical significance from T1, and were lower for physiological ranges of liver concentration in cattle (Miranda et al., 2006). The absence of detectable toxic metals confirms that WH from this source can be used safely at moderate dietary inclusion levels; however, continued monitoring is advisable due to the plant's known ability to bioaccumulate pollutants. The heavy metals of As, Cd and Pb were not detected (< 0.02 mg/kg for As, < 0.05 mg/kg for Cd and < 0.01 mg/kg for Pb) in the samples tested. Furthermore, the daily reference intakes for minerals (for adults) are 14 mg for Fe and 1 mg for Cu (European Commission Regulation (EU) Nº 1169/2011). A portion (100 gram) of meat will provide less than that, whilst liver will provide more than the daily requirement.

Copper and iron concentrations were significantly higher in the liver compared with meat (Table 7), which aligns with the well-established role of the liver as the central storage and regulatory organ for trace minerals in ruminants. The liver contained 28.46 mg/kg Cu than the 0.77 mg/kg in meat, reflecting the physiological tendency of hepatocytes to accumulate Cu for metabolic functions including ceruloplasmin synthesis and antioxidant enzyme activity (Suttle, 2010). Similarly, Fe concentration was significantly greater in liver (48.46 mg/kg) than in meat samples (13.1 mg/kg), probably because of the liver's function as the primary depot for ferritin and hemosiderin and its role in iron homeostasis and erythropoiesis (McDowell, 2003). The strong significant difference ($P < 0.001$) confirms that tissue type rather than dietary treatment was the main determinant of Fe accumulation (Table 7). Moisture content showed the reverse pattern, with meat containing significantly higher moisture (75.72%) than liver (69.54%). This is consistent with the structural and biochemical features of skeletal muscle, which contains abundant myofibrillar proteins that confer high water-binding capacity, resulting in typical moisture levels of 72–77% in ruminant muscle (Lawrie & Ledward, 2006).

Conclusion

Overall, the findings suggest that dried WH can be used safely as a component of beef cattle diets without risk of heavy-metal contamination, but its nutritional limitations significantly constrain growth performance when included above 25% of the diet. The poor feed intake and low energy contribution at higher inclusion levels undermine its value as a primary feed ingredient. Improving WH utilisation may require treatments that enhance palatability and digestibility such as ensiling, supplementation with energy-rich feeds, or combining with molasses or cassava, which have previously shown promise in ruminant feeding trials (Mukherjee & Nandi, 2004; Ojeifo et al., 2000). Future research should focus on processing methods or feed additives that could improve palatability, adding of a copper source and energy availability to optimise WH inclusion levels for feedlot performance.

Declarations

Competing interest.

The authors have no relevant financial or non-financial interest to disclose.

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Author contributions.

Klaas-Jan leeuw contributed to the study design. Material preparation and data collection by Lemohang Makhanya and Klaas-Jan Leeuw. Data was analysed statistically by Nicolene Cochrane. Manuscript preparation and revisions were done by all authors.

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Data availability.

The datasets generated and/or analysed during this study are available on request by the corresponding author.

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Figures

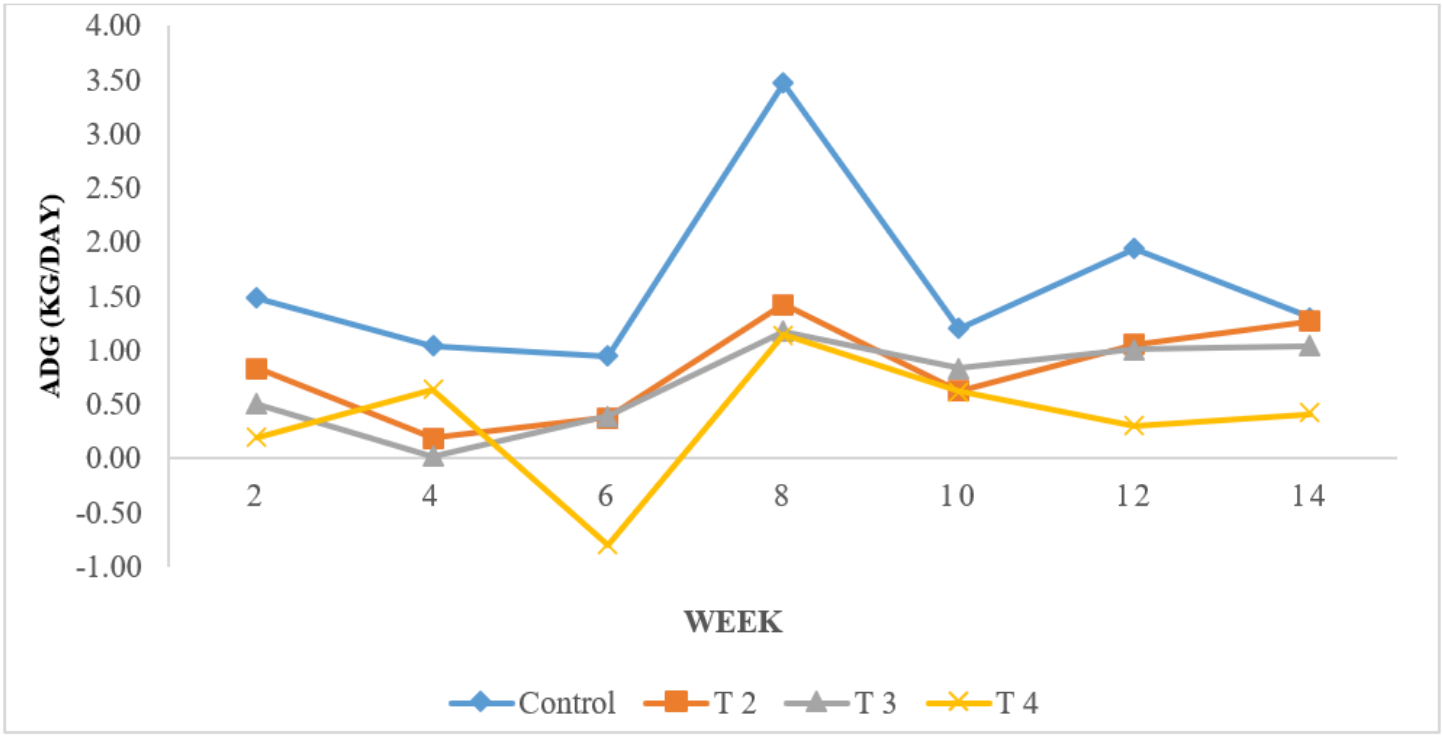


Figure 1

Average weight gain of steers fed increasing levels of dried water hyacinth–based diets over a 14-week feeding period.

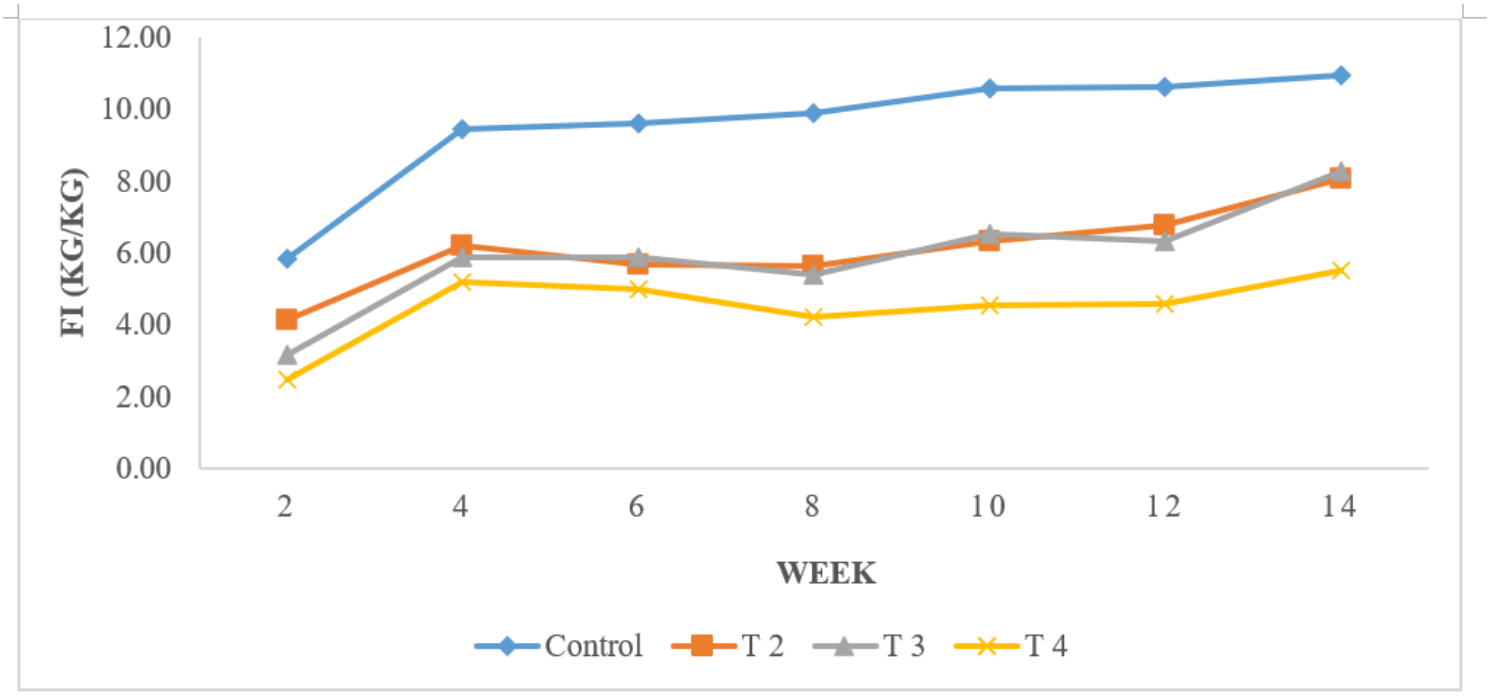


Figure 2

Average feed intake of steers fed increasing levels of dried water hyacinth–based diets over a 14-week feeding period.