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Grassland Research

SHORT COMMUNICATION

Forage yield and nutritive value of plantain and chicory for livestock feed at high altitudes in Peru

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Abstract

Background: Evaluation of forage resources is vital for the sustainability of livestock farming in the South American Andes, especially under conditions of low water availability for irrigation and acid soils.

Methods: We evaluated the productivity and nutritive value of two cultivars of chicory (*Cichorium intybus* L.) and one of plantain (*Plantago lanceolata* L.) in three high‐altitude sites (AL) of the northern highlands of Peru: AL‐I: 2300–2800 m.a.s.l, AL‐II: 2801–3300 m.a.s.l. and AL‐III: 3301–3800 m.a.s.l., for 1 year. The parameters evaluated were dry matter yield (DMY), plant height (PH), growth rate (GR) and nutritional value.

Results: Plantain achieved the greatest annual DMY (ADMY), PH and GR compared to the two chicory cultivars (9.34, 9.56 and 13.39 Mg ha^{-1} for Puna II and Sese 100 chicory and Tonic plantain, respectively; $p = 0.0019$). The greatest ADMY and GR occurred at AL‐I. Regarding nutritional value, differences were observed only for in vitro digestibility of dry matter and metabolisable energy with chicory cultivars higher than plantain.

Conclusions: The results indicate that the three cultivars evaluated may be used as a nutritional supplement in cattle feed, associated with grasses because they have high nutritive value suitable for milk production in the mountain regions of Peru.

KEYWORDS

Cichorium intybus L., dry matter yield, high‐altitude environments, nutritive value, *Plantago lanceolata* L.

INTRODUCTION

Bovine milk production, developed in different high altitudes (ALs), represents the primary source of income for most rural families, constituting 64.6% of the total population of the northern highlands of Peru (INEI, 2017). Dairy cattle farming is based on a grazing system, with the forage base being pastures comprised of an association between ryegrass (*Lolium multiflorum* L. 'Cajamarquino ecotype') and white clover (*Trifolium repens* L. Ladino variety). However, thanks to genetic improvement and exploitation of diversity by breeders, there are other forage species, such as chicory (*Cichorium intybus* L.) and plantain (*Plantago lanceolata* L.), that could improve the forage supply due to their comparatively high crude protein (CP) content compared to grasses and high concentration of minerals, resistance to abiotic stresses such as drought and tolerance of low ambient temperature (González et al., 2020; Hamacher et al., 2021; Li & Kemp, 2005; Teshome et al., 2020) and potential as soil improvers (Crush et al., 2019; Zaini et al., 2021).

The introduction of these species in our environment would potentially enhance the quality of the diet of dairy cattle, especially considering that the ALs of environments such as the northern highlands of Peru have low ambient temperature and acidic soils with high aluminium concentration (Vallejos‐Fernández et al., 2020), which would limit pasture growth (Pornaro et al., 2018;

Silveira & Kohmann, 2020; Vahabinia et al., 2019; Zhumanova et al., 2021).

Plantain tolerates soils with a pH range of 4.2–7.8 and varied texture, except those that are extremely clayey or saline. Chicory grows in well-drained soils of medium to high fertility, with a pH tolerance range from 4.8 to 6.5, and can produce high-nutritive value forage (Li & Kemp, 2005).

The yield and nutritive value of these species depend on the cutting time, pH and soil fertilisation (Hamacher et al., 2021). Yields of 7000–10 100 kg dry matter (DM) ha^{-1} $year^{-1}$ have been reported for *C. intybus* and 11 300 kg DM ha^{-1} $year^{-1}$ in *P. lanceolata* (Cheng et al., 2017; Mangwe et al., 2019; Martin et al., 2017). The growth rate (GR) ranges from 30 kg DM ha^{-1} day^{-1} (Cheng et al., 2020) to 66 kg DM ha^{-1} day^{-1} in soil with pH 6.0–6.6 and mowing intervals of 4–6 weeks (Glassey et al., 2013).

Reported nutritive value parameters of these cultivars (Cv) range from of 15.1% to 16.7% for ash, from 9.8% to 31.6% for crude protein, from 20.4% to 40.4% for neutral detergent fibre (NDF), from 63.1% to 84.8% for in vitro digestibility of dry matter (IVDDM) and from 9.4 to 12.3 MJ kg^{-1} DM for metabolisable energy (ME) (Cave et al., 2015; Minnée et al., 2020; Pembleton et al., 2016; Rattanasomboon et al., 2019). This research aimed to determine the productivity, GR, plant height (PH) and nutritive value of forage monocultures and *C. intybus* and *P. lanceolata* in three ALs of the northern highlands of Peru.

MATERIALS AND METHODS

Location and design of the experiment

The experiment was conducted in Santa Cruz Province, Cajamarca region, located in the northern Andes of Peru, Latitude 06°48′00″ S and Longitude 78°48′00″ W, from January 2018 to March 2019, at three ALs: AL-I (2300–2800 m.a.s.l.), AL-II (2801–3300 m.a.s.l.) and AL-III (3301–3800 m.a.s.l.).

Plant material and experimental design

Two Cv of *C. intybus* (Puna II and Sese 100) and one of *P. lanceolata* (Tonic), originating from New Zealand, were established. The Cv were planted at three ALs whose soils varied in pH from 3.45 to 4.86 (Soil, Plant, Water and Fertilizer Analysis Laboratory of the National Agrarian University La Molina). The experiment was conducted for 1 year, from January 2018 to March 2019. A randomized complete block design with three replications was used at each AL. Plots were 3 m × 2 m in area at all sites. The purity, germination and weight of 1000 seeds were determined to define the sowing density of each Cv (Table 1).

Soil characteristics and weather conditions

Three months before planting, the soils were sampled and then prepared by conventional tillage (ox team), and at the same time, dolomite lime was applied, the amount depending on soil acidity. Planting was done by broadcasting. Island guano and triple superphosphate were used as nitrogen, phosphorus and potassium sources. In AL-I and AL-III, the soil texture was sandy clay loam and in AL-II, the soil texture was sandy loam. Soil characteristics are presented in Table 2. Table 3 shows the temperature and rainfall during the year of evaluation. Temperatures are cooler at higher AL, but because of proximity to the equator, they vary very little with seasonal conditions.

Data collection

Seven harvests were made during the year in AL-I, six in AL-II and three in AL-III. Before harvest, PH was measured from the soil level to the height where (>70%) leaves were concentrated. At each harvest, three quadrat (1.0 m^2) samples were taken from each plot to estimate DMY. Quadrats were harvested using scissors when plants reached a height between 15 and 25 cm (Cranston et al., 2016), leaving a 5 cm stubble on the soil surface.

TABLE 2 Soil chemical composition and fertilisation in the experimental plots.

Soil chemical composition	AL-I	AL-II	AL-III
pH	4.86	4.71	3.45
Organic matter (%)	3.86	18.32	20.46
Nitrogen (%)	0.32	0.96	0.86
Phosphorus (mg kg^{-1})	1.00	2.10	1.30
Potassium (mg kg^{-1})	1062	1048	208
Aluminium (cmol(+) kg^{-1})	0.20	0.40	4.45
Fertilisation			
Nitrogen (kg ha^{-1})	55	40	40
P_2O_5 (kg ha^{-1})	100	100	100
K_2O (kg ha^{-1})	30	30	45
$CaMg(CO_3)_2$ (t ha^{-1})	0.2	0.4	2.5

Note: The soil chemical compositions were measured in Laboratory of Soil, Plant, Water and Fertilizer Analysis, National Agrarian University La Molina. AL-I: 2300–2800 m.a.s.l.; AL-II: 2801–3300 m.a.s.l.; AL-III: 3301–3800 m.a.s.l.

TABLE 1 Qualitative seed characteristics of chicory and plantain cultivars evaluated for forage at three Andean altitudinal floors in northern Peru.

Species and cultivar	Purity (%)	Germination (%)	1000 seed weight (g)	Sowing rate (kg ha^{-1})
Cichorium intybus 'Puna II'	96.4	90	1.5	7
C. intybus 'Sese 100'	99.4	71	1.5	8
Plantago lanceolata 'Tonic'	93.3	95	2.15	9

TABLE 3 Average temperature and rainfall from January 2018 to March 2019 at the experimental sites.

Site	January	February	March	April	May	June	July	August	September	October	November	December
Temperature (°C)												
AL-I	17.6	17.5	17.2	16.9	16.3	15.8	15.4	15.7	16.2	16.6	16.8	16.9
AL-II	14.2	13.4	13.5	13.4	12.7	11.8	11.9	12.3	12.8	13.6	13.3	13.4
AL-III	7.3	6.9	6.9	6.9	7.1	6.4	6.2	6.2	6.9	6.8	8.0	7.8
Precipitation (mm)												
AL-I	77	93	161	113	62	33	20	37	69	90	69	54
AL-II	98	111	133	91	42	15	8	14	40	92	68	83
AL-III	128	59	92	141	146	8.6	5	3	35	119	147	94

Note: AL-I: 2300–2800 m.a.s.l.; AL-II: 2801–3300 m.a.s.l.; AL-III: 3301–3800 m.a.s.l.

The samples were placed in plastic bags and then transported in polystyrene boxes with cooling gel packs at 4°C to the National University of Cajamarca, where 100 g of each sample was used to determine the percentage of DM in a forced-air oven at 105°C for 24 h and another 400 g of the forage was dried at 65°C for 48 h and sent to the Soil, Water, Fertilizer and Pasture Service Laboratory of INIA-Cajamarca and the Laboratory of Animal Nutrition and Food Bromatology of the National University Toribio Rodriguez de Mendoza of Amazonas to analyze the nutritive value.

GR was determined by dividing the DMY by the days elapsed per harvest and expressed as kg DM ha^{-1} day^{-1}. Annual DMY (ADMY) was the sum of all harvests for a given plot.

Nutritive value

The CP and ash analysis was performed using the Association of Official Analytical Chemists (AOAC) 984.13 methodology (AOAC, 2012; Jiang et al., 2014). NDF was determined according to the methodology of Van Soest et al. (1991). The IVDDM was determined using the DAISY digester (ANKOM) (Mabjeesh et al., 2000; Weiss, 2015) at the Laboratory of Animal Nutrition and Food Bromatology of the Universidad Nacional Toribio Rodríguez de Mendoza of Amazonas.

ME was computed using the below equation (CSIRO, 2007; Pembleton et al., 2016) for monoculture forages.

$$\text{Estimated ME} = 0.194\,(\text{OMD}) - 2.577, \quad (1)$$

where OMD denotes organic matter digestibility, and OMD = 0.84 IVDDM + 7.32.

Statistical analysis

The ADMY, GR, PH and nutritive value were analysed by analysis of variance using the general linear model of the RStudio platform (R Core Team, 2023). ALs (i.e., locations), Cv and their interaction were fixed effects and replication and harvest were random effects. The analysis of ADMY did not include the harvest term. An analysis of normality and homogeneity of variance of the data obtained was carried out using the Levene ($p < 0.05$) and Kolmogorov–Smirnov ($p < 0.05$) tests, respectively. Pearson's correlation test was used to relate PH and GR to DMY. Duncan's test ($p < 0.05$) was used to compare the mean values.

RESULTS

DMY components

The ADMY of plantain averaged for the three AL was higher than chicory (Table 4). For the three AL, the ADMY averaged for chicory and plantain was, as expected, the highest ($p \leq 0.05$) in AL-I (14.90 Mg DM ha^{-1} $year^{-1}$), followed by AL-II (11.39 Mg DM ha^{-1} $year^{-1}$) and AL-III, with 6.01 Mg DM ha^{-1} $year^{-1}$. An AL × Cv interaction was not statistically detected, although the plantain–chicory ADMY difference was more strongly evident at AL-II ($p < 0.0001$) than at AL-III ($p < 0.08$) (Data not shown). Plantain also produced taller plants than chicory (Table 4), and no interaction of AL and Cv for PH was noted. For both ADMY and PH, the two chicory Cv were similar. A key feature of the yield data across the three altitudinal levels was a high value of ADMY for plantain in AL-II, even higher than that at AL-I.

Nutritive value

Ash, CP and NDF did not differ among Cv, but plantain had lower IVDMD and ME than the two chicory Cv (Table 5). AL had similar herbage nutritive value, except for NDF, where AL-III had lower values.

DISCUSSION

Fewer harvests were taken at higher ALs, with only three harvests at the highest latitude, as a consequence of reduced GR attributable to lower temperatures, extremely acid pH, high concentrations of aluminium in the soil and limited fertilisation (Pornaro et al., 2018; Silveira & Kohmann, 2020; Vahabinia et al., 2019;

TABLE 4 ADMY, PH and GR on a dry matter basis of selected chicory cultivars and one plantain cultivar at three altitudinal levels in northern Peru.

Species	Cultivar	ADMY Mg ha^{-1}	ADMY Mg ha^{-1} year^{-1}	PH (cm)	GR (kg ha^{-1} day^{-1})
Chicory	Puna II	1.68b	9.34b	18.32b	25.61
Chicory	Sese 100	1.74b	9.56b	17.57b	26.22
Plantain	Tonic	2.60a	13.39a	22.43a	36.72
Altitudes (AL)					
AL-I (7 harvests)		2.13	14.90a	21a	41a
AL-II (6 harvests)		1.89	11.39a	22a	31a
AL-III (3 harvests)		2.00	6.01b	15b	17b
p					
Cv		0.0161	0.0311	0.0374	0.0874
AL		0.6218	0.0010	0.0047	0.0010
AL × Cv		0.1094	0.1496	0.2798	0.1493

Note: Values are the means of three replicates and either three cultivars or three ALs. Treatment means within a column followed by the different letter(s) are significantly different based on the Duncan test; $p \leq 0.05$. AL-I: 2300–2800 m.a.s.l.; AL-II: 2801–3300 m.a.s.l.; AL-III: 3301–3800 m.a.s.l.

Abbreviations: ADMY, annual dry matter yield; Cv, cultivar; GR, growth rate; PH, plant height.

TABLE 5 Average nutritional value of two *Cichorium intybus* cultivars and *Plantago lanceolata,* and of herbage at the three altitudes (ALs).

Species	Cultivar	Ash (%)	CP (%)	NDF (%)	IVDDM (%)	ME (MJ kg^{-1} DM)
Chicory	Puna II	15.75	16.32	19.72	77.45a	11.47a
Chicory	Sese 100	15.55	16.55	20.73	76.94a	11.38a
Plantain	Tonic	15.53	15.45	20.73	73.74b	10.83b
p		0.9030	0.1905	0.8109	0.0151	0.0104
ALs						
AL-I		16.17	16.53	22.48a	75.08	11.07
AL-II		15.03	16.13	21.44a	75.44	11.13
AL-III		15.63	15.65	17.27b	77.61	11.48
p		0.1422	0.3619	0.0276	0.1008	0.0972

Note: Treatment means within a column followed by the different letter(s) are significantly different based on the Duncan test; $p \leq 0.05$. AL-I: 2300–2800 m.a.s.l.; AL-II: 2801–3300 m.a.s.l.; AL-III: 3301–3800 m.a.s.l.

Abbreviations: AF, altitudinal floor; CP, crude protein; IVDDM, in vitro digestibility of dry matter; ME, metabolisable energy; NDF, neutral detergent fibre.

Vallejos-Fernández et al., 2020). The low yield in AL-III was also reflected in shorter plants (Table 4). In AL-I, the three Cv have similar yield, PH and GR ($p > 0.05$). Therefore, any of these Cv could be sown in a feed improvement plan for dairy cattle. In AL-II, *P. lanceolata* expressed its highest yield potential, probably due to the soil organic matter content and potassium levels being higher than that in AL-I and AL III (Table 2).

The yield of the two chicory Cv is within the ranges reported by Cheng et al. (2017), Mangwe et al. (2019) and Martin et al. (2017), demonstrating that the chicory, and by extension, the plantain Cv show adaptation to the climatic conditions and soil characteristics in our experiment (González et al., 2020; Hamacher et al., 2021; Teshome et al., 2020; Zaini et al., 2021). Therefore, these Cv constitute an attractive alternative to complement the ryegrass–white clover mixtures widely used as the basis of dairy cattle feeding in this high Andean region (Cichota et al., 2020; Pirhofer-Walzl et al., 2011). The yield advantage of *P. lanceolata* is especially evident in higher AL conditions despite the low temperature and the low soil pH (Vahabinia et al., 2019; Vallejos Fernández et al., 2021; Zhumanova et al., 2021).

Both the PH and GR of plantain (Table 4) were higher ($p \leq 0.05$) than those of the chicory Cv. The values of GR for chicory and plantain are similar to those obtained by Cheng et al. (2020) and lower than those found by Glassey et al. (2013), probably due to the characteristics of the soil and the climatic conditions where this study was conducted being similar to those in the other studies.

The higher IVDDM and ME ($p \leq 0.05$) of the two Cv of chicory (Table 5) is probably due to the higher growth of plantain. The nutrient concentrations found in this analysis are within the range found by Minnée et al. (2020), Rattanasomboon et al. (2019), Pembleton et al. (2016) and Mangwe et al. (2019). There was a lower NDF concentration at AL-III ($p \leq 0.05$), probably due to the slower growth and reduced lignification under low temperature (Vahabinia et al., 2019; Vallejos Fernández et al., 2021; Zhumanova et al., 2021), but the higher quality was offset by only three harvests in this AL during the year.

The high concentration of minerals (ash), CP, IVDDM and ME in the chicory and plantain would be very important in effectively supplementing the diet of dairy cattle. In addition, when compared to ryegrass under the same climatic and soil conditions, chicory and plantain have a higher percentage of crude protein and minerals (Vallejos-Fernández et al., 2020) and also higher mineral levels than white clover and red clover (Vallejos-Fernández et al., 2020). We recommend that future work associate the three species and evaluate forage yield in relation to soil characteristics. This study shows the importance of chicory and plantain for the high AL conditions of the present study, and in particular, highlights the outstanding performance of plantain in ALs of approximately 2800–3300 m.

CONCLUSIONS

Plantain showed greater productivity than chicory, although chicory showed higher IVDDM than plantain, which affects the availability of their ME. The yield of the three Cv studied shows that chicory and plantain have a high potential for livestock feed in the Peruvian Andes. Plantain and chicory have highly digestible protein and mineral levels that equal or exceed those of other common forages. This study opens the possibility of planting these herbs in association with companion grasses, which are the majority crop in rural highland production systems (especially ryegrass), and with legumes such as white clover. This initiative aims to improve the sustainability of livestock farming under the conditions outlined in this research.

AUTHOR CONTRIBUTIONS

Luis A. Vallejos-Fernández: Conceptualisation; data curation; funding acquisition; investigation; methodology; project administration; supervision; validation; visualisation; writing—original draft; writing—review and editing. **Ricardo Guillén**: Funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualisation; writing—original draft. **César Pinares-Patiño**: Conceptualisation; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision. **Rubén García-Ticllacuri**: Conceptualisation; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision. **Yudith Y. Muñoz-Vilchez**: Formal analysis; software; validation; visualisation; writing—original draft; writing—review and editing. **Carlos Quilcate**: Funding acquisition; project administration; resources; validation; visualisation. **Wuesley Y. Alvarez-García**: Data curation; formal analysis; resources; software; supervision; validation; visualisation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors on request.

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