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Assessment of cultivation efficiency of several cultivars of blue lucerne (*Medicago sativa* L.) in the conditions of Shirak region of Armenia

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Abstract. Background: Lucerne (*Medicago sativa* L.) is a highly productive forage legume valued for its exceptional protein concentration, vitamin richness, digestible fiber, and bioactive compounds. One kilogram of lucerne green mass contains approximately 50 g of carotene, alongside calcium, phosphorus, and other essential nutrients, making it a cornerstone of sustainable livestock farming and a potential functional food source.
Objective: The study aimed to assess agro-biological traits, green mass and hay yield, seed productivity, and protein concentration of 29 introduced lucerne cultivars from the All-Russian Institute of Crop Production (VIR) compared with the traditional local cultivar 'Aparani' under the agro-climatic conditions of the Shirak region in Armenia.
Methods: Field experiments were conducted from 2019 to 2022 using a randomized design with four replications (plot size: 25 m²). Standard agronomic practices were applied. Protein concentration in seeds was determined by the Kjeldahl method, while dry matter and nitrogen values were analyzed at the Organic Agriculture Laboratory of ANAU. Statistical analysis was performed using ANOVA, *LSD*, and relative error (Ex, %).

Results: Considerable variation was observed among cultivars in yield and adaptability. The Canadian cultivars ‘Admiral’ and ‘Adge’, the French cultivar ‘Derby’, and the American cultivar ‘Schild’ demonstrated the highest productivity. ‘Admiral’ showed superior early regrowth, growth vigor, leafiness, and seed productivity (8.8 c ha^{-1}). Green mass yield reached 325.5 c ha^{-1} for ‘Admiral’ and 308.4 c ha^{-1} for ‘Adge’, while their seed protein concentrations were 16.3% and 15.6%, respectively, exceeding the local ‘Aparani’.
Conclusion: The results indicate that ‘Admiral’ and ‘Adge’ are highly suitable for the Shirak region due to their high yields, adaptability, and nutritional value. Their adoption could enhance fodder self-sufficiency, improve livestock productivity, and expand the role of lucerne as a functional food crop rich in protein and bioactive compounds.

Key words: agro-climatic conditions, cultivar performance, forage legumes, lucerne, *Medicago sativa* L., protein concentration, yield efficiency.

INTRODUCTION

Lucerne (*Medicago sativa* L.) is one of the most important perennial forage legumes worldwide, highly valued for its high protein content, carotene concentration, and digestible fiber. Its cultivation plays a vital role in sustainable livestock production, soil fertility improvement through nitrogen fixation, and biodiversity conservation (Gaweł, 2012; Tanchyk, 2021; Akhtar et al., 2023; Pourebrahimi Foumani et al., 2023). In Armenia, lucerne has traditionally been the dominant forage crop and continues to serve as a cornerstone of animal husbandry systems.

The Shirak region is characterized by cold winters, frequent frosts, and relatively short vegetation periods, which significantly influence the productivity, persistence, and adaptability of lucerne stands. Consequently, evaluating foreign and local cultivars under these specific conditions is of great importance for improving fodder security and increasing the efficiency of livestock production. Although more than 29 cultivars introduced from international breeding centers have been tested in Armenia, comprehensive comparative studies remain scarce (Doguzova, 2020; Harutyunyan et al., 2023; Martirosyan et al., 2023c).

Previous research has shown that the average productivity of forage crops in Armenia remains lower than that of leading European countries. This limitation is not only attributed to the genetic potential of cultivars but also to inadequate fertilization, limited use of modern agrotechnologies, irrigation constraints, and poor adaptation of some imported cultivars to local agro-climatic conditions. As a result, the selection and introduction of lucerne cultivars with proven adaptability and productivity under regional conditions have become a national priority (Harutyunyan, 2022; Matevosyan et al., 2023).

Given these challenges, the present study was designed to conduct a comparative evaluation of 29 lucerne cultivars obtained from the All-Russian Institute of Crop Production (VIR) against the traditional Armenian cultivar ‘Aparani’. Special emphasis was placed on agro-biological traits, green mass and hay yield, seed productivity, and protein concentration under the agro-climatic conditions of Shirak. The findings are expected to provide both scientific and practical guidance for improving fodder self-sufficiency and for introducing highly productive lucerne cultivars with potential applications not only in animal feed but also as functional food resources.

MATERIALS AND METHODS

The field trials were conducted from 2019 to 2022 at the experimental fields of the Gyumri Breeding Station, Shirak region, Armenia (40°47′ N, 43°50′ E; 1,550 m a.s.l.). The region has a temperate continental climate with cold winters and moderately warm summers. The average annual air temperature is 6.8 °C, ranging from –12 °C in January to 25–27 °C in July. Annual precipitation averages 520–560 mm, mostly occurring in spring and early summer. The experimental soils are meadow-chernozems with pH 7.4, humus 3.2%, and moderate levels of available phosphorus and potassium.

Seeds of 29 lucerne cultivars obtained from the All-Russian Institute of Crop Production (VIR, Russia) were compared with the traditional Armenian cultivar ‘Aparani’. Among them, the cultivars Admiral and Adge (Canada), Derby (France), and Schild (USA) were subjected to detailed analysis due to their superior performance during preliminary evaluations.

The experimental layout followed a randomized complete block design (RCBD) with four replications. Each plot measured 25 m², with 15 cm row spacing. Seeds were sown without cover crops during the first decade of May. Standard agronomic practices—including weed control, irrigation when necessary, and pest management - were applied uniformly across all plots.

The following measurements were taken:

- Green mass yield – determined as fresh biomass weight (c ha^{-1}) at each mowing
- Hay yield – calculated after air-drying subsamples to constant weight
- Seed yield – measured at full maturity and expressed in c ha^{-1}
- Leaf-to-stem ratio – determined from 10 randomly selected plants per plot, dried at 70 °C, and weighed.

Protein concentration in seeds was analyzed using the Kjeldahl method (N × 6.25). Dry matter and nitrogen contents were determined at the Organic Agriculture Laboratory of the Armenian National Agrarian University (Yagodin, 1987; Dospekhov, 1985; Conova & & Samoilov, 2015; Shaboyan et al., 2024).

Data were statistically processed using one-way ANOVA, and mean comparisons were performed with the *LSD* test at $p \leq 0.05$. Relative error (Ex, %) was also calculated to assess data accuracy. Statistical calculations were carried out using Microsoft Excel 2019.

RESULTS AND DISCUSSION

Morphological Traits

The evaluation of 29 lucerne cultivars under the agro-climatic conditions of the Shirak region revealed considerable variation in morphological characteristics. Four cultivars - Admiral, Adge, Derby, and Schild - demonstrated superior performance in terms of green mass, hay yield, seed productivity, and agro-biological traits. These cultivars also showed strong winter hardiness and rapid spring regrowth, with Admiral and Adge (Canada) being particularly well adapted, followed by Derby (France) and Schild (USA).

Morphological traits are recognized as key indicators of lucerne productivity and nutritional quality, since leaves and inflorescences contain 1.5–1.8 times higher protein and digestible nutrients compared to stems (Kudeyarov, 2021; Solozhentseva, 2021;

Stødkilde, 2023). As shown in Table 1, the Admiral cultivar was characterized by large, slightly serrated leaves, while Adge displayed predominantly oval leaves. Inflorescence type and flower number also varied: the local cultivar Aparani produced compact clusters with up to 40 flowers per cluster, whereas imported cultivars generally formed looser clusters with 15–30 flowers. Pod morphology and 1,000-seed weight differed moderately between cultivars but remained within ranges reported for lucerne in other temperate regions (Shi, 2017; Ramos-Ulate, 2022).

Table 1. Morphological and morphological description of tested cultivars

Morphological trait	Aparani (local)	Derby (France)	Schild (USA)	Adge (Canada)	Admiral (Canada)
Leaf shape	Compound, medium-sized, oval leaf with long petiole	Compound, lanceolate, toothed margin	Compound, elliptic, with petioles	Compound, obovate, serrated at the ends	Compound, large leaves, weakly serrated
Inflorescence	Compact cluster with short petiole	Elongated cluster (~4 cm)	Compact bunch without petiole	Scattered cluster with a short peduncle	Compact, small cluster with few flowers
Number of flowers/cluster	Up to 40	Up to 25	Up to 28	Up to 30	Up to 15
Pod shape	Spring-shaped, up to 3 coils	Spring-shaped, 1–2 coils	Spring-shaped, 1.5–2 coils	Spring-shaped, with 2 coils	Spring-shaped, up to 3 coils
1,000 seed weight (g)	2.3	2.1	2.1	2.3	2.2

Overall, the morphological variation confirms that imported cultivars - particularly Admiral and Adge - possess structural advantages such as larger leaf size and more favorable leaf-stem ratios, which are directly linked to higher forage quality. These results suggest that morphological traits, especially leaf size and leaf-stem ratio, are reliable indicators of lucerne adaptability under the cold and relatively short growing season of Shirak. Cultivars combining high leafiness with compact inflorescences can therefore be recommended as promising candidates for both productivity and nutritional improvement.

Growth and Development Phases

All tested cultivars completed three mowing cycles per season under the agro-climatic conditions of the Shirak region (Table 2). Among them, the Canadian cultivar Admiral demonstrated the earliest spring regrowth (March 13), which was 5–9 days earlier than the local control Aparani and 2–4 days earlier than the cultivars Derby, Schild, and Adge. Early regrowth allowed Admiral to reach the bud formation and flowering stages more quickly, thereby contributing to shorter harvest cycles.

The duration of the first harvest ranged from 62 to 71 days, depending on the cultivar. Admiral required the shortest period (62 days), while Aparani showed the longest (71 days). Subsequent harvests were also shorter in Admiral and Adge compared with the control, confirming their better adaptability and faster turnover under short growing seasons.

The advantage of earlier regrowth and shortened harvest cycles lies in the opportunity to achieve higher annual biomass production, particularly in regions with relatively short vegetation periods such as Shirak. Lucerne cultivars with early spring growth and rapid regrowth capacity are more productive and better suited to cooler climates (Vasileva, 2012; Mielmann, 2013; Osipova, 2018; Perpetuo, 2021).

Overall, the results suggest that phenological traits - especially early spring regrowth and shorter inter-harvest periods - are reliable indicators of cultivar adaptability. Cultivars such as Admiral and Adge, which combine early development with high productivity, can be recommended as valuable options for maximizing forage yield in highland environments.

Table 2. Phenological stages and harvesting durations (days) of tested lucerne cultivars

Cultivar	Stage I Regrowth	Cocooning	Blooming	Stage II Regrowth	Cocooning	Blooming
Aparani local	18.03	20.05	28.05	04.06	27.07	03.08
Derby (France)	15.03	14.05	20.05	27.05	16.07	22.07
Schild (USA)	15.03	16.05	23.05	30.06	21.07	27.07
Adge (Canada)	14.03	10.05	17.06	23.06	13.07	20.07
Admiral (Canada)	13.03	29.05	14.05	21.05	07.07	13.07

Table 2 (continued)

Cultivar	Stage III Regrowth	Cocooning	Blooming	Harvest I (days)	Harvest II (days)	Harvest III (days)
Aparani local	11.08	01.10	08.10	71	67	64
Derby (France)	01.08	26.09	02.10	65	63	62
Schild (USA)	05.08	29.09	06.10	68	65	63
Adge (Canada)	29.07	19.09	26.09	64	62	60
Admiral (Canada)	23.07	14.09	20.09	62	59	58

Note: Stage I–III = first, second, and third mowing cycles; ‘Cocooning’ = bud formation; ‘Blooming’ = onset of flowering. Dates are presented as day. month (dd.mm). Harvest duration is the period from regrowth to mowing.

Growth Characteristics and Foliage

The assessment of growth characteristics across three harvests revealed significant cultivar-dependent variation in stem density, plant height, and foliage contribution (Table 3). The Canadian cultivar Admiral showed superior performance in all traits compared with both the local Aparani and the other introduced cultivars.

Stem number and density. During the first harvest, Admiral produced 18.5 stems per plant and 3,977 stems per m², exceeding Aparani by 5.8 stems per plant and approximately 1,300 stems per m². Although stem numbers decreased in subsequent harvests for all cultivars, Admiral and Adge consistently maintained higher averages. This trend agrees with findings by some scientists who reported that greater stem density is strongly associated with higher biomass accumulation in lucerne (Mantovi, 2015; Hoppen, 2021; Tadevosyan, 2023; Teixeira, 2023).

Plant height. Admiral also outperformed the other cultivars in height, reaching 70.5 cm in the first harvest, which was 12.4 cm taller than Aparani. The difference remained significant in subsequent harvests, confirming its superior growth vigor. Adge ranked second, while Schild was closest to the control. Since plant height is known to correlate positively with forage yield (ARMSTAT, 2023), these results further support the high biomass productivity of Admiral and Adge.

Leaf mass and foliage ratio. Foliage contribution, a key determinant of nutritive value, was highest in Admiral, with 38.8 g of leaf mass per 10 plants, accounting for 54% of total biomass. Adge followed with 53.3%, while Aparani reached only 45.2%. The higher leaf-stem ratio in Admiral and Adge reflects their superior forage quality, as lucerne leaves contain 1.5–1.8 times more protein than stems.

Statistical validation. ANOVA analysis confirmed statistically significant differences ($p < 0.05$) among cultivars for all measured parameters. The consistently superior performance of Admiral and Adge aligns with results from Canadian and European breeding programs (FAO, 2018; Abdullayev et al., 2021), demonstrating their strong adaptability to the agro-climatic conditions of Armenia.

Table 3. Growth characteristics and foliage mass of tested lucerne cultivars during three harvests (mean values ± SE, $n = 4$)

Cultivar	Stems per plant (pcs)	Stems per m² (pcs)	Plant height (cm)	Leaf mass (g per10 plants)	Stem mass (g per10 plants)	Leaf % of total mass
Aparani (local)	12.7 ± 0.4	2,679 ± 85	61.2 ± 1.5	32.8 ± 1.2	39.8 ± 1.3	45.2
Derby (France)	16.2 ± 0.5	3,450 ± 92	63.4 ± 1.6	34.9 ± 1.3	41.9 ± 1.4	45.5
Schild (USA)	15.4 ± 0.6	3,234 ± 88	62.1 ± 1.4	32.2 ± 1.1	42.6 ± 1.2	43.0
Adge (Canada)	17.9 ± 0.4	3,830 ± 95	67.8 ± 1.8	37.2 ± 1.4	45.8 ± 1.6	53.3
Admiral (Canada)	18.5 ± 0.5	3,977 ± 97	70.5 ± 1.7	38.8 ± 1.5	46.2 ± 1.5	54.0
LSD ($p < 0.05$)	0.8	110	2.0	1.9	2.1	–

Note: Values are means of four replicates. Statistical differences among cultivars were determined by one-way ANOVA followed by *LSD* test ($p < 0.05$).

(Values for stems per plant, stems per m², and plant height are presented across I / II / III mowings. Data represent mean values of four replicates. Statistical analysis was performed by one-way ANOVA, and means were compared using *LSD* test at $p < 0.05$).

In summary, Admiral and Adge not only ensured higher stem density and plant height but also maintained a higher proportion of leaf biomass, directly contributing to both forage yield and nutritive value. These traits make them particularly promising for large-scale cultivation in the Shirak region.

Yield Performance

The analysis of forage productivity across three mowing cycles revealed statistically significant differences among cultivars (Table 4).

Table 4. Yield and feed value of tested lucerne cultivars (c ha^{-1})

Cultivar	Green mass yield (c ha^{-1})	Hay yield (c ha^{-1})	Feed units (c ha^{-1})*
Aparani (local)	246.1 ± 5.8	80.3 ± 3.1	43.8 ± 1.7
Derby (France)	278.1 ± 6.2	93.2 ± 3.6	50.5 ± 1.9
Schild (USA)	266.4 ± 6.0	88.8 ± 3.5	48.4 ± 1.8
Adge (Canada)	308.4 ± 6.5	102.8 ± 3.9	56.1 ± 2.0
Admiral (Canada)	325.5 ± 6.8	108.5 ± 4.1	59.1 ± 2.1
LSD ($p < 0.05$)	7.9	4.6	2.5

Note: *Feed unit conversion: 100 kg of hay = 54.5 feed units.

Green mass yield. The local Aparani cultivar produced the lowest green mass yield (246.1 c ha^{-1}), while the Canadian cultivar Admiral achieved the highest productivity (325.5 c ha^{-1}), exceeding the control by 79.4 c ha^{-1}. Adge also demonstrated high productivity (308.4 c ha^{-1}), confirming its adaptability to Shirak conditions. Derby and Schild performed moderately, with yields of 278.1 and 266.4 c ha^{-1}, respectively. These findings are consistent with earlier reports that Canadian lucerne cultivars show superior yield stability under temperate continental climates (FAO, 2018).

Hay yield and feed unit conversion. Hay yield followed similar trends, ranging from 80.3 c ha^{-1} in Aparani to 108.5 c ha^{-1} in Admiral. The feed unit conversion efficiency was highest in Admiral (59.1 c ha^{-1}), which exceeded Aparani by 15.3 c ha^{-1}, while Adge also performed well (56.1 c ha^{-1}). The high feed unit values reflect both greater dry matter accumulation and more favorable leaf-stem ratios. These results agree with Eldeiry & Garcia (2008), who emphasized that lucerne foliage proportion is a decisive factor determining nutritive value.

Nutritional efficiency. On average, approximately 31–32% of green mass was converted into hay. Admiral showed the highest efficiency in the second harvest, where hay yield accounted for 36.9% of total biomass. Such efficiency is particularly important for ensuring stable forage reserves under Armenia's semi-arid climatic conditions.

Statistical validation. ANOVA analysis confirmed that differences among cultivars in green mass yield, hay yield, and feed unit production were statistically significant ($p < 0.05$). The results clearly demonstrate the superiority of Admiral and Adge over both the local Aparani and the other imported cultivars.

In summary, Admiral and Adge combined high green mass productivity, elevated hay yields, and improved feed unit efficiency, confirming their potential to substantially increase fodder production and support livestock sustainability in the Shirak region.

Chemical Composition

The analysis of fresh-mass chemical composition revealed clear cultivar effects on moisture, dry matter, nitrogen, and crude protein concentrations (Table 5). Admiral demonstrated the highest dry matter (25.91%) and crude protein content (16.3%), followed by Adge (25.09% DM; 15.6% CP). Derby and Schild showed intermediate values (≈24.0–23.3% DM; 15.6–15.0% CP), while the local cultivar Aparani exhibited the lowest dry matter (23.41%) and crude protein content (15.0%). The inverse relationship between moisture and dry matter was consistent across all cultivars.

Statistical validation. ANOVA confirmed significant differences ($p < 0.05$) among cultivars for both dry matter and crude protein concentration. Pairwise *LSD* tests ranked Admiral > Adge > Derby ≈ Schild ≈ Aparani for CP. Although the absolute differences were modest - for instance, Admiral exceeded Aparani by 1.3 percentage points – the field-scale impact is meaningful. Considering Admiral's hay yield of 108.5 c ha^{-1} (10,850 kg ha^{-1}), this protein advantage corresponds to approximately 141 kg more crude protein per hectare.

Link to morphology and forage quality. The higher crude protein concentrations in Admiral and Adge are consistent with their greater leaf mass and higher leaf-stem ratios (Table 3), reflecting the well-established gradient of higher protein content in leaves compared with stems (Eldeiry & Garcia, 2008). Reported crude protein values for lucerne at early bloom in temperate regions typically range from 15–20% (Goncharov, 1985; Guo, 2020), aligning closely with the results obtained under Shirak's agro-climatic conditions.

In summary, the chemical composition results confirm that Admiral and Adge are nutritionally superior cultivars, combining higher dry matter accumulation with enhanced protein concentration. These traits further increase their value not only for forage production but also for improving the overall efficiency of livestock feeding systems in the region.

Table 5. Chemical composition of green mass of studied cultivars (%)

Cultivar	Moisture (%)	Dry matter (%)	Nitrogen (%)	Crude protein (%)
Aparani local	76.59	23.41	2.4	15.0
Derbi (France)	75.93	24.07	2.5	15.6
Schild (USA)	76.73	23.27	2.4	15.0
Adge (Canada)	74.91	25.09	2.5	15.6
Admiral (Canada)	74.09	25.91	2.6	16.3

Note: Crude protein calculated as N × 6.25; The *Admiral* cultivar demonstrated the highest dry matter and protein content among all studied cultivars.

Seed Productivity

Seed yield was another critical performance indicator, and the results revealed substantial and statistically significant variation among cultivars (Table 6). Across the three-year testing period (2019–2021), the Canadian cultivars Admiral and Adge consistently achieved the highest yields, averaging 8.8 and 8.5 c ha^{-1}, respectively. These values markedly exceeded those of the local Aparani cultivar (5.9 c ha^{-1}), as well as Derby (6.8 c ha^{-1}) and Schild (6.3 c ha^{-1}). ANOVA confirmed that these differences were significant ($p < 0.05$).

Table 6. Average lucerne seed yield in the 1st year of use (2019–2021), c ha^{-1}

Cultivar	2019	2020	2021	3-year average
Aparani (local)	6.1	6.3	5.4	5.9
Derby (France)	7.0	6.8	6.6	6.8
Schild (USA)	6.4	6.6	5.5	6.3
Adge (Canada)	8.3	8.5	8.8	8.5
Admiral (Canada)	8.8	8.6	9.0	8.8

The consistent performance of Admiral and Adge highlights their strong adaptation to the agro-climatic conditions of Shirak. Their superior reproductive capacity ensures a reliable seed supply, which is essential both for maintaining long-term lucerne cultivation and for supporting the expansion of forage-based production systems. Similar trends have been reported in international studies, where the introduction of high-performing cultivars resulted in stable yield increases in forage legumes (Bani Khalaf et al., 2021; Martirosyan, 2023a). There are scientific works that also emphasize that genetic potential, combined with agro-ecological adaptation, plays a decisive role in lucerne seed productivity (Burceva, 2020; Argenti, 2021; Beslemes, 2023).

The results of Armenian research once again confirm that cultivar selection is a key factor for achieving stable lucerne seed production under contrasting climatic conditions. The consistent superiority of the Canadian cultivars in Shirak confirms their potential as high-performing, well-adapted genotypes (Matevosyan, 2020; Martirosyan, 2023b).

In conclusion, Admiral and Adge not only outperform the local Aparani and other imported cultivars in forage yield and protein content but also ensure significantly higher and more stable seed productivity. Their integration into Shirak's forage production systems could substantially strengthen the regional fodder base, enhance livestock sector sustainability, and contribute to the long-term resilience of Armenia's forage cultivation.

CONCLUSION

This study evaluated the agro-biological performance of 29 lucerne (*Medicago sativa* L.) cultivars from diverse geographic origins under the soil and climatic conditions of the Shirak region of Armenia. Among them, the Canadian cultivars Admiral and Adge consistently demonstrated superior performance in terms of green mass, hay and seed yield, protein content, and adaptability to local environmental conditions.

Based on these results, Admiral and Adge are recommended for wider integration into Armenia's forage production systems. Their high productivity, early regrowth, short vegetation period, and tolerance to harsh winters make them suitable for intensive crop rotations and climate-resilient fodder production. The adoption of these cultivars can significantly strengthen the regional fodder base, improve feed quality, and contribute to the sustainability of livestock farming in Armenia.

In addition to their agronomic advantages, lucerne cultivars - particularly Admiral and Adge – exhibit nutritional properties relevant to functional food and nutraceutical applications. Their content of essential amino acids, vitamins, and bioactive phytochemicals highlights their potential for use in dietary supplements and health-promoting food products. Lucerne sprouts and protein concentrates could thus serve as valuable ingredients contributing to nutritional security.

Nevertheless, this research was conducted in a single region under specific climatic conditions. Further multi-year and multi-location trials are required to assess the long-term stability and wider adaptability of the selected cultivars. Complementary biochemical studies, including amino acid profiling and phytochemical characterization, are also recommended to substantiate their functional food potential.

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