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Comparative Study of Winter and Summer Fodder Species and Their Mixtures on-Station and on-Farm Conditions

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ABSTRACT

Cultivated fodder species and cereal-legume mixtures can boost fodder supply, enhance nutritive value, and decrease reliance on crop residues, thereby helping to address the severe feed shortage faced by ruminant livestock in Nepal. This study aimed to evaluate winter and summer fodders and their mixtures under on-station conditions and verify them across diverse agro-ecological regions. In the first year, 12 winter and eight summer fodder treatments—including sole cereals, sole legumes, and mixtures—were tested in separate experiments at the National Pasture and Fodder Research Program, Khumaltar. Both winter and summer trials used a Randomized Complete Block Design with three replications. Based on first-year performance, one winter package (Oat + Berseem) and one summer package (Teosinte + Cowpea) were selected for farmers' field tests in four districts: Dhading, Kabhrepalanchowk, Banke, and Sunsari. Data on dry matter yield and related attributes were analyzed using ANOVA and Tukey's Honest Significant Difference Test at the 5% significance level. On-station results showed that sole Oat (*Avena sativa*) produced the highest ($p<0.001$) winter dry matter yield (15.63 t/ha), and the Oat + Berseem (*Trifolium alexandrium*) mixture yielded similarly (14.82 t/ha; ($p>0.05$)). Among summer fodders, Teosinte (*Euchlaena mexicana*) + Cowpea (*Vigna unguiculata*) achieved the highest yield (22.74 t/ha). In the second year's on-farm experiments, Oat + Berseem yielded the highest in Banke (14.95 t/ha) and the lowest in Kabhrepalanchowk (6.18 t/ha), while Teosinte + Cowpea also produced the best yield in Banke (27.65 t/ha). These results indicate that Oat + Berseem and Teosinte + Cowpea are suitable package options across locations for year-round fodder production to improve livestock productivity.

Keywords: Berseem, cereal–legume mixture, cowpea, oat, teosinte

INTRODUCTION

Livestock forms a vital part of mixed crop-livestock farming systems in Nepal. Despite its essential role, the sector faces ongoing challenges from consistently low productivity, mainly caused by a significant lack of adequate, high-quality feed (FAO, 2004; Singh and Singh, 2019). This shortage shows clear seasonal patterns, with severe deficits during winter and spring. These shortages lead to lower animal performance, higher feeding costs, and a heavy dependence on low-quality crop residues and imported feed concentrates (Singh and Singh, 2019). Therefore, resolving this fodder shortage is crucial and involves boosting cultivated fodder production through the use of improved species, better mixtures, and improved management practices (Ghimire, 2025).

Among winter fodders, oats (*Avena sativa* L.) are widely cultivated for their high biomass yield, rapid growth, and broad adaptability across Nepal's diverse ecological regions (FAO, 2004; Pant *et al.,* 2022). However, a major limitation of sole cereal fodders like oats is their inherently lower crude protein and mineral content. This nutritional shortfall can be effectively addressed by intercropping with leguminous species such as Berseem (*Trifolium alexandrinum* L.) or Vetch (*Vicia* spp.). These legumes provide high protein content, improve digestibility, and enhance overall system sustainability by fixing atmospheric nitrogen (Barsila, 2018). Consequently, cereal-legume mixtures are recognized for offering a more nutritionally balanced diet for ruminants while maintaining competitive dry matter (DM) yields (Dangi, 2020; Khanal *et al*., 2020). Similarly, for summer production, tropical grasses such as Teosinte (*Euchlaena mexicana* (Schrad.) Kuntze) and Sorghum (*Sorghum bicolor* (L.) Moench) are well-suited for the Terai and mid-hills of Nepal. When intercropped with legumes like Cowpea (*Vigna unguiculata* (L.) Walp.), these systems demonstrate a synergistic potential to significantly increase both the quantity and nutritional value of fodders (Devkota *et al*., 2015; Khanal *et al*., 2020). Recent research indicates that Teosinte-Cowpea combinations, in particular, can produce superior biomass and higher crude protein levels compared to their sole crops (Khanal *et al*., 2020; Khanal *et al*., 2021).

Despite the documented agronomic potential of these fodder species, their performance is greatly affected by Nepali diverse agro-ecological conditions, including altitude, climate, and local management practices. Therefore, a systematic evaluation of these fodder systems through thorough on-station screening followed by multi-location on-farm trials is a better approach to find the most resilient and suitable combinations for specific regions (Devkota *et al*., 2015). This study was conducted to address this issue by comparing promising seasonal fodders and their combinations across both on-station and on-farm environments.

MATERIALS AND METHODS

Study site

The research was carried out over two consecutive winter seasons, from November 2017 to May 2019. The first-year experiments took place at the research field of the National Pasture and Fodder Research Program (NPFRP) in Khumaltar, Lalitpur (27°39′N, 85°19′E; 1340 meters above sea level), under the Nepal Agricultural Research Council (NARC). This site is situated in Nepal's mid-hill agro-ecological regions and has a subtropical climate with cool winters and warm, humid summers. The soil is silty and moderately fertile, representative of typical fodder-growing conditions in the mid-hills.

During the second year, on-farm validation trials took place in four districts representing various agro-ecological regions of Nepal. These four sites included Kumpur village in Dhading district (2749'N and 8453'E, 667-753 masl) in the lower mid-hill region, Ryale village in Kabhrepalanchowk district (2735'N, 8527'E, and 1440-1582 masl) in the upper mid-hill region, Betahani village in Banke district (2800'N, 8142'E, and 160 masl) in the Western Terai lowland, and Inaruwa village in Sunsari district (2636'N, 8708'E, and 106 masl) in the Eastern Terai lowland.

Experimental design and crop management

During the first year, the study identified the highest-yielding winter and summer fodder crops, evaluating both sole crops and cereal-legume mixtures. The experiment was carried out using a Randomized Complete Block Design (RCBD) for each season. For the winter season, 12 fodder treatments with three replications were tested. These treatments included sole plantings of key cereals and legumes, such as Oat (*Avena sativa* L.) cv. Netra, Berseem (*Trifolium alexandrinum* L.) cv. Green gold and Illite II, Common vetch (*Vicia sativa* L.) cv. Kutilkosha-1 and Black pod, Purple vetch (*Vicia benghalensis* L.) cv. Popany, Hairy vetch (*Vicia villosa* subsp. Dasycarpa) cv. Capillo, Shaftal clover (*Trifolium resupinatum* L.) cv. Majus, Fodder pea (*Pisum sativum* L.) cv. AP2, and Garden pea (*Pisum sativum* L.) cv. Sikkim, along with two important mixtures: Oat combined with Berseem and Oat combined with Common vetch. In the summer season, eight treatments were tested with three replications, including sole cereals—Teosinte (*Euchlaena mexicana* (Schrad.) Kuntze) cv. Makaichari-1, Sorghum (*Sorghum bicolor* (L.) Moench.) cv. Green pearl, Sama grass (*Echinochloa colona* (L.) Link), and Bajra (*Pennisetum glaucum* (L.) R. Br.) (Nutrifeed 16)—and their respective mixtures with the local Kartike Cowpea (*Vigna unguiculata* (L.) Walp.). The plot size for each experimental unit was 12 m^2, managed according to NARC recommended agronomic practices.

Based upon the first-year results, the second year study focused on the on-farm validation of the highest-performing fodder packages for both seasons. The selected treatments were the winter combination of Oat and Berseem and the summer combination of Teosinte and Cowpea, both established at a 60:40 seed ratio. These packages were evaluated through the farmers' field experiments conducted across four distinct agro-ecological regions in Nepal. Specific NARC recommended variety of Oat for the particular agro-ecological region were used for those four locations. The variety Netra was used in Dhading district, Kamadhenu in Kabhrepalanchowk, Nandini in Banke and Amritdhara in Sunsari.

The experimental design for these multi-location trials was a RCBD, where four locations were considered as treatments and each participating farmer within a site was considered a replication, with five replications (farmers) per site.

Crop establishment and management practices were standardized across all experimental sites to ensure consistency. For both seasons, sowing was done using the broadcast method. Winter fodders were sown in the second week of November, with seeding rates of 100 kg/ha for sole oat, 25 kg/ha for Berseem, 40 kg/ha for vetch, and 120 kg/ha for peas. For cereal-legume mixtures, a 60:40 seed ratio was used. Summer fodders, Teosinte and cowpea, were sown in mid-April at rates of 40 kg/ha for sole crops, with mixtures also maintaining a 60:40 seed ratio. Fertilizer applications followed NARC guidelines, with different nutrient doses for cereals, legumes, and their mixtures. Specifically, oat plots received N: P_2O_5:K_2O at 80:60:40 kg/ha, while sole-legume plots received 25:60:30 kg/ha; mixture plots received a combined dose of 60:60:40 kg/ha. For summer crops, Teosinte received 60:40:40 kg/ha, sole cowpea received 25:60:30 kg/ha, and their mixture received 60:60:40 kg/ha. In both seasons, half of the nitrogen was applied as a basal dose, with the remaining top-dressed after the first and second harvests.

A standardized cutting management regime was followed, with the first harvest at 60 days after sowing (DAS) and subsequent cuts at 30-day intervals, resulting in three total cuts per season at a uniform height of 5 cm above the soil surface. Other management practices, including weeding, irrigation where feasible, and pest control, were carried out according to NARC recommendations.

Data collection

Data on growth and yield parameters were systematically recorded from each plot at every harvest. Growth measurements included sward height (cm), leaf length (cm), leaf breadth (cm), the number of leaves per plant, the number of tillers per plant (in case of cereals), and the number of branches per plant (in case of leguminous species). For yield estimation, the fresh weight of the fodder harvested from a one-square-meter sample area in each plot was recorded and then converted to green matter yield per hectare. To determine dry matter content, representative subsamples were oven-dried at a constant temperature of 65°C until a constant weight was achieved. The resulting dry matter percentage was then used to calculate dry matter yield in tons per hectare. In the on-farm trials, the protocol was effective in focusing on the most practical and farmer-relevant metrics, recording only sward height and dry matter yield.

Statistical analysis

All data were analyzed using Analysis of Variance (ANOVA) following RCBD procedures. Significant differences among treatment means were identified at a 5% probability level ($p < 0.05$) with Tukey's Honest Significant Difference Test. Statistical analyses were conducted using GenStat 18th Edition (VSN International, 2015).

RESULTS AND DISCUSSION

On-station experiment

The Khumaltar on-station experiment revealed highly significant differences ($p<0.001$) among winter fodder species and mixtures for growth and yield traits (Table 1). Sole Fodder Oat (cv. Netra) produced the highest ($p<0.001$) biomass among treatments (15.63 t/ha DM) and had the tallest sward and the longest leaves. This aligns with another study that identifies oat as a high-yielding, reliable winter fodder under mid-hill conditions of Nepal (Pant *et al*., 2022). The rapid vegetative growth and higher tiller production of fodder oat are repeatedly reported as reasons for its strong biomass performance in winter-cut fodder systems (FAO, 2004; Pant *et al*., 2022).

Legumes in the experiment showed variable performance. The Common and Purple vetch produced moderate to high dried fodder biomass (10.81-11.00 t/ha) and had significantly more branching ($p<0.001$) and leaves ($p<0.001$) compared to Berseem and Peas. Such differences among legume species and cultivars are well documented. Vetch tends to grow quickly and branch extensively, which helps produce more herbage mass during winter, while some Pea varieties may be better as protein supplements rather than as bulk fodder producers (Barsila, 2018).

The Oat + Berseem mixture produced a similar ($p>0.05$) DM yield as sole Oat (14.82 t/ha), while Oat + Vetch produced a lower ($p<0.001$) cumulative DM yield (11.85 t/ha). These results align with findings from studies on Oat and legume mixtures, which report that cereal and legume blends often increase fodder nutritive value (higher crude protein, better protein-to-energy balance) while maintaining competitive total DM yields, especially when Oats are combined with legumes adapted to local winter climates (Barsila, 2018; Dangi, 2020). The mixture advantage is also due to complementarity in canopy architecture and nitrogen (N) dynamics. The legumes add N through biological fixation and improve fodder quality, while the cereal provides bulk DM (Barsila, 2018; Dangi, 2020).

For winter feeding in the mid-hills (Lalitpur) and similar environments, sole Oats are most reliable for bulk DM, but Oat + Berseem mixtures offer a practical tradeoff, with slightly less or comparable DM but better fodder protein and system sustainability (reduced inorganic N needs).

In the on-station summer fodder experiment, sole Teosinte (cv. Makaichari-1) and sorghum produced substantial dry matter (16.20 and 13.71 t/ha, respectively), while the Teosinte + Cowpea mixtures yielded the highest ($p<0.001$) dry matter (22.74 t/ha; Table 2). This pattern—higher productivity of Teosinte and significant yield increases when intercropped with legumes—is consistent with other studies that reported Teosinte responds strongly to mixed cropping with legumes, which improves both the quantity and quality of fodders (Devkota *et al*., 2017; Khanal *et al*., 2020). Khanal *et al*. (2020, 2021) also reported that the

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Teosinte + Cowpea combinations produce larger herbage mass and higher crude protein content than Teosinte grown in monoculture.

Table 1. Dry matter yield and its attributes of winter fodders and their combinations in Lalitpur

Fodder	Sward height at first cut (cm)	Leaf length at first cut (cm)	Leaf breadth at first cut (cm)	Number of leaves/plant at first cut	Number of branches or tillers/plant at first cut*	Cumulative Fodder DM yield (t/ha) from three cuts
Fodder Oat cv. Netra	57.53±4.85^{a}	32.50±5.14^{a}	1.23±0.19^{h}	6.12±0.82^{e}	4.60±0.42^{b}	15.63± 1.59^{a}
Berseem cv Green gold	13.61±3.42^{d}	5.00±2.44^{cd}	2.14±0.29^{g}	6.87±0.57^{e}	4.09±0.41^{c}	9.84±0.41^{d}
Berseem cv. Illite II	16.84±0.82^{d}	6.23±5.27^{bc}	2.57±1.08^{fg}	6.67±0.89^{e}	4.12±0.73^{c}	6.86±1.36^{f}
Common vetch cv. Kutilkosa-1	46.02±6.51^{b}	7.51±1.08^{b}	3.29±0.16^{e}	15.04±2.46^{ab}	4.67±1.18^{b}	10.81±0.95^{cd}
Common vetch cv. Black Pod	37.6±5.63^{c}	6.54±1.46^{bc}	2.94±0.42^{ef}	16.00±2.81^{a}	4.65±0.50^{b}	7.22±0.58^{f}
Purple vetch cv. Popany	46±6.56^{b}	6.74±1.59^{bc}	4.60±0.89^{bc}	14.66±2.34^{ab}	6.16±1.56^{a}	11.00±0.98^{bc}
Hairy vetch cv. Capello	62±6.55^{a}	4.63±0.48^{cd}	3.65±0.72^{d}	16.06±2.02^{a}	6.73±1.57^{a}	8.52±1.55^{e}
Saftal clover cv. Majus	46±6.05^{b}	6.46±1.28^{bc}	4.66±1.06^{b}	6.04±1.06^{e}	6.82±1.52^{a}	10.74±0.53^{cd}
Fodder pea cv. AP2	43.5±7.89^{bc}	6.36±0.73^{bc}	3.97±0.48^{cd}	13.46±2.48^{bc}	4.49±0.37^{c}	4.08±0.49^{g}
Garden pea cv. Sikkim local	45.5±4.27^{b}	7.92±1.9^{b}	5.41±0.97^{a}	10.51±2.71^{d}	4.67±0.79^{b}	4.05±0.44^{g}
Oat + Berseem clover cv. Green gold	44.62±6.28^{b}	-	-	-	-	14.82±2.72^{a}
Oat + Common Vetch cv. Kutilkosha-1	46.97±11.74^{b}	-	-	-	-	11.85±0.57^{b}
F-probability	<0.001	<0.001	<0.01	<0.001	<0.05	<0.001

*Number of tillers in case of cereals and number of branches in case of leguminous species.

Sama grass consistently yielded lower fodder dry matter (DM) in the experiment, supporting reports that some small millet-type fodders produce less DM than tall summer grasses (Animasaun *et al*., 2018). Bajra (Nutrifeed 16) and sorghum produced good biomass yields but were inferior in fodder DM yield compared to Teosinte. This result aligns with previous reports indicating that teosinte grows taller and produces more biomass under favorable climate and management conditions (Khanal *et al*., 2020). The Teosinte and Cowpea mixture is recognized as the most promising summer fodder combination for maximizing DM yield in the mid-hill agro-ecologies of Nepal. The result aligns with the findings of Khanal *et al*. (2021), who reported that this mixture performs best when sowing date and fertilizer management are properly optimized.

Table 2. Dry matter yield and its attributes of winter fodders and their combinations in Lalitpur

Fodder	**Sward height at first cut (cm)**	**Leaf length at first cut (cm)**	**Leaf breadth at first cut (cm)**	**Number of leaves/ plant at first cut**	**Number of tillers or branches/ plant at first cut***	**Cumulative Fodder DM yield (t/ha) from three cuts**
Teosenti cv. Makaichari-1	120.49±17.91[bc]	67.86±6.71[a]	4.22±1.32[ab]	7.51±0.84[a]b	6.00±0.99[ab]	16.20±3.60[c]
Sorghum cv. Green Pearl	160.77±17.48[a]	63.73±2.50[a]	4.91±1.07[a]	6.73±1.32[b]	5.48±1.24[b]	13.71±2.67[d]
Sama grass	60.73±17.83[e]	23.79±2.53[b]	3.97±1.06[b]	6.07±1.37[b]	5.09±1.22[b]	7.75±1.37[f]
Bajra (Nutrifeed 16)	115.87±22.08[cd]	65.72±7.74[a]	3.46±0.21[b]	7.73±0.84[a]	7.00±1.28[a]	12.82±1.71[d]
Teosinte cv. Makaichari-1 + Cowpea (Kartike local)	100.55±16.97[d]	-	-	-	-	22.74±3.81[a]
Sorghum cv. Green Pearl + Cowpea (Kartike local)	132.81±18.99[b]	-	-	-	-	18.29±3.81[bc]
Bajra (Nutrifeed 16) + Cowpea (Kartike local)	122.46±13.33[bc]	-	-	-	-	18.81±2.18[b]
Sama + Cowpea (Kartike local)	65.43±9.91[e]	-	-	-	-	10.32±1.81[e]
F-probability	<0.001	<0.001	<0.05	<0.001	<0.01	<0.001

*Number of tillers in case of cereals and number of branches in case of leguminous species.

On-farm experiment

Both winter (Oat + Berseem) and summer (Teosinte + Cowpea) experiments conducted on farmers' fields across four agro-ecological regions showed highly significant location effects (p<0.001) on sward height and fodder DM yield. The sward height and fodder DM yield of the Oat + Berseem and Teosinte Cowpea mixtures across different cuts are shown in Figures 1 and 2, respectively. For the total fodder yield of the Oat + Berseem mixture, Banke (lower elevation) produced the highest ($p<0.001$) cumulative DM yield (14.95 t/ha), followed by Sunsari and Dhading, while Kabhrepalanchowk (higher elevation) recorded the lowest yield (6.18 t/ha; Table 3). These altitudinal and climatic gradients affecting Oat-based mixtures are also well documented in other reports. Oats and related legumes respond to warmer temperatures and longer growing periods in the Terai and lowland plains with increased sward height and higher yields from multiple cuts, whereas higher-elevation sites with cooler temperatures and shorter growing seasons generally produce less cumulative DM (FAO, 2004; Devkota *et al*., 2015; Pant *et al*., 2022). The second-cut increases in sward height at Banke and Sunsari indicate favorable mid-season regrowth related to temperature and soil fertility in these lowland areas (Figure 1). Oat + Berseem is a reliable winter package for the Terai and lower mid-hills, but at higher elevations, it may need adjustments such as later sowing, variety selection, or protected cultivation to reach similar productivity.

The Teosinte + Cowpea package produced the highest cumulative DM yield ($p<0.001$) in the farmers' field in Banke district (27.65 t/ha) during the summer season, and also performed well in Dhading (19.08 t/ha), while Kabhrepalanchowk yielded the lowest (Table 3). The trend was similar to that observed in the winter fodder mixture, indicating that lowland and warmer mid-hill sites favor heat-tolerant, tall summer fodders like Teosinte and Cowpea. Other studies in Nepal also report that Teosinte responds strongly to local climate, with much higher productivity in Terai and lowland regions when combined with legumes (Devkota *et al*., 2017; Khanal *et al*., 2020). The study shows that the Teosinte +Cowpea mixture is especially suitable for summer fodder production in the Terai and lower mid-hills, while cooler highlands may need alternative species or different management practices.

The two-year study across multiple locations demonstrates clear seasonal complementarity in fodder production. Mixtures of cereals and legumes produced superior winter biomass and the highest DM yield during summer as well. These findings support regional research recommendations advocating for location-specific fodder packages and species or variety adjustments to optimize year-round fodder supply (Khanal *et al*., 2020; Devkota *et al*., 2017; Pant *et al*., 2022; FAO, 2004).

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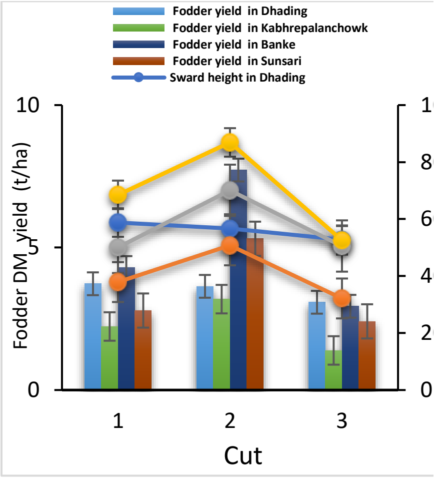

Figure 1. Sward height and fodder DM yield of Oat Berseem mixture for different cuts in the farmer field across different agro-ecological regions

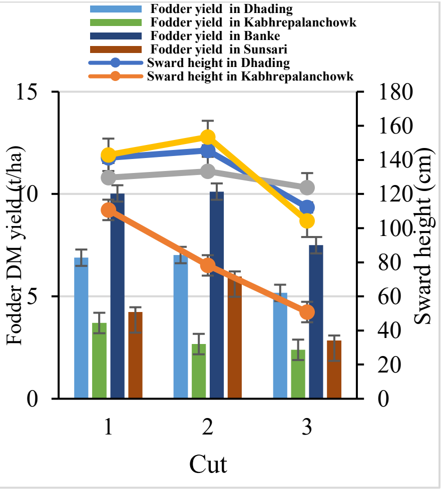

Figure 2. Sward height and fodder DM yield of Teosinte +Cowpea mixture for different cuts in the farmers' field across different agro-ecological regions.

Table 3. Fodder DM yield of Oat Berseem and Teosinte Cowpea mixtures for winter and summer in the farmers' field across different agro-ecological regions

Location	Total fodder DM yield (t/ha)*	
	Winter mixture (Oat + Berseem)	Summer mixture (Teosinte + Cowpea)
Dhading	10.45±1.28[b]	19.08±1.28[b]
Kabhrepalanchowk	6.18±0.68[c]	8.96±2.68[d]
Banke	14.95±2.96[a]	27.65±5.06[a]
Sunsari	11.55±1.88[b]	13.05±1.88[c]
F-probability	<0.001	<0.001

*Cumulative yield of three cuts

For winter, the Oat + Berseem mixture is recommended in the Terai and lower mid-hills for combined dry matter and protein benefits. For summer, the Teosinte + Cowpea mixture is best suited for the Terai and warm mid-hills, providing high summer dry matter along with improved nutritional quality in the fodders (Khanal *et al*., 2020; Khanal *et al*., 2021).

CONCLUSION

This study identified the Oat + Berseem mixture as the most suitable winter fodder package and the Teosinte + Cowpea mixture as the best summer package for different agro-ecological regions of Nepal. On-station testing confirmed their high productivity, while the on-farm study showed strong performance in lowland areas like Banke and Sunsari, with moderate yields in mid-hills and lower productivity at higher elevations. These results emphasize the importance of matching species and management practices to local climate conditions.

Adopting these cereal-legume mixtures can help bridge seasonal feed gaps, improve fodder quality, and reduce reliance on crop residues and purchased feeds. Promoting these packages more widely, along with enhancing farmer capacity, ensuring reliable seed supply, and conducting adaptive research, supports sustainable crop-livestock systems and boosts livestock productivity in Nepal.

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