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COMPARATIVE EVALUATION OF MILLETS FOR YIELD, ECONOMIC RETURNS AND ENERGY EFFICIENCY IN SEMI-ARID ZONE OF HARYANA

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SUMMARY

Prevailing changed climatic conditions compelled us to go for climate smart low input requiring crops which have short life, high tolerance to water and temperatures stress. So, millets which are also known as 'Nutri Cereals' may be best choice to ensure national food and nutritional security. To see the scope of millets in semi-arid conditions of Hisar district of Haryana eight millets (foxtail millet, little millet, browntop millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) were evaluated for their economic, yield and energy performance by conducting a field experiment at CCS Haryana Agricultural University, Hisar, Haryana, India during *Kharif* seasons of 2022 and 2023 in randomized block with three replications. On the basis of two years field study, it was concluded that all millets were feasible in Hisar district of Haryana but except pearl millet and foxtail millet, other millets were found uneconomical having negative returns and B:C less than one. Among all millets, Pearl millet recorded significantly higher grain yield (2427 kg/ha) and net energy returns (1,21,172 MJ/ha), while foxtail millet recorded higher net returns (Rs. 4353/ha) and B:C (1.09). So, farmers in semi arid regions of Haryana may go for pearl millet or foxtail millet to earn higher economic and energy returns.

Key words: Economics, energy, millets, yield, returns

Cereals play a pivotal role in satisfying the global food demand of the burgeoning population, particularly in developing nations like India, where the cereal-based production system is the predominant source of nutrition and calorie intake. At present, the agricultural sector is confronted with formidable challenges arising from climate change and global warming. The primary consequences of climate change encompass rising temperatures, irregularities in rainfall patterns, and the escalation of greenhouse gas emissions, predominantly carbon dioxide. Millets are considered climate smart and nature friendly crops because of high nutritive value and can withstand under warm and drought conditions with short life, low external inputs requirement. tolerance to water and temperatures stress. Being C_4 plants, millets can also use enhanced atmospheric CO_2 and convert into biomass (Bandyopadhyay *et al*, 2017; Dhaka *et al*, 2023). So, there is an urgent requirement to advocate for the widespread cultivation of millets to guarantee national food and nutritional security. Ten millet crops have been declared as 'Nutri Cereals' which include three major millets *i.e.*, pearl millet, sorghum and finger millet; five minor millets i.e. foxtail millet, proso millet, kodo millet, barnyard millet, little millet; and two pseudo millets *i.e*. kuttu (buckwheat) and amaranthus (Dhaka *et al*, 2025).

India is the largest grower (with 19% contribution) and producer (20% production) of millets in the world. India's share in Asia stands at 85% in area and 80% in production of millets. Thus, among the major millets, India ranks first in the world with respect to pearl millet cultivation and third in sorghum cultivation (NAAS, 2022). In India, millets are cultivated in an area of 12.45 million hectares, producing 15.53 million tonnes with a yield of 1247 kg/ha. Rajasthan has the highest area under millet cultivation (29.05%), followed by Maharashtra (20.67%), Karnataka (13.46%), Uttar Pradesh (8.06%), Madhya Pradesh (6.11%), Gujarat (3.94%), and Tamil Nadu (3.74%). The most important states for pearl millet cultivation are Rajasthan, Uttar Pradesh, and Maharashtra, accounting for a total share of 78 percent. Karnataka alone accounts for more than two-

thirds of the acreage of finger millet. Chhattisgarh and Madhya Pradesh grow more than 60 percent of small millets (Dhaka *et al*, 2023a).

Haryana ranks second as a contributor of food grains to the nation's food basket, with nearly 70 percent of its population engaged in agriculture. It boasts a rich legacy of sustainable agricultural development, witnessing an increase in food-grain production from 2.6 MT in 1966-67 to 18.3 MT in 2020-21, including an eleven-fold increase in wheat and a sixteen-fold increase in rice production during this period (Anonymous, 2022). However, the continuous adoption of cereal based systems with faulty and improper crop management practices has resulted in the loss of soil fertility and a decline in factor productivity. Therefore, most of these production systems require crop diversification for greater sustainability, better economics, and conservation of natural resources. Long-term planning and the development of various strategies for crop diversification are needed in the best national interest (Kumar *et al*, 2023; Singh *et al*., 2023; Dhaka *et al*, 2024). For diversification of the second most adopted crop rotation of Haryana i.e. Pearl millet-wheat rotation, the adoption of small millets (finger millet, foxtail millet, proso millet, little millet, brown top millet, barnyard millet, and kodo millet) in addition to pearl millet may be a viable option. Millets can play a vital role in the livelihoods of the poor and malnourished population, provide food and nutrition security, and help achieve the first three sustainable development goals of the United Nations: reducing poverty, zero hunger, and good health and well-being. Farmers need to be continuously motivated and encouraged to pursue crop diversification for better sustainability as well as income and employment opportunities (NAAS, 2022). All efforts made by the government to promote millets have been well responded to by farmers and consumers. However, very limited research work has been conducted so far on different millets except pearl millet and sorghum in semi-arid regions of Haryana. Therefore, considering all the facts mentioned above, a field experiment was conducted continuously for two years at CCS Haryana Agricultural University, Hisar, Haryana, India, to study the yield, energy and economic performance of eight millets.

MATERIALS AND METHODS

A field experiment was conducted at the Agronomy field research area of CCS Haryana Agricultural University, Hisar, Haryana, India (29°10'N latitude, 75°46'E longitude, and 215.2 M altitude) during *kharif* seasons of 2022 and 2023 in a randomized block design replicated thrice with eight treatments (foxtail millet, little millet, browntop millet, proso millet, kodo millet, barnyard millet, finger millet, and pearl millet) to evaluate yield, energy, and economic performance. The soil of the field was sandy loam in texture, slightly alkaline in pH (7.6), low in organic carbon, poor in available phosphorus, medium in available nitrogen, and rich in available potassium. The maximum and minimum temperatures during the crop study period were conducive to the growth and

TABLE 1
Weather parameters during crop duration

Year	Months	Temperature (°C)		Relative Humidity (%)		Average wind speed (km/hr)	Bright sun shine (hrs)	PAN Evaporation (mm)	Rainfall (mm)	Rainy days
		Maximum	Minimum	Morning	Evening					
2022	July	34.7	27.1	87	70	6.7	4.6	4.7	225.6	9
	August	33.9	26.4	89	65	5.9	6.9	3.9	130.5	4
	September	34.4	25.5	88	60	4.9	6.6	4.2	192	4
	October	31.3	19.0	88	53	2.6	7.0	3.1	1.3	0
	November	27.8	11.9	90	53	2.4	6.0	2.1	4.2	1
	December	21.0	6.5	96	66	2.4	5.7	1.3	0	0
	Average	30.5	19.4	89.6	61.1	4.2	6.1	3.2	553.6	18.0
2023	July	35.0	27.1	87	68	5.7	4.3	4.2	107.3	6
	August	35.9	26.7	82	55	6.5	7.6	5.6	16.6	2
	September	35.8	25.0	87	54	5.6	6.9	5.4	14.2	2
	October	33.4	17.7	86	39	3.5	7.6	3.9	19.2	1
	November	27.2	12.8	92	48	1.8	2.1	1.5	0	0
	December	22.5	7.1	96	53	2.1	4.9	1.4	5.5	1
	Average	31.6	19.4	88.2	52.9	4.2	5.6	3.7	162.8	12.0

development of crops. Sowing of all millets, namely, Foxtail millet (SIA 3156), Little millet (DHLM 36-3), Browntop millet (IIMR AK 2), Proso millet (TNAU 202), Kodo millet (JK 41), Barnyard millet (VC 27), Finger millet (GPU 67), and Pearl millet (HHB 67), in the *Kharif* season was done 3rd week of July during both years of study and these were harvested at 78, 92, 73, 69, 91, 78, 116, and 71 days after sowing, respectively. Agronomic management for each millet was done separately as per the recommendations given by the Indian Institute of Millets Research, Hyderabad. As per the meteorological data provided by Department of Agro meteorology, CCS Haryana Agricultural University, Hisar, given in Table 1, the mean maximum temperature, minimum temperature, relative humidity morning, relative humidity evening , wind speed, bright sun shine hours, PAN evaporation, total rainfall, total rainy days during *Kharif* 2022 (July- December) and *Kharif* 2023 (July- December) were 30.5, 19.4, 89.6, 61.6, 4.2, 6.1, 3.2, 553.6, 18 and 31.6, 19.4, 88.2, 52.9, 4.2, 5.6, 3.7, 162.8, 12, respectively.

The energy equivalents of all inputs in the form of labor, seeds, fertilizers, hoeing, implements, and pesticides, and the energy output as produce, were converted into energy (MJ) to calculate the input and output energy of both crop seasons as well as crop rotations, using energy equivalent factors as given by Meena *et al*. (2024), Devasenapathy *et al*. (2009), Mittal and Dhawan (1988), Kumar *et al*. (2022) and Dhaka *et al*. (2017) in Table 2. The different energy based indices were calculated as per the procedure given by Devasenapathy *et al*. (2009) and Mittal and

TABLE 2

Equivalent coefficient for various inputs sources of energy used for energy calculation under different cropping sequences.

Inputs	Unit	Energy equivalent (MJ unit^{-1})	References
Human labour			
Human labour (Male)	h	1.96	Ghosh *et al*. (2021)
Human labour (Female)	h	1.57	Ghosh *et al*. (2021)
Harvesting	h	1.96	Singh and Mittal (1992)
Spraying	h	1.96	Ram and Verma (2015)
Transportation	kg	1.08	Pimentel and Burgess (1980)
Irrigation Water	m^3	1.02	Tuti *et al*. (2012)
Cultural practices	h	1.96	Singh and Mittal (1992)
Machinery			
Sprayer	h	0.50	Nassiri and Singh (2010)
Tractor	h	64.80	Pathak *et al*. (2022)
Sickle	h	0.83	Nassiri and Singh (2010)
Farm machinery	kg	62.70	Tuti *et al*. (2012)
Electricity	KWH	11.93	Ozkan *et al*. (2004)
Electric motor (2 HP)	kg	64.80	Devasenapathy *et al*. (2009)
Machinery (All kind)	kg	68.40	Singh and Mittal (1992)
Diesel	l	56.31	Canakci and Akinci (2006)
Chemical fertilizers			
Nitrogen (N)	kg	60.6	Toader and Gheorghe (2014)
Phosphorus (P_2O_5)	kg	11.1	Toader and Gheorghe (2014)
Potassium (K_2O)	kg	6.7	Devasenapathy *et al*. (2009)
Zinc sulphate ($ZnSO_4$)	kg	20.9	Singh and Mittal (1992)
Gypsum	kg	10	Devasenapathy *et al*. (2009)
Superior chemical	kg	120	Devasenapathy *et al*. (2009)
Plant protection			
Fungicide	kg	97	West and Marland (2002)
Herbicides	kg	288	Pimentel and Burgess (1980)
Insecticide	kg	237	West and Marland (2002)
Organic fertilizers			
Manure/FYM	kg	0.30	Tuti *et al*. (2012)
Vermicompost	kg	0.50	Ram and Verma (2015)
Biofertilizers	kg	2.98	Mihov *et al*. (2012)
Pearl millet	kg	14.7	Devasenapathy *et al*. (2009)
Stover/stalk	kg	12.5	Devasenapathy *et al*. (2009)

Dhawan (1988). To compute the relative economics of all crop rotations, the data provided by the Department of Agricultural Economics, CCS Haryana Agricultural University, Hisar, was considered for crop inputs and outputs. The prices considered for grains of Foxtail millet, Little millet/Browntop millet/Proso millet, Kodo millet, Barnyard millet, Finger millet, and Pearl millet were Rs. 2909, 2300, 2599, 2800, 3578, and 2350 per quintal, respectively, while the straw rate was Rs. 1500/acre. The total and variable costs, gross and net returns, B:C ratio, and per-day returns for all eight millets were calculated.

RESULTS AND DISCUSSION

Yield performance

Regarding crop duration, yield and yield attributes significant variations were recorded among millets (Table 3). Proso millet took minimum days (69) to mature and it was statistically at par with pearl millet (71) and browntop millet (73), while finger millet took maximum days (116) to mature. Kodo millet and Little millet matured in almost same days (91-92). Pearlmillet recorded significantly higher plant height (201.5 cm), while lowest plant height was recorded with Kodo millet (86.3 cm) which was statistically at par with proso millet. Littile millet, Browntop millet and Barnyard millet recorded statistically similar plant height. Significantly smallest earhead length (5.8 cm) was recorded with kodo millet which was statistically at par with finger millet, while Proso millet closely followed by little millet recorded significantly higher earhead length (28.7 cm). Regarding earhead length non-significant variation was found among pearl millet and foxtail millet, Browntop millet and Barnyard millet. Significantly higher and lower numbers of tillers and ear heads were recorded with Proso millet and Finger millet, respectively. Barnyard millet, kodo millet and foxtail millet recorded non-significant variations regarding total number of tillers and ear heads per plants. Similarly, browntop millet, little millet and pearl millets had also recorded statistically similar tillers and ear heads per plant. Little millet and finger millet recorded significantly higher (9.8) and lower (0.5) non effective tillers per plant, respectively. Pearlmillet, little millet and proso millet had shown non-significant variations regarding numbers of non-effective tillers per plant. Similarly, foxtail millet, browntop millet, kodo millet and barnyard millet were also found statistically at par regarding non effective tillers per plant. Significantly higher (52.7 g) and lower (9.2 g) seed weight per plant was recorded with pearl millet and proso millet, respectively. Little millet, browntop and proso millet were found statistically at par regarding seed weight per plant. Pearl millet and little millet recorded significantly higher (6.34 g) and lower (1.91 g) test weight, respectively. Browntop millet, finger millet and barnyard millet recorded statistically similar test weight (3.25-3.29 g). Among all millets, Pearlmillet recorded significantly higher grain yield (2427 kg/ha) which was 27.4, 74.4, 49.8, 60.4, 35.3, 37.2 and 31.1 percent higher than foxtail millet, little millet, browntop millet, proso millet, kodo millet, finger millet and

TABLE 3
Comparative yield performance of millets in Hisar district of Haryana

Millets	Total duration (days)	Yield attributes per plant						Yield per hectare area			
		Plant height (cm)	Ear head length (cm)	Tillers (nos.)	Ear heads (nos.)	Non effective tillers (nos.)	Seed weight (g)	Test weight (g)	Biological yield (kg)	Grain yield (kg)	HI (%)
Pearl millet	71	201.5	21.0	29.2	21.2	7.8	52.7	6.34	10042	2,427	24.2
Foxtail millet	78	179.5	20.2	18.5	15.5	3.1	31.2	2.52	6229	1,762	28.3
Little millet	92	161.5	27.2	25.2	15.5	9.8	9.5	1.91	5490	621	11.3
Browntop millet	73	160.7	17.1	23.8	19.0	4.2	10.9	3.29	7810	1,217	15.6
Proso millet	69	93.0	28.7	86.5	77.3	8.9	9.2	4.35	5612	960	17.1
Kodo millet	91	86.3	5.8	18.3	15.2	3.0	14.3	4.82	7609	1,568	20.6
Finger millet	116	106.0	7.0	8.3	7.7	0.5	24.3	3.25	10172	1,525	15.0
Barnyard millet	78	155.2	16.8	17.0	12.7	4.5	37.2	3.28	8004	1,672	20.9
SEm±	2.1	4.0	0.7	1.6	1.8	1.5	1.4	0.05	467	92	1.0
CD (p=0.05)	6.7	12.1	2.2	5.0	5.6	4.8	4.3	0.15	1,432	282	3.0

barnyard millet, respectively. Little millet yielded significantly lower grain yield (621 kg/ha). Kodo millet, Finger millet, Barnyard millet and foxtail millet had shown non-significant differences regarding grain yield. Similarly, Proso millet and browntop millet were also reported with statistically at par yield levels. The variation among millets for their grain yield levels may be attributed to their genetic makeup and differences in their yield attributes. Similarly, all millets except finger millet have produced significantly lower biological than pearl millet. Significantly higher (10172 kg/ha) and lower (5490 kg/ha) biological yield were reported with finger millet and little millet, respectively. Pearl millet recorded 61.2, 82.9, 28.5, 78.9, 31.9 and 25.4 percent higher biological yield over foxtail millet, little millet, browntop millet, proso millet, kodo millet and barnyard millet, respectively. Finger millet produced 1.3 percent higher biological yield than pearl millet. Foxtail millet, Little millet and Proso millet recorded statistically similar biological yield. Similarly, pearl millet and finger millet had also shown non-significant difference regarding biological yield. Foxtail millet and little millet were reported with significantly higher (28.3 %) and lower (11.3 %) harvest index, respectively. Browntop millet, proso millet and finger millet recorded statistically at par harvest index. Similarly, proso millet, kodo millet and barnyard millet have shown non-significant variations regarding harvest index. Corroborative findings have also been reported by Garg *et al.*, 2020. The increase in grain yield of some millets might be due to increased photosynthetic activity, which resulted in a higher accumulation of photosynthates and their translocation to sink due to better source and sink channel (Krishna

TABLE 4
Comparative economics of different millets in Hisar district of Haryana

Treatments	Variable cost (Rs/ha)	Total cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Per day return (Rs/day/ha)
Pearl millet	28463	57280	60,786	3,506	1.06	49.4
Foxtail millet	22958	50675	55,028	4,353	1.09	55.8
Little millet	23298	51083	18,033	-33,050	0.35	-359.2
Browntop millet	25885	54188	31,747	-22,441	0.59	-307.4
Proso millet	24780	52863	25,839	-27,024	0.49	-391.6
Kodo millet	23168	50928	44,410	-6,518	0.87	-71.6
Finger millet	32523	62153	58,327	-3,826	0.94	-33.0
Barnyard millet	24473	52495	50,589	-1,906	0.96	-24.4
SEm±	-	-	2,424	2,424	0.05	31.2
CD (p=0.05)	-	-	7,424	7,424	0.14	95.7

TABLE 5
Energy budget of different millets in Hisar district of Haryana

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy profitability (MJ/ha)	Energy intensiveness (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Pearl millet	9,698	130,870	121,172	13.5	0.25	12.50	14.05	4.00	133.0
Foxtail millet	6,758	81,746	74,988	12.1	0.26	11.10	11.06	4.16	83.1
Little millet	6,747	70,000	63,253	10.4	0.09	9.38	10.96	11.70	71.1
Browntop millet	6,729	100,307	93,578	14.9	0.18	13.91	10.30	6.21	101.9
Proso millet	6,947	72,274	65,327	10.4	0.14	9.40	10.90	7.25	73.5
Kodo millet	6,758	98,571	91,813	14.6	0.23	13.59	11.01	5.63	100.2
Finger millet	7,421	130,510	123,089	17.6	0.21	16.59	9.91	5.38	132.6
Barnyard millet	6,758	103,730	96,972	15.3	0.25	14.35	10.68	4.12	105.4
SEm±	-	2,057	2,057	0.3	0.01	0.31	0.004	0.53	2.1
CD (p=0.05)	-	6,299	6,298	0.9	0.04	0.94	0.013	1.63	6.4

et al., 2020; Reddy *et al*., 2020; Mohan *et al*., 2019). The increase in grain yield could be explained based on their beneficial effects on yield-attributing characteristics (Hemalatha *et al.,* 2021; Patel *et al*., 2023). Nalini *et al*., 2020 in a study on pearl millet, Hemalatha *et al.,* 2021 in a study on kodo millet, Krishna *et al*., 2020 in a study on finger millet and Reddy *et al*., 2020 in a study on foxtail millet have also reported similar findings.

ECONOMICS

Economic returns and B:C have been varied significantly among millets (Table 4). Among all millets, finger millet followed by pearl millet reported with maximum variable cost (32523 Rs./ha) and total cost (62153 Rs./ha), while foxtail millet was reported with minimum variable cost (22958 Rs./ha) and total cost (50675 Rs./ha). Pearl millet closely followed by foxtail millet and finger millet recorded significantly higher (60786 Rs./ha), while little millet closely followed by proso millet recorded significantly lower (18033 Rs./ ha) gross returns. All millets except pearl millet and foxtail millet, were found uneconomical having negative returns (net and per day) and B:C less than one. Foxtail millet statistically at par with pearl millet recorded significantly higher net returns (4353 Rs./ ha), B:C (1.09) and per day returns (55.8 Rs./day/ha) which were found 24.1, 2.8 and 12.9 percent higher than pearl millet, respectively. These results are in close conformity with the findings of Bana *et al*., 2016; Bhavani *et al*., 2021; Kumar *et al*., 2009; Garg *et al*., 2020; Krishna *et al*., 2020; Reddy *et al*., 2020.

ENERGY

All energy based indices have been affected significantly by different millets (Table 5). Pearl millet and browntop millet have been recorded with maximum (9698 MJ/ha) and minimum (6729 MJ/ha) input energy, respectively. Similarly, pearl millet closely followed by finger millet recorded significantly higher output energy (130870 MJ/ha) and Human energy profitability (133.0 MJ/ha). While, significantly lower output energy (70000 MJ/ha) and Human energy profitability (71.1 MJ/ha) were recorded with little millet. Little millet and proso millet have found statistically at par regarding output energy and human energy profitability. Among all millets, Pearl millet recorded 30.7-44.1, 0.3-86.9, 4.0-188.8, 26.9-41.8 and 0.3-87.0 percent higher input energy, output energy, energy productivity, energy intensiveness and human energy profitability compared to other millets. Finger millet recorded significantly higher net energy returns (123089 MJ/ha), energy ratio (17.6) and energy profitability (16.59 MJ/ha), while little millet was reported with significantly lower net energy returns (63253 MJ/ha), energy ratio (10.4) and energy profitability (9.38 MJ/ha). Pearl millet recorded significantly higher net energy returns than all millets except finger millet, which was 61.5, 91.5, 29.5, 85.5, 31.9 and 24.9 percent higher over net returns gained by foxtail millet, little millet, browntop millet, proso millet, kodo millet and barnyard millet, respectively, while it was 1.6 percent lower than finger millet. Pearl millet and little millet recorded significantly higher energy intensiveness (14.05 MJ/USD) and specific energy (11.70 MJ/kg), respectively. These results were in conformity with the findings of Kumar *et al*., 2022; Dhaka *et al*., 2017; Choudhary *et al.,* 2017; Singh *et al.,* 2007.

CONCLUSIONS

Proso millet, pearl millet and browntop millet were earliest to mature (69-73 days), while finger millet took maximum days (116) to mature. Among all millets, Pearl millet recorded significantly higher grain yield (2427 kg/ha), output energy (130870 MJ/ha) and human energy profitability (133.0 MJ/ha), while Foxtail millet recorded significantly higher net returns (Rs. 4353/ha), B:C (1.09) and per day returns (55.8 Rs./ day/ha). All millets except pearl millet and foxtail millet were found uneconomical having negative returns and B: C less than one. So, on the basis of two-year field study it was concluded that cultivation of all millets were feasible in Hisar district of Haryana but Pearl millet closely followed by foxtail millet proved most economical with significantly higher yield, economics and energy returns.

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