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RESEARCH ARTICLE

Enhancing finger millet yield and grain quality through stale seedbed and live mulch strategies

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Abstract

Finger millet grains are highly nutritious and contain higher amount of mineral nutrients compared to other cereals and millets. However, weed infestation remains a major biological constraint that significantly reduces its productivity. To address this challenge, field experiments were conducted during the *Rabi* and summer seasons of 2022–23 to assess the impact of non-chemical weed management practices on the yield and grain quality of finger millet. The experiments were laid out in Randomized Block Design (RBD) with three replications, incorporating two factors: seedbed preparation methods (normal seedbed [NSB], stale seedbed [SSB] with light raking and SSB with flaming) and live mulching treatments (control and three different leguminous live mulches). Live mulches were incorporated into the soil at 40 days after sowing (DAS) using a wheel hoe weeder. Pooled data indicated a significant interaction between seedbed and live mulching treatments. The highest grain yield (885 kg ha^{-1}) was recorded under SSB with light raking combined with cowpea live mulching. This combination also enhanced grain phosphorus (0.180 % in *Rabi*, 0.165 % in summer) and protein content (14.50 % in *Rabi*, 14.23 % in summer). Meanwhile, SSB with flaming combined with green gram live mulch significantly increased grain potassium levels (1.49 % in *Rabi*, 1.46 % in summer), while the highest starch content was found with SSB + flaming and cowpea mulch (74.03 % in *Rabi*, 82.17 % in summer). These results highlight the effectiveness of integrating stale seedbed preparation with live mulching to improve both the productivity and nutritional quality of finger millet under non-chemical weed management systems.

Keywords: cow pea; cluster bean; flaming; green gram; protein content; stale seedbed; starch content

Introduction

Finger millet (*Eleusine coracana* L. Gaertn.), commonly known as ragi, is the most important and widely cultivated small millet in India. India is recognized as the secondary centre of origin for finger millet and accounts for approximately 1.211 Mha of cultivation area and 1.696 Mt (1). It serves as a staple food grain for many tribal communities across the country. Predominantly grown under rainfed conditions and is highly adaptable to a wide range of soil types and climatic conditions. In the state of Kerala, finger millet was cultivated over an area of 230.26 ha during the 2020-21 season, with a total production of 329.553 t (2).

Finger millet grains are highly nutritious and contain higher amounts of calcium and potassium compared to other cereals and millets. They are also rich in proteins, carbohydrates, vitamins, minerals and dietary fibre. Therefore, finger millet is highly beneficial for maintaining human health. In addition to its use as a food grain, finger millet is also cultivated as a fodder crop for making hay and silage.

Weed management had a significant effect on the quality of produce. Compared to plastic mulch, straw mulch improved the quality of rice grain (3). Research findings also revealed that integration of herbicides with brown manuring enhanced the protein content of grain in direct seeded rice (4). In vegetable cowpea, SSB recorded a higher pod protein content (19.69 %) compared to NSB (16.07 %) (5). It was further reported that among different weed management practices, dried banana leaf mulching @ 10 t ha^{-1} resulted in the highest protein content of pods in vegetable type bush cowpea (21.88 %) (5). In okra, SSB resulted in the highest protein content (12.22 %) compared to NSB (11.04 %). Additionally, dried banana leaf mulching 10 t ha^{-1} *fb* wheel hoe weeding at 30 DAS and 45 DAS recorded the highest ascorbic acid content (23.04 mg per 100 g) compared to other weed management practices (6).

Living mulches are typically fast growing crops sown on the same day, before, after the sowing of the main crop, to maintain ground cover during part or all of the growing season (7). The primary objective is to create better soil ecosystem conducive to crop growth. Live mulching also increases the soil organic matter content through biomass addition, improves the water holding capacity and infiltration, reduces bulk density and helps maintain optimal soil temperature (8-11). In broccoli, although live mulching did not have any significant effect on the quality and yield, it provided effective weed control (12).

Mechanical hoeing at 30 DAS, 45 DAS and 60 DAS recorded significantly higher kernel protein and amylose content in direct seeded rice compared to the weedy check and chemical treatments (6). Weed management practices significantly improved the starch and protein content of finger millet grain. In contrast, weedy check registered the lowest starch and protein content (7). In this background, the present study is formulated to assess the impact of stale seedbed preparation and live mulching on the yield and quality of finger millet grain.

Materials and Methods

Field experiments were conducted in the model organic farm at College of Agriculture, Vellayani situated at 8.50 N latitude and 76.90 E longitude and 29 m above mean sea level during *Rab*i 2022-23 and summer 2022-23. Soil of the study area was sandy loam and belongs to Entisol. Soil was acidic in reaction, normal in pH, low in organic carbon and N, medium in P and K. The crop variety used for the study was PPR 2700. The crop was manured as per POP recommendations (organic) of Kerala Agricultural University (13).

The experiments were conducted using a RBD with three replications. Treatments consisted of two factors. The first factor was land preparation, which included: (i) normal seedbed (NSB), (ii) stale seedbed (SSB) with light raking and (iii) SSB with flaming. The second factor was live mulching, comprising three different leguminous species- cowpea, green gram and cluster bean-along with a control treatment (no mulch). In total, 12 treatment combinations (as detailed in Table 1) were laid out and replicated across the blocks. Finger millet was sown in lines at a spacing of 25 cm × 15 cm. Each treatment plot measured 4.5 m × 3 m (gross plot size), while a net plot area of 3.5 m × 2.6 m was used for data collection to minimize border effects and ensure consistency in measurements.

Table 1. Treatment combinations

S. No.	Treatment combinations	Treatment abbreviation
1	Normal seedbed (NSB) without live mulching	l_1m_1
2	NSB followed by cowpea live mulching	l_1m_2
3	NSB followed by green gram live mulching	l_1m_3
4	NSB followed by cluster bean live mulching	l_1m_4
5	Stale seedbed (SSB) with light raking without live mulching	l_2m_1
6	SSB with light raking with cowpea live mulching	l_2m_2
7	SSB with light raking followed by green gram live mulching	l_2m_3
8	SSB with light raking followed by cluster bean live mulching	l_2m_4
9	SSB with flaming without live mulching	l_3m_1
10	SSB with flaming followed by cowpea live mulching	l_3m_2
11	SSB with flaming followed by green gram live mulching	l_3m_3
12	SSB with flaming followed by cluster bean live mulching	l_3m_4

Note: Live mulches were incorporated into the soil at 50 % flowering stage (40 DAS) using a wheel hoe weeder

As per the treatments, SSB was prepared for 24 treatment plots. In SSB treatments, after the plots were levelled, a pre-sowing irrigation was given and kept undisturbed for 14 days to allow the weed seeds to germinate. On elapse of 14 days, in the treatment, SSB with light raking, germinated weeds were destroyed by shallow tillage (light raking) and in the treatment SSB with flaming, germinated weeds were destroyed by flaming using a flame torch.

Live mulches were introduced in a 1:1 proportion by sowing a row of mulch species between every two rows of finger millet, maintaining a plant-to-plant spacing of 15 cm. The live mulches were sown on the fifth day after the emergence of the finger millet crop. To ensure uniform germination of both finger millet and live mulches, a light irrigation was applied on the second day after sowing. The live mulches were incorporated into the soil at 40 DAS, coinciding with the 50 % flowering stage of the mulch species. In the absence of rainfall, the crop was irrigated twice a week during both growing seasons.

The finger millet crop was harvested when the ears turned brown and the grains reached a sufficient level of hardness. The crop was harvested on 90^{th} DAS. Border row plants were harvested first followed by harvesting the plants in the net plot area. Subsequently, the harvested plants were subjected to threshing, winnowing and sun-drying. The weights of grain were recorded separately for each treatment and expressed in kg ha^{-1} on dry weight basis. To assess the quality parameters of finger millet grain, composite grain samples were collected from each treatment plot and dried in the hot air oven at 65 °C during both the seasons. Precisely measured samples were subjected to single acid digestion for N determination and diacid digestion for P and K, Vanadomolybdate phosphoric yellow colour method was adopted for determining the P content of the grain using a spectrophotometer and K content of finger millet grain was determined using flame photometer (14). Crude protein content of the grain was determined by multiplying the N content of the grain with a factor 6.25 (15) and was expressed in percentage. Nitrogen content of the grain was determined by the modified micro Kjeldahl method (14). The content was then presented as percentage on dry weight basis. The starch content of finger millet grain was assessed using the titrimetric method and the results were expressed as percentage (16). Net return and B:C ratio were calculated by the following formulas

Net return (₹ha^{-1})= Gross return - Total cost of cultivation (Eqn. 1)

B:C ratio = Gross return/Total cost of cultivation (Eqn. 2)

Statistical Analysis

Since the error variances were found to be homogeneous, a pooled analysis was conducted for the yield data of *Rabi* 2022-23 and summer 2022-23 seasons. However, for quality parameters, the data from each season were analysed separately using appropriate statistical methods. Data on net return and benefit cost (B:C) ratio were calculated based on mean values and were not subjected to statistical analysis. Experimental data were analysed using the analysis of variance

(ANOVA) technique (17). The significance of treatment effects was tested using the F-test (18) and the least significant difference (LSD) was calculated at a 5 % probability level ($P < 0.05$) to determine significant differences among means. Statistical analyses were performed using GRAPES software (Agri L version) (19).

Results and Discussion

Effect on grain yield

Pooled data from two seasons revealed that grain yield of finger millet was significantly (p=0.05) influenced by the interaction between land preparation and live mulching. Among the treatments, 1_2m_2 (SSB with light raking + live mulching with cowpea) recorded the highest grain yield (885 kg ha^{-1}), followed by l_3m_2, while the lowest yield was observed in l_1m_1 (Table 2). Stale seedbed combined with live mulching resulted in a yield enhancement of 47 to 104 % over NSB + no mulch. The higher yields observed in the SSB + live mulching treatments may be attributed to the fact that the initial flushes of weeds in the seedbed were eliminated either through light raking or flaming, creating a competition free environment for the crop seed germination, emergence and establishment. This allowed finger millet seedlings to gain a competitive advantage over later emerging weeds. Furthermore, live mulching with cowpea, green gram and cluster bean helped suppress weed emergence due to rapid canopy coverage. Incorporation of live mulches at 40 DAS using a wheel hoe weeder facilitated soil turning, improved aeration and further controlled weeds. The incorporation and subsequent decomposition of weeds and live mulches increased the organic matter content of the soil thereby reducing the soil compaction (8, 20), improving water holding capacity and enhancing nutrient availability. The increased availability and uptake of nutrients contributed to improved yield attributes resulting in the highest yield in the l_2m_2 treatment (SSB with light raking + cowpea live mulch).

Table 2. Finger millet yield, net return and B: C ratio as influenced by land preparation and live mulches (pooled data of *Rabi* 2022-23 and summer 2022-23)

Treatments	Yield (kg ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
NSB × No mulch (l_1m_1)	431	4858	1.13
NSB × cowpea live mulch (l_1m_2)	670	18258	1.37
NSB × green gram live mulch (l_1m_3)	620	13508	1.28
NSB × cluster bean live mulch (l_1m_4)	597	9958	1.20
SSB with light raking × no mulch (l_2m_1)	587	15458	1.36
SSB with light raking × cowpea live mulch (l_2m_2)	885	34758	1.65
SSB with light raking × green gram live mulch (l_2m_3)	712	17708	1.33
SSB with light raking × cluster bean live mulch (l_2m_4)	649	10158	1.19
SSB with flaming × no mulch (l_3m_1)	590	4758	1.09
SSB with flaming × cowpea live mulch (l_3m_2)	753	10558	1.16
SSB with flaming × green gram live mulch (l_3m_3)	661	1608	1.02
SSB with flaming × cluster bean live mulch (l_3m_4)	635	1.21	0.97
SEm (±)	9	-	-
CD (p=0.05)	26.9	-	-

NSB: Normal seedbed, SSB: Stale seedbed

Previous studies have shown that cowpea live mulching improved maize yield due to its positive influence on soil properties and nutrient availability (21). Live mulching with sun hemp enhanced the yield of maize compared to no mulch (22). Integrating stale seedbed preparation to deplete the weed seedbank along with leguminous cover crops such as cowpea and sun hemp, effectively suppressed weeds, reduced weed pressure and improved cotton yield (23).

Effect on net return and B:C ratio

The assessment of weed management methods under field conditions is crucial for enhancing crop productivity and profitability. Among the treatments evaluated, the stale seedbed method with light raking followed by cowpea live mulching and its incorporation at 40 DAS (l_2m_2) recorded the highest net return (₹34758 ha^{-1}) and a benefit-cost (B:C) ratio of 1.65 (Table 3). The superior grain yield observed under this treatment was primarily attributed to effective weed suppression and improved nutrient availability resulting from the incorporation of cowpea. These factors collectively contributed to enhanced economic returns and the production of higher quality grains.

Effect on P and K content of finger millet grain

The interaction between land preparation and live mulches had a significant effect on the P and K of finger millet grain. During *Rabi* season, the P content of the finger millet grain was found to be higher in l_2m_3 (SSB with light raking + live mulching with green gram) and was statistically on par with l_2m_2 (SSB with light raking + live mulching with cowpea). However, during the summer season, P content was found to be higher in l_2m_2 which was on par with l_2m_3. The K content of the grain was significantly higher in l_3m_3 (SSB with flaming + live mulching with green gram) during both seasons. The higher P and K content observed in these treatments can be attributed to the combined beneficial effects of SSB and live mulching. The stale

Table 3. Quality attributes of finger millet grain as influenced by land preparation and lives mulches (*Rabi* 2022-23)

Treatments	P (%)	K (%)	Protein content (%)	Starch content (%)
NSB × No mulch (l_1m_1)	0.133	1.06	10.31	53.99
NSB × cowpea live mulch (l_1m_2)	0.166	1.17	13.13	60.50
NSB × green gram live mulch (l_1m_3)	0.168	1.16	13.56	57.26
NSB × cluster bean live mulch (l_1m_4)	0.150	1.14	12.25	55.63
SSB with light raking × no mulch (l_2m_1)	0.154	1.10	13.63	56.64
SSB with light raking × cowpea live mulch (l_2m_2)	0.181	1.21	14.50	74.03
SSB with light raking × green gram live mulch (l_2m_3)	0.182	1.15	14.25	65.98
SSB with light raking × cluster bean live mulch (l_2m_4)	0.163	1.33	13.75	63.07
SSB with flaming × no mulch (l_3m_1)	0.151	1.29	13.56	55.0
SSB with flaming × cowpea live mulch (l_3m_2)	0.172	1.25	14.50	71.01
SSB with flaming × green gram live mulch (l_3m_3)	0.159	1.49	13.50	67.00
SSB with flaming × cluster bean live mulch (l_3m_4)	0.140	1.21	13.38	64.04
SEm (±)	0.003	0.04	0.20	0.84
CD (p=0.05)	0.008	0.125	0.589	2.490

NSB: Normal seedbed, SSB: Stale seedbed

seedbed with light raking or flaming created a weed free environment allowing finger millet seeds to germinate and emerge successfully, resulting in the development of vigorous seedling with better root growth. Furthermore, live mulching with cowpea or green gram, followed by its incorporation into the soil at 40 DAS, enhanced nutrient availability by contributing biomass and stimulating microbial activity. Improved nutrient availability, uptake and translocation from source to sink contributed to higher nutrient content in the grain. The stale seedbed increased nutrient availability by effectively controlling weeds, thereby minimising competition and enhancing crop nutrient uptake (24). The inclusion of live mulches further improved soil physical, chemical and biological properties, which likely led to enhanced nutrient availability (25). Another beneficial effect of live mulching is the reduction in weed density due to better ground coverage. Moreover, the live mulch species used were primarily leguminous crops, whose incorporation into the soil increased soil organic matter and available N, improved soil aggregation, porosity and water holding capacity. These changes collectively favoured vigorous root growth, efficient nutrient uptake and improved nutrient translocation, ultimately resulting in higher grain yield (26).

Effect on protein and starch content of grain

The protein and starch content of finger millet was significantly influenced by land preparation and live mulching during both seasons. During *Rabi* 2022-23, treatments l_2m_2 and l_3m_2 resulted in higher protein content which was on par with l_2m_3. In summer 2022-23, l_3m_2 recorded a higher protein content which was on par with l_2m_2, l_2m_3 and l_3m_4 (Table 4). This increase may be attributed to the favourable effect of SSB with light raking or flaming followed by live mulching with cowpea or green gram, which effectively reduced weed density and biomass. This improvement in protein content is not solely due to better control of weeds but also due to enhanced nutrient availability resulting from the incorporation of live mulch at its flowering stage using wheel hoe weeding which led to increased N uptake by finger millet. The stale seedbed with light raking significantly reduced crop weed competition, allowing the crop to grow more vigorously while reducing the N uptake by weeds. This ultimately led to greater N availability and uptake by finger millet. The increased uptake of N is known to stimulate enzymes such as nitrate reductase and glutamine synthase, which play crucial roles in the incorporation of absorbed N into amino acid during protein synthesis (27). This may explain the higher protein content observed in stale seedbed treatments. Similar findings have been reported in soybean, where effective weed elimination through SSB led to higher protein content (28). In cowpea, greater N availability and absorption also resulted in increased grain protein content (29). In rice, weed free treatments led to a protein content of 7.46 %, attributed to increased nutrient availability (30). In several countries, it is common practice to blend cereal forages, such as barley and oats, with legumes like field pea, to improve the protein content without compromising overall yield (31). In wheat, higher N accumulation in the grain has been linked to increased grain protein content (32) and an increase in P availability and uptake has similarly been associated with higher protein content in wheat grain (33, 34). Furthermore, increased K availability and uptake has been shown to enhance the leaf photosynthesis, improve translocation of photosynthates and enhanced their conversion into proteins in potato (35).

Table 4. Quality attributes of finger millet grain as influenced by land preparation and lives mulches (summer 2022-23)

Treatments	P (%)	K (%)	Protein content (%)	Starch content (%)
NSB × No mulch (l_1m_1)	0.130	1.11	9.09	46.20
NSB × cowpea live mulch (l_1m_2)	0.135	1.13	12.44	60.23
NSB × green gram live mulch (l_1m_3)	0.150	1.11	12.17	56.56
NSB × cluster bean live mulch (l_1m_4)	0.145	1.12	12.76	52.64
SSB with light raking × no mulch (l_2m_1)	0.140	1.07	13.02	55.53
SSB with light raking × cowpea live mulch (l_2m_2)	0.165	1.16	14.23	82.19
SSB with light raking × green gram live mulch (l_2m_3)	0.160	1.13	13.85	63.71
SSB with light raking × cluster bean live mulch (l_2m_4)	0.150	1.28	13.48	61.27
SSB with flaming × no mulch (l_3 m_1)	0.120	1.15	13.02	54.19
SSB with flaming × cowpea live mulch (l_3m_2)	0.135	1.18	14.27	71.07
SSB with flaming × green gram live mulch (l_3m_3)	0.145	1.46	13.31	66.59
SSB with flaming × cluster bean live mulch (l_3m_4)	0.157	1.28	13.81	65.16
SEm (±)	0.002	0.029	0.24	2.12
CD (p=0.05)	0.006	0.084	0.721	6.242

NSB: Normal seedbed, SSB: Stale seedbed

The starch content of finger millet grain was also significantly influenced by land preparation and live mulching. In both seasons, l_2m_2 (SSB with light raking × cowpea live mulching) recorded the highest starch content. Compared to the control the percentage increase in starch content in l_2m_2 was 37 % during the *Rabi* season and 78 % during the summer season treatments with live mulch consistently resulted in higher starch content compared to no- mulch treatments. This improvement may be attributed to better availability and uptake of nutrients, particularly due to effective early stage weed control enabled by the SSB. In later growth stages, fast growing live mulches helped suppress weed growth, further supporting nutrient availability. Additionally, biomass incorporation at 40 DAS followed by microbial decomposition released nutrients into the soil, enhancing their availability. The higher starch content observed in these treatments may also be due to increased N availability. Under sufficient N supply, plants produce greater quantities of enzymes involved in starch synthesis leading to higher starch accumulation in grain. Enhanced availability of N increases the activity of enzymes responsible for the conversion of sucrose to starch, as reported in tuber crops (36). Another plausible reason for the higher starch content in 1_2m_2 is the increased availability of K and P. Higher availability of K the promotes the transport of assimilates from leaves to grains for starch biosynthesis and supports hydrolysis of sucrose into hexose sugar, which serve as precursors for starch synthesis in grains (35, 37). Similarly, increased P availability, enhances the expression of genes responsible for the synthesis of starch and the transport of enzymes responsible for starch biosynthesis (38).

Conclusion

The integration of a stale seedbed with light raking, followed by live mulching using cowpea in a 1:1 ratio and its incorporation at 50 % flowering (40 DAS) using a wheel hoe weeder (treatment l_2m_2), has proven to be a cost effective and sustainable organic weed management strategy for finger millet. This approach significantly enhanced crop productivity, grain quality, net returns and the benefit-cost (B:C) ratio. Specifically, the l_2m_2 treatment led to a 105 % increase in grain yield and an additional net return of ₹29900 per hectare compared to the control (normal seedbed without live mulch, l_1m_1).

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Authors' contributions

SKR conceptualized and designed the research topic. VDVS drafted the manuscript. Proper guidance was provided by SKR, JD, SPP and AB. PPG conducted the pooled analysis and provided the necessary guidance for the statistical analysis of the data. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of Interest : The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process : During the preparation of this work the authors used ChatGPT in order to improve the language. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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