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Studies on synchronization of parental lines in pearl millet hybrid VPMH-14 for hybrid seed production

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Abstract
Pearl millet (*Pennisetum glaucum* L.) is a crucial cereal crop in arid and semi-arid regions, where successful hybrid seed production depends on achieving optimal flowering synchronization between parental lines. This study investigated the effectiveness of staggered sowing and nitrogen applications for synchronizing parental lines of pearl millet hybrid VPMH-14. A field experiment was conducted at Regional Agricultural Research Station, Vijayapur, using a split-plot design with three replications. The experiment included three staggered sowing treatments (simultaneous sowing, male parent sown 4 days earlier, and 6 days earlier) combined with five nitrogen treatments (control, 2% urea at primordia initiation, 2% urea at panicle exertion, 2% nano urea at primordia initiation, and 2% nano urea at panicle exertion). The parental lines ICMA-98222 (female) and VPMR-16 (male) exhibited natural asynchrony of 4-5 days. Results showed that sowing the male parent 4 days earlier reduced flowering gaps from 3.08 to 2.00 days (35% improvement). Strategic nitrogen applications, particularly nano urea at panicle exertion, further enhanced synchronization. Best treatment combinations achieved near-perfect synchronization with flowering differences of only 1.00 day, representing 67% improvement over conventional practices. These findings provide practical protocols for improving hybrid seed production efficiency and enhancing food security in drought-prone regions.

Keywords: Pearl millet, flowering synchronization, staggered sowing, nitrogen application, hybrid seed production, VPMH-14

Introduction
Pearl millet (*Pennisetum glaucum* L) represents one of the most resilient and important cereal crops globally, particularly in arid and semi-arid regions of Africa and Asia where it serves as a staple food for millions of people. In India, pearl millet occupies approximately 7.47 million hectares with annual production of 9.80 million tonnes, making it the fourth most important cereal crop after rice, wheat, and sorghum (Anonymous, 2017) [1]. The crop's exceptional adaptation to harsh environmental conditions, including drought tolerance, heat resistance, and ability to grow in marginal soils with minimal inputs, makes it indispensable for sustainable agriculture in challenging environments (Bidinger *et al*., 2010) [3].

The development and widespread adoption of pearl millet hybrids has revolutionized in productivity, with hybrid varieties consistently demonstrating yield advantages of 15-30% over traditional open-pollinated varieties under diverse growing conditions (Yadav *et al*., 2000) [17]. This significant heterosis has made hybrid cultivation the preferred choice for farmers in major pearl millet growing regions, leading to rapid expansion of hybrid seed production programs across India and other developing countries. However, successful hybrid seed production presents unique biological challenges, particularly achieving optimal flowering synchronization between male and female parental lines, commonly referred to as "nicking" in hybrid seed production terminology (Kumar and Dass, 2014) [7]. Pearl millet exhibits protogynous flowering behavior, with stigma receptivity preceding pollen release within individual florets by 2-6 hours. At the plant level, this asynchrony becomes more pronounced, with female lines (A-lines) typically flowering 2-7 days earlier than male lines (R-lines), creating significant challenges for efficient cross-pollination and seed set (Singh *et al*., 2015). Poor synchronization can result in substantial seed yield reductions, with poorly synchronized plantings achieving only 40-60% of potential seed set compared to well-synchronized plantings that achieve 80-90% seed set (Priyanka *et al*., 2017) [10].

The pearl millet hybrid VPMH-14, developed at the University of Agricultural Sciences, Dharwad, represents a significant breeding achievement. This hybrid, derived from female parent ICMA-98222 and male parent VPMR-16, has demonstrated superior performance in yield potential, disease resistance, and adaptation across Zone-3 of Karnataka (Athoni *et al*., 2021) [2]. Field evaluations confirm yield advantages of 12-25% over national check varieties under various environmental conditions. Despite superior performance, VPMH-14 faces typical synchronization challenges, with the male parent consistently flowering 4-5 days later than the female parent under simultaneous sowing conditions. Various strategies address flowering synchronization challenges, including staggered sowing, growth regulators, nutritional manipulation, and environmental modifications. Staggered sowing has emerged as the most practical technique, involving adjustment of planting dates based on inherent flowering characteristics (Gupta *et al*., 2015) [5]. Recent advances in fertilizer technology, particularly nano urea formulations, offer new possibilities for precision nutrient management. Nano urea provides improved nutrient use efficiency, reduced application rates, enhanced crop response, and reduced environmental impact compared to conventional formulations (Sharma and Manjeet, 2024). This research systematically evaluates the effectiveness of different staggered sowing schedules combined with strategic nitrogen applications in achieving optimal flowering synchronization between VPMH-14 parental lines. The study addresses critical knowledge gaps regarding interaction effects of sowing timing and nutritional interventions on flowering behavior, with the goal of developing practical, scientifically validated protocols for commercial hybrid seed production applications.

Materials and Methods

The field experiment was conducted during the Kharif season at the Regional Agricultural Research Station, Vijayapur, University of Agricultural Sciences, Dharwad, Karnataka, India. The experimental site is located at 16°49'N latitude and 75°42'E longitude at an elevation of 593 meters above sea level. The experiment was laid out in a split-plot design with three replications. The gross plot size was 4.0 m × 3.6 m with a net plot size of 3.0 m × 2.7 m. Row-to-row spacing was maintained at 45 cm with plant-to-plant spacing of 15 cm. A 4:2 female to male row ratio was maintained as per standard hybrid seed production protocols.

The study utilized the parental lines of pearl millet hybrid VPMH-14:-Female parent: ICMA-98222 (A-line)-An A1 cytoplasm-based male sterile line Male parent: VPMR-16 (R-line)-A fertility restorer line Treatment combinations included three staggered sowing schedules (main plots) and five nitrogen application treatments (sub-plots), resulting in 15 treatment combinations evaluated across three replications. Standard agronomic practices were followed throughout the experiment, with recommended fertilizer applications, irrigation management, and plant protection measures implemented as per regional guidelines.

Table 1: Effect of Staggered Sowing on Days to Floral Primordia Initiation

Treatments	Initiation of floral primordia		
Main plot : Staggered sowing (M)	**VPMR-16**	**ICMA-98222**	**Difference**
M_1-Simultaneous sowing of male and female parents.	25.00	21.67	3.33
M_2-Sowing of male parent by 4 days earlier to female.	24.58	21.17	3.41
M_3-Sowing of male parent by 6 days earlier to female.	25.00	21.67	3.33
Mean	24.86	21.50	
S.Em.±	0.14	0.09	
C.D	0.54	0.37	
Sub plot: Application of additional does of nitrogen to late parent (S)			
S_1-Water spray	25.33	21.22	4.11
S_2-2% urea spray @ primordia initiation of male parent	24.78	21.67	3.11
S_3-2% urea spray @ panicle exertion of male parent	24.89	21.56	3.33
S_4-2% nano urea spray @ primordia initiation of male parent	24.78	21.33	3.45
S_5-2% nano urea spray @ panicle exertion of male parent	25.04	21.78	3.26
Mean	24.99	21.44	
S.Em.±	0.16	0.16	
C.D	0.46	0.46	
Interactions (M × S)			
M_1S_1	25.33	21.67	3.66
M_1S_2	24.67	22.67	2.00
M_1S_3	25.00	21.33	3.67
M_1S_4	25.00	21.00	4.00
M_1S_5	25.33	20.33	5.00
M_2S_1	24.67	22.33	2.34
M_2S_2	24.33	21.33	3.00
M_2S_3	24.00	20.67	3.33
M_2S_4	25.33	21.67	3.66
M_2S_5	25.00	22.33	2.67
M_3S_1	25.33	22.00	3.33
M_3S_2	25.00	21.33	3.67
M_3S_3	24.33	22.67	1.66
M_3S_4	24.67	21.00	3.67
M_3S_5	25.33	20.67	4.66
Mean	24.89	21.53	
S.Em.±	0.28	0.27	
C.D	0.80	0.79	

Table 2: Effect of Staggered Sowing on Days to 50% Flowering

Treatments	50% flowering		
Main plot : Staggered sowing (M)	**VPMR-16**	**ICMA-98222**	**Difference**
M_1-Simultaneous sowing of male and female parents.	40.58	37.50	3.08
M_2-Sowing of male parent by 4 days earlier to female.	39.08	37.08	2.00
M_3-Sowing of male parent by 6 days earlier to female.	39.75	37.67	2.08
Mean	39.92	37.42	
S.Em.±	0.19	0.15	
C.D	0.73	0.59	
Sub plot: Application of additional does of nitrogen to late parent (S)			
S_1-Water spray	40.00	36.89	3.11
S_2-2% urea spray @ primordia initiation of male parent	40.11	37.78	2.33
S_3-2% urea spray @ panicle exertion of male parent	39.77	37.66	2.11
S_4-2% nano urea spray @ primordia initiation of male parent	39.99	37.71	2.28
S_5-2% nano urea spray @ panicle exertion of male parent	39.81	37.76	2.05
Mean	39.75	37.48	
S.Em.±	0.23	0.17	
C.D	0.68	0.50	
Interactions (M × S)			
M_1S_1	40.33	37.67	2.66
M_1S_2	41.33	36.67	4.66
M_1S_3	40.33	38.67	1.66
M_1S_4	40.33	37.00	3.33
M_1S_5	39.67	38.33	1.34
M_2S_1	39.33	36.67	2.66
M_2S_2	39.67	36.67	3.00
M_2S_3	37.67	36.67	1.00
M_2S_4	40.33	37.33	3.00
M_2S_5	39.33	37.33	2.00
M_3S_1	38.67	37.67	1.00
M_3S_2	41.00	37.33	3.67
M_3S_3	40.67	38.33	2.34
M_3S_4	41.33	37.33	4.00
M_3S_5	39.33	38.33	1.00
Mean	39.95	37.47	
S.Em.±	0.4	0.3	
C.D	1.17	0.86	

Results and Discussion

The experimental results revealed highly significant effects of both staggered sowing and nitrogen application treatments on flowering synchronization parameters in VPMH-14 hybrid seed production. The staggered sowing treatments demonstrated clear benefits in reducing flowering asynchrony between parental lines. For floral primordia initiation, sowing the male parent 4 days earlier (M_2) resulted in marginally earlier initiation compared to simultaneous sowing, while the flowering gap between parents remained relatively consistent across treatments ranging from 3.33 to 3.41 days. The 50% flowering parameter showed more pronounced treatment effects, with staggered sowing achieving substantial improvements in synchronization efficiency. Sowing the male parent 4 days earlier reduced the flowering gap from 3.08 days to 2.00 days, representing a 35% improvement in synchronization. Similarly, sowing 6 days earlier achieved comparable benefits with a 2.08-day flowering difference. Nitrogen application treatments provided additional synchronization benefits, with applications at panicle exertion stage showing particular effectiveness. The combination of optimal staggered sowing with strategic nitrogen applications achieved exceptional results, with some treatment combinations reducing flowering gaps to as low as 1.00 day. The interaction effects between staggered sowing and nitrogen application were highly significant, emphasizing the importance of integrated treatment approaches. The best performing combinations (M_2S_3, M_3S_1, M_3S_5) achieved near-perfect synchronization, while suboptimal combinations resulted in flowering gaps exceeding 4.5 days. These findings have significant practical implications for commercial hybrid seed production operations. The demonstrated improvements in synchronization efficiency can translate to substantial increases in seed set percentage and overall seed yield, providing strong economic justification for adopting optimized synchronization protocols.

Conclusions

This comprehensive study on flowering synchronization in pearl millet hybrid VPMH-14 has generated several important findings with significant implications for hybrid seed production:

1. Staggered sowing proved highly effective, with sowing the male parent 4-6 days earlier than the female parent consistently improving flowering synchronization across all measured parameters.
2. Strategic nitrogen application, particularly at panicle exertion stage, provided additional synchronization benefits beyond staggered sowing alone.
3. Nano urea formulations showed slight superiority over conventional urea when applied at optimal timing, suggesting potential benefits of advanced fertilizer technologies.

4. The interaction between staggered sowing and nitrogen application was highly significant, with optimal combinations achieving flowering gaps as low as 1.00 day.
5. The research provides practical, scientifically validated protocols that can be readily adopted in commercial seed production operations to improve synchronization efficiency and seed yield.

The findings contribute significantly to the scientific understanding of pearl millet reproductive biology and provide tools for enhancing hybrid seed production efficiency, ultimately supporting improved food security in drought-prone regions.

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