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Research Article

Unraveling the genetics of trait associateship and nutrient significance of determinate horse gram mutants

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Abstract
Horse gram is a nutrient-rich and photo-sensitive legume crop. The experiments were carried out to study the association among traits in horse gram. A total of six determinate and photo-insensitive horse gram mutants were raised in RBD with five replications in two locations in all three seasons (*Kharif'*22, *Rabi'*22 and *Summer'23*), and the mean data for ten quantitative traits were subjected to correlation and path analyses. The findings of correlation analysis indicated that the traits number of clusters per plant and number of pods per plant had a positive association with seed yield per hectare. Similarly, the path analysis revealed that the number of pods per plant and hundred seed weight exhibited a positive and direct effect on seed yield per hectare. There was a noticeable variation observed for both macro and micronutrients. From the current experiment, two determinate mutants TNAU-HG-DM-004 and TNAU-HG-DM-001 were selected as nutrient-rich genotypes with high yield potential. Hence, these determinate mutants can be used as donors for yield as well as nutrient improvement programs in horse gram.

Keywords: Determinate mutants, horse gram, nutritional profiling, trait relatedness

INTRODUCTION

Horse gram (*Macrotyloma uniflorum* (Lam.) Verdc.) is a self-pollinated diploid legume species with a genome size of 294.7 Mb. It is a multi-purpose crop for the resource-poor farmers of India and is cultivated in dry and marginal lands during the *Rabi* season due to its photosensitivity. It is nutrient-rich rich and its consumption lowers the risk of diseases (Prasad and Singh, 2015). It has an innate ability to withstand YMV and powdery mildew diseases (Sudhagar *et al*., 2022 and Rajaprakasam *et al*., 2023) and drought stress (Chahota *et al*., 2020). Many of the cultivated horse gram varieties are indeterminate types and belong to long- duration groups, which reduce the seed production efficiency of the crop (Krylova *et al.,* 2020 and Priyanka *et al*., 2021). This issue can be mitigated by developing determinate and photo-insensitive cultivars (DM). In addition, DMs are suited for mechanical harvesting, year- round cultivation, and can increase productivity through increased plant density. The full potential yield of horse gram remains untapped due to limited genetic diversity and the absence of focused breeding programs. Added to that, Chahota *et al*. (2013) reported limited sources of economic traits for horse gram in the global germplasm. Hence, induced mutagenesis was used to create genetic variability in a horse gram variety PAIYUR 2 and DMs were evolved and the same were used in the present study. Earlier, Priyanka *et al*. (2023) reported the utility of induced mutagenesis in creating variability in horse gram. Trait association studies provide valuable insights to plant breeders, to devise selection strategies for enhancing genetic potential. Path analysis allows the correlation coefficients to be partitioned into the direct and indirect effects of the various traits on yield (Visakh *et al*., 2023). Assessing the nutritional potential of the determinate mutants holds importance in selecting the most suitable mutant for further investigation, as there is a negative relationship between yield and nutrient contents (Sudhagar *et al*., 2022). With this background, the study was conducted to evaluate the genetic relationship of yield and its attributing traits for formulating breeding strategies and to identify nutrient-specific genetic stocks for exploitation.

MATERIALS AND METHODS

The experimental material comprised of six determinate and photo-insensitive horse gram mutants TNAU-HG-DM-001 (D1), TNAU-HG-DM-002 (D2), TNAU-HG-DM-003 (D3), TNAU- HG-DM-004 (D4), TNAU-HG-DM-005 (D5), and TNAU-HG-DM-006 (D6), and a photosensitive control variety PAIYUR 2 (photosensitive). The yield performance of the DMs was evaluated during the *kharif* 2022*, rabi* 2022&23*,* and *summer* 2022&23 seasons. The experiments were carried out in a Randomized Block Design (RBD) with five replications in two environments *viz*., Department of Pulses, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (11.02°N and 76.92°E) and Sugarcane Research Station, Tamil Nadu Agricultural University, Melalathur, Vellore (12.91°N and 78.87°E). Each experimental unit (plots) of mutants consisted of seven rows of 5.0m length, with plants spaced at intervals of 30 cm between rows and 15 cm between plants. Following the procedure recommended by Mahajan *et al.* (2000), the data on yield- related traits were recorded for ten plants/ replication from each replication at suitable growth stages. Data for days to 50% flowering (DFF) and days to maturity (DTM) were recorded at the appropriate growth stages. Traits like plant height (PH), number of pods per plant (NPP), number of pods per cluster (NPC), number of clusters per plant (NC), number of primary branches (NPB), and number of seeds per pod (NSPP) were documented at harvest. While hundred seed weight (HSW), and seed yield per hectare (YDH) were calculated after post-harvest processing. The yield performance of the DMs is compared with the photosensitive parent PAIYUR 2 only during the *rabi* season for the following two reasons (i) there is no photo-insensitive check available for comparison in all seasons, and (ii) to identify the yield supremacy of the DMs over the parent PAIYUR 2 for their further utilization in the breeding cycles. The average season wise data excluding PAIYUR 2 were utilized for analyses.

In order to formulate a trait improvement program, correlation as per Johanson *et al*. (1995) and path analysis as per Dewey and Lu (1959) were performed to determine the relative impact of traits on yield and their cause-and-effect relationships. Further, to identify nutrient-specific genetic stocks, profiling was done for the DMs for macronutrients (crude protein, crude fiber, and crude fat) and micronutrients (boron, magnesium, phosphorus, potassium, calcium, manganese, iron, copper, zinc, and molybdenum).

Crude protein and crude fibre were estimated as per Lynch and Barbano (1999) and Maynard's (1970) respectively. Crude fat was estimated using the Soxhlet apparatus. The data sets were graphically analyzed using 'R' Studio (version 2023.03.0**),** R-based shiny package PB-Perfect (Allan, 2023), and Microsoft Excel 2016 (Version 2306).

RESULTS AND DISCUSSION

Horse gram is a nutritionally important legume whose all-season cultivation significantly would cater to the nutrient requirement of dry land farmers. This is feasible by evolving photo-insensitive genotypes and their further evaluation in the next generations. The parent, PAIYUR 2 is an indeterminate and photosensitive variety that is grown only in the *rabi* season in Tamil Nadu. Hence, the *rabi* season performance of parent PAIYUR 2, was considered for assessing the yield potential of the determinate mutants (**Fig. 1.**). The mutants D4 (812.66 kg/ha) and D1 (783.62 kg/ha) are the good yielders among the tested genotypes. Pooled Analysis of variance over seasons revealed the presence of significant differences among the genotypes for most of the traits (**Table 1.1 to 1.3**). This indicates the existence of a sufficient amount of variability among the genotypes studied and therefore offers an ample scope for effective selection. With a view to understanding the overall breeding potency of the mutants, the ranges, and mean values documented for ten quantitative traits across six environments are furnished in **Table 2**. During *Kharif'22,* the mean values for the trait YDH were 567.57 and 567.30 at the Coimbatore and Melalathur locations respectively. During *Rabi'22,* they were 729.11 and 735.77. In the *Summer'23* season, the mean values were 503.03 and 495.90 respectively. The yield performance of the DMs was significant during the *rabi* season followed by the *kharif* and *summer* seasons respectively.

To understand the seasonal influence on trait expression, pooled season-wise correlation coefficients were estimated. During the *Kharif* season, the traits NPP,

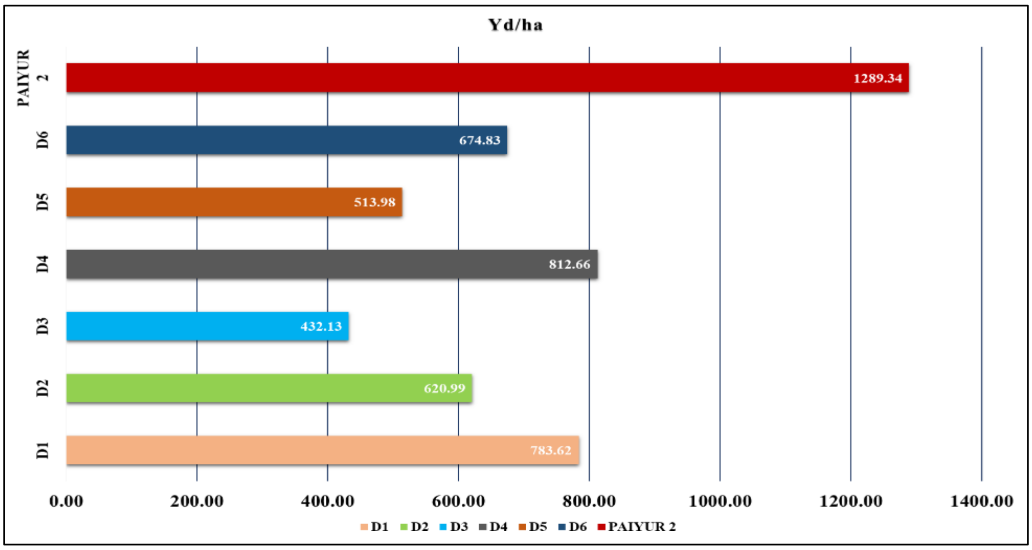

Fig. 1. Mean yield performance of determinate mutants and parent PAIYUR 2 during *rabi* season

Table 1.1. Pooled ANOVA of six determinate mutants across environments during *Kharif 2022*

Source	df	DFF	DTM	PH	NPB	NPC	NPP	NC	NSPP	HSW	YDH
Genotypes	5	102.49	82.87	83.64	3.94*	1.63	5898.94**	382.23**	2.95*	0.36	185643.65**
Environment	1	58.01	126.15	0.41	6.66	0.15	160.06	6.01	0.15	0.07	0.81
Replication	8	35.14	135.98	25.06	0.58	0.36	427.04	39.20	0.41	0.12	24683.75
GxE	5	91.53	156.07	25.08	0.62	0.43	180.58	29.21	0.07	0.10	3640.53
Error	40	49.09	141.75	38.77	1.45	0.99	1173.34	64.59	1.07	0.28	38661.88

Significance levels: $p < .01$ '**', $p < .05$ '*'

Table 1.2. Pooled ANOVA of six determinate mutants across environments during *Rabi 2022*

Source	df	DFF	DTM	PH	NPB	NPC	NPP	NC	NSPP	HSW	YDH
Genotypes	5	84.34	467.95*	91.36	4.29*	1.82	3307.44	282.73*	3.54**	0.73*	37616.37
Environment	1	60.00	498.81	87.36	6.01	4.26	1960.81	74.81	0.55	1.46	39066.01
Replication	8	34.91	192.31	29.07	0.14	1.04	688.01	45.44	0.30	0.56	31256.55
GxE	5	89.36	492.05	76.12	0.85	0.90	1923.75	135.05	0.80	0.52	42329.01
Error	40	44.53	192.23	52.32	1.85	1.29	2151.81	124.92	0.91	0.29	42518.13

Significance levels: $p < .01$ '**', $p < .05$ '*'

Table 1.3. Pooled ANOVA of six determinate mutants across environments during *Summer 2023*

Source	df	DFF	DTM	PH	NPB	NPC	NPP	NC	NSPP	HSW	YDH
Genotypes	5	78.26*	290.21	108.09**	4.33*	3.46*	3520.94**	294.70**	3.44**	0.33	145623.74**
Environment	1	6.66	114.81	33.60	2.81	0.06	64.06	8.06	0.60	0.02	763.26
Replication	8	27.84	117.81	32.32	0.53	0.81	279.36	37.15	0.66	0.13	19778.87
GxE	5	25.62	139.33	18.15	0.49	0.78	89.50	28.42	0.56	0.08	13624.50
Error	40	25.77	122.97	33.40	1.43	1.02	653.07	65.45	0.86	0.29	24128.93

Significance levels: $p < .01$ '**', $p < .05$ '*'

Table 2. Mean performance of six determinate mutants across environments

***Kharif* 2022**

Environment 1 (Coimbatore)

	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	37.93	33.80	41.88	5.43	2.22	17.17
DTM	86.50	72.80	90.00	6.16	2.52	30.26
PH	34.67	31.00	39.00	2.49	1.02	14.79
NPB	3.83	3.00	5.00	0.70	0.28	2.53
NPC	3.80	3.40	4.60	0.42	0.17	2.02
NPP	107.10	74.40	141.20	20.68	8.44	69.96
NC	38.13	30.80	48.00	5.59	2.28	18.00
NSPP	2.10	1.40	2.60	0.51	0.21	2.06
HSW	3.12	2.80	3.58	0.23	0.10	1.32
YDH	567.57	353.40	774.00	133.43	54.47	382.4

Environment 2 (Melalathur)

	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	37.47	34.80	39.00	1.69	0.69	4.88
DTM	89.40	87.40	91.80	1.35	0.55	2.29
PH	34.83	30.00	40.00	3.58	1.46	5.77
NPB	4.50	3.80	5.20	0.53	0.21	1.75
NPC	3.70	3.20	4.20	0.41	0.17	1.54
NPP	110.37	74.40	141.40	24.19	9.88	52.23
NC	38.77	29.80	47.40	6.11	2.50	9.78
NSPP	2.20	1.60	2.80	0.49	0.20	1.65
HSW	3.05	2.80	3.31	0.15	0.06	0.32
YDH	567.30	418.80	742.40	117.62	48.02	323.93

***Rabi* 2022**

Environment 3 (Coimbatore)

	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	38.29	31.60	52.60	2.54	0.96	12.61
DTM	87.69	69.20	118.60	6.29	2.38	27.52
PH	47.19	32.10	112.10	2.48	0.94	29.78
NPB	3.97	3.00	5.00	0.53	0.20	2.48
NPC	3.83	3.40	4.20	0.31	0.12	1.88
NPP	138.60	90.20	204.60	21.67	8.19	71.50
NC	43.91	32.80	64.00	5.59	2.11	19.27
NSPP	2.43	1.20	3.80	0.86	0.33	1.27
HSW	3.44	3.12	3.98	0.29	0.11	0.27
YDH	729.11	423.40	1308.00	127.12	48.05	173.70

Environment 4 (Melalathur)						
	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	39.46	34.00	52.00	5.73	2.17	10.08
DTM	93.43	83.40	119.00	11.39	4.30	19.7
PH	50.47	35.28	109.46	25.12	9.49	42.06
NPB	4.51	3.40	5.40	0.76	0.29	1.602
NPC	4.29	3.60	5.00	0.48	0.18	1.719
NPP	144.63	92.00	200.40	38.31	14.48	48.9654
NC	45.49	31.40	63.60	10.38	3.92	16.01
NSPP	2.46	1.80	3.20	0.56	0.21	1.4867
HSW	3.54	3.23	3.95	0.23	0.09	0.296
YDH	735.77	440.80	1270.00	259.58	98.11	135.077

***Summer* 2023**

Environment 5 (Coimbatore)						
	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	34.93	30.00	39.40	3.29	1.34	12.70
DTM	82.83	67.00	89.80	7.79	3.18	27.88
PH	36.45	31.26	41.38	3.44	1.41	13.63
NPB	3.87	3.20	4.60	0.51	0.21	2.499
NPC	3.90	3.40	4.60	0.51	0.21	2.05
NPP	96.13	77.60	127.20	16.43	6.71	53.80
NC	34.97	28.40	44.00	4.66	1.90	17.97
NSPP	2.20	1.00	3.40	0.72	0.29	1.61
HSW	3.19	2.92	3.61	0.22	0.09	1.33
YDH	503.03	380.80	772.60	136.25	55.62	320.39

Environment 6 (Melalathur)						
	Mean	Range		SD	SE	CD 1%
		Min	Max			
DFF	35.60	31.20	38.80	2.55	1.04	2.47
DTM	85.60	81.20	89.40	3.31	1.35	4.61
PH	37.95	34.08	43.10	3.03	1.24	5.57
NPB	4.30	3.40	5.60	0.74	0.30	1.75
NPC	3.83	2.80	4.60	0.67	0.27	1.56
NPP	98.20	76.40	127.40	18.22	7.44	36.72
NC	35.70	27.80	43.80	5.67	2.31	10.10
NSPP	2.40	2.00	3.00	0.38	0.16	1.73
HSW	3.21	3.01	3.48	0.15	0.06	0.32
YDH	495.90	372.00	627.20	89.32	36.46	232.67

HSW, NPB, NC, and NSPP expressed a highly significant and positive association with YDH. It is evident that when the number of primary branches in creases, there is a direct impact on the number of clusters and pods per plant. As a result of this relationship, there is a noticeable improvement in the overall seed yield. In the same way, NPB and NC also expressed a significant and positive association with NPP (**Table 3.1**).

In *Rabi* trials, the traits HSW and NPP had a significant and positive relationship with YDH. The traits DFF and DTM exhibited highly significant and positive relationships with each other. This can be explained by the feature of PAIYUR 2, a photoperiod-sensitive variety, with an indeterminate growth habit (~120 cm). This growth habit leads to longer DFF and DTM, resulting in more NC, NPC, and NPP. Consequently, it contributes to a higher overall yield **(Table 3.2)**. During *Summer* seasons, the traits NPP, HSW, NC, and NPB showed a significant and positive relationship with YDH **(Table 3.3)**.

The relatednesses of the traits over seasons and cropping years, in horse gram DMs indicate a positive and significant relationship between the traits NPP, NC and HSW with YDH. Similar results by Mahalingam *et al*. (2020) and Sineka *et al.* (2021) in mung bean, revealed that there is positive correlation between NPP and NC with YDH. In a multiple environment-based stability experiment, the direction of correlation (positive or negative) and variations in the coefficient values mainly depends on G x E interactions (Vir and Singh, 2015). In the current study, on the contrary, a lesser influence of G x E interactions on trait expression is ascertained. The correlation study even though reveals the associations between variables does not provide insights into direct

Table 3.1. Correlation for six determinate mutants across two environments during *Kharif* 2022*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	YDH
DFF	1									
DTM	0.17	1								
PH	-0.04	-0.01	1							
NPB	0.34 **	0.40 **	0.49**	1						
NPC	0.06	0.36 **	0.41**	0.50**	1					
NC	0.23	0.67**	0.27*	0.64**	0.41**	1				
NPP	0.16	0.67 **	0.54**	0.66**	0.57**	0.74**	1			
NSPP	0.27 *	0.28 *	0.63**	0.60**	0.55**	0.46**	0.65**	1		
HSW	0.05	0.32 *	0.57**	0.58**	0.39*	0.68**	0.65**	0.49 **	1	
YDH	0.17	0.53 **	0.65**	0.72**	0.59**	0.71**	0.93**	0.68 **	0.74 **	1

Significance levels: p < .01 '**', p < .05 '*'
*Mean values of two locations namely Coimbatore and Melalathur were pooled and analysed

Table 3.2. Correlation for six determinate mutants along with parent PAIYUR 2 across two environments during *Rabi* 2022*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	YDH
DFF	1									
DTM	0.71**	1								
PH	0.17	0.48**	1							
NPB	0.21	0.43**	0.76 **	1						
NPC	0.03	0.14	0.35 **	0.53**	1					
NC	0.21	0.67 **	0.85**	0.69**	0.25	1				
NPP	0.21	0.42**	0.47**	0.50**	0.51**	0.60**	1			
NSPP	0.32*	0.37**	0.63**	0.78**	0.45**	0.52**	0.38**	1		
HSW	0.25 *	0.48**	0.66**	0.70**	0.39**	0.70**	0.65**	0.56**	1	
YDH	0.17	0.34**	0.48**	0.60**	0.49**	0.54**	0.79**	0.49**	0.69**	1

Significance levels: p < .01 '**', p < .05 '*'
*Mean values of two locations namely Coimbatore and Melalathur were pooled and analyzed

Table 3.3. Correlation for six determinate mutants across two environments during *Summer* 2023*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	YDH
DFF	1									
DTM	0.49**	1								
PH	-0.43**	-0.20	1							
NPB	0.20	0.37**	0.32*	1						
NPC	0.06	0.07	0.45**	0.54**	1					
NC	0.12	0.56**	0.03	0.69**	0.40**	1				
NPP	0.23	0.57**	0.23	0.81**	0.53**	0.92**	1			
SPP	-0.04	0.25	0.36**	0.58**	0.50**	0.63**	0.72**	1		
HSW	0.06	0.37**	0.37**	0.78**	0.55**	0.78**	0.89**	0.76**	1	
YDH	0.19	0.52**	0.35**	0.69**	0.42**	0.74**	0.88**	0.65**	0.82**	1

Significance levels: p < .01 '**', p < .05 '*'
*Mean values of two locations (Coimbatore and Melalathur) are pooled and analysed

or indirect influences on yield, therefore path analysis was performed.

Direct and indirect effects of variables: Path coefficient analysis helps a breeder in two ways (i) measures the direct and indirect effects of a trait on others (ii) helps in understanding the specific contributions of each factor and forms the basis of selection to enhance yield (Raturi *et al*., 2015). Results of path analysis revealed that during the *Kharif* seasons, the traits NPP, HSW, PH, NPB, NPC, and DFF exerted a high positive direct effect on seed yield per hectare (**Table 4.1**). Similar result was also reported by Singh *et al.* (2021) in chickpea. During *Rabi* trials, the traits NPP, HSW, NPB, and NSPP recorded a high and positive direct effect on seed yield per hectare (**Table 4.2**). Similar results were also reported by Salgotra *et al.* (2016) in chickpea. The traits NPP, PH, DTM, and HSW displayed a high positive and direct effect on YDH during *summer* trials (**Table 4.3**).

The pooled results of path analysis for all three seasons suggested that the traits NPP and HSW had high positive and direct effects on YDH. Hence, to maximize the seed yield of determinate horse gram mutants, it is crucial to select plants with higher NPP and HSW. These findings are in accordance with Katoch *et al*. (2016) in garden pea and Devi *et al*. (2015) in French bean.

Nutrient profiling: Horse gram has been regarded as a promising protein and nutrient resource (Bhartiya *et al,* 2015). Its seeds are rich in polyphenols, flavonoids, proteins, and major antioxidants (Sharma *et al*., 2019). In the current study, the DMs were profiled for various macro and micronutrients to ascertain their nutritional profile. The macronutrient with the highest coefficient of variation (**Table 5.**) was crude protein (11.50%), while crude fiber had a minimum variation (9.81%). Among the tested determinate mutants, D4 (24.80%) had the significantly highest crude protein content followed by D1 (23.64%) and D3 (22.62%). Similar protein studies in horse gram were also reported by Marimuthu and Krishnamoorthi, (2013), Patangare *et al.* (2019), and Sudhagar *et al.* (2023). Determinate mutants superior to the parent PAIYUR 2 for macronutrients were identified. The determinate mutant D4 (2.40%) recorded the highest and most significant mean crude fiber content than parent PAIYUR 2 (2.38%). The determinate mutants D5 and D2 had the highest crude fat content of 1.29% and 1.26% respectively.

The DMs possessed a wide of range of micronutrients. The boron content ranged from 4.64 to 7.29 ppm. The magnesium content varied from 288.84 to 414.62 ppm. The ranges for phosphorus, potassium, calcium, manganese, iron, copper, zinc and molybdenum are 872.47 to 1226.11 ppm, 1504.82 to 2142.05 ppm, 437.45 to 706.21 ppm, 7.15 to 10.28 ppm, 1.97 to 2.58 ppm, 1.98 to 2.94 ppm, 5.65 to 8.42 ppm, and 0.24 to 0.51 ppm respectively (**Table 6.**). The micronutrient contents were found to be varied among the mutants as 12.14% for boron (B), 10.48% for magnesium (Mg), 11.20% for phosphorus (P), 10.46% for potassium (K), 17.22% for calcium (Ca), 14.58% for manganese (Mn), 15.27% for iron (Fe), 11.46% for copper (Cu), 13.92% for zinc (Zn), and 17.31% for molybdenum (Mo**) (Table. 6.)**. The mutant D1 has the favorable profile for B, Mg, P, Ca, and Mn, while D6 is better for K, Fe, and Zn and D4 for Cu and Mo.

By considering the yield potential, macro and micronutrient contents, the DM D4 showed better performance for yield, crude protein, crude fiber, Cu, and Mo followed by D1 which had the highest amount of crude protein, B, Mg, P, Ca, and Mn with appreciable yield. The DM, D6 was identified as a genetic stock for Fe, Zn, and K. The mutant with low yield and high nutrients can be used as a donor for trait-specific introgression-based breeding programs. Hence, the determinate

Table 4.1. Path analysis across two environments during *Kharif* 2022*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	Correlations YDH
DFF	**0.048**	-0.007	-0.005	0.029	0.002	-0.010	0.119	-0.005	0.001	0.172
DTM	0.008	**-0.045**	-0.001	0.034	0.017	-0.029	0.501	-0.005	0.058	0.537
PH	-0.002	0.000	**0.106**	0.042	0.020	-0.012	0.405	-0.012	0.104	0.652
NPB	0.017	-0.018	0.052	**0.084**	0.024	-0.028	0.494	-0.011	0.106	0.721
NPC	0.002	-0.016	0.043	0.042	**0.049**	-0.018	0.428	-0.010	0.072	0.593
NC	0.011	-0.030	0.029	0.054	0.020	**-0.044**	0.553	-0.009	0.126	0.711
NPP	0.007	-0.030	0.058	0.056	0.028	-0.032	**0.741**	-0.012	0.120	0.935
NSPP	0.013	-0.013	0.068	0.051	0.027	-0.020	0.487	**-0.019**	0.091	0.685
HSW	0.000	-0.014	0.060	0.049	0.019	-0.030	0.488	-0.009	**0.183**	0.746

Diagonal bold values indicate direct effects
*Mean values of two locations namely Coimbatore and Melalathur were pooled and analyzed

Table 4.2. Path analysis across two environments during *Rabi* 2022*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	Correlations YDH
DFF	**-0.016**	-0.044	-0.016	0.044	-0.000	-0.011	0.131	0.021	0.064	0.173
DTM	-0.011	**-0.062**	-0.044	0.089	-0.000	-0.037	0.260	0.024	0.122	0.340
PH	-0.002	-0.030	**-0.092**	0.157	-0.000	-0.047	0.292	0.042	0.168	0.487
NPB	-0.003	-0.026	-0.070	**0.206**	-0.001	-0.038	0.307	0.052	0.178	0.604
NPC	-0.000	-0.009	-0.033	0.111	**-0.002**	-0.013	0.315	0.030	0.101	0.498
NC	-0.003	-0.041	-0.079	0.144	-0.000	**-0.055**	0.368	0.034	0.178	0.546
NPP	-0.003	-0.026	-0.044	0.104	-0.001	-0.033	**0.610**	0.025	0.165	0.796
NSPP	-0.005	-0.023	-0.058	0.161	-0.000	-0.028	0.235	**0.066**	0.144	0.491
HSW	-0.004	-0.030	-0.061	0.145	-0.000	-0.038	0.397	0.037	**0.254**	0.699

Diagonal bold values indicate direct effects
*Mean values of two locations namely Coimbatore and Melalathur were pooled and analysed

Table 4.3. Path analysis across two environments during *Summer* 2023*

	DFF	DTM	PH	NPB	NPC	NC	NPP	NSPP	HSW	Correlations YDH
DFF	**-0.071**	0.035	-0.042	-0.026	-0.000	-0.080	0.375	0.001	0.003	0.195
DTM	-0.035	**0.072**	-0.020	-0.049	-0.011	-0.358	0.915	-0.010	0.023	0.525
PH	0.030	-0.015	**0.097**	-0.042	-0.073	-0.022	0.374	-0.015	0.023	0.357
NPB	-0.014	0.027	0.031	**-0.131**	-0.087	-0.438	1.288	-0.025	0.048	0.697
NPC	-0.000	0.005	0.044	-0.072	**-0.159**	-0.254	0.846	-0.021	0.034	0.422
NC	-0.009	0.041	0.003	-0.091	-0.064	**-0.629**	1.471	-0.027	0.048	0.742
NPP	-0.016	0.041	0.022	-0.106	-0.084	-0.583	**1.587**	-0.031	0.055	0.884
NSPP	0.003	0.018	0.035	-0.077	-0.079	-0.397	1.152	**-0.042**	0.047	0.658
HSW	-0.004	0.027	0.036	-0.103	-0.087	-0.493	1.417	-0.033	**0.062**	0.821

Diagonal bold values indicate direct effects
*Mean values of two locations namely Coimbatore and Melalathur were pooled and analysed

Table 5. Macronutrient contents of determinate horse gram mutants (values in %)

S. No.	Mutant	Crude protein	Crude fibre	Crude fat
1	TNAU-HG-DM- 001	23.64*	2.36*	0.81
2	TNAU-HG-DM- 002	22.45	2.20	1.26*
3	TNAU-HG-DM- 003	22.62*	2.00	1.05
4	TNAU-HG-DM- 004	24.80*	2.40*	1.17
5	TNAU-HG-DM- 005	21.54	2.32	1.29*
6	TNAU-HG-DM- 006	22.00	2.14	1.15
	PAIYUR 2 (Parent)	24.92*	2.38*	0.74
	Maximum	24.92	2.38	1.29
	Minimum	21.54	2.00	0.74
	Mean	23.23	2.19	1.02
	Standard deviation	0.71	39.62	115.00
	Standard error	0.15	10.44	31.73
	Coefficient of variation (%)	11.50	9.81	10.35

*Significant at p=5% level

Table 6. Micronutrient contents (ppm) of determinate horse gram mutants

S. No.	Mutant	B	Mg	P	K	Ca	Mn	Fe	Cu	Zn	Mo
1	TNAU-HG-DM- 001	7.29*	414.62*	1226.11*	2084.28	706.21*	10.28*	2.17*	2.10*	6.54	0.24
2	TNAU-HG-DM- 002	6.42	329.54	1026.35	1855.42	606.48	7.41	1.97	2.41	6.77	0.33
3	TNAU-HG-DM- 003	5.82	319.48	1064.14	1849.15	508.22	8.13	2.08	2.34	6.12	0.29
4	TNAU-HG-DM- 004	6.54	338.00	1084.25	1888.74	529.40	7.15	2.48	2.94*	5.94	0.51*
5	TNAU-HG-DM- 005	4.64	288.84	872.47	1504.82	437.45	7.19	2.32	1.98	5.65	0.37
6	TNAU-HG-DM- 006	5.51	362.50	1194.79*	2142.05*	539.75	9.45	2.58*	2.79*	8.42*	0.45*
	PAIYUR 2 (Parent)	6.58	400.12*	1221.33*	2069.08	625.89	6.69	2.48	2.70	8.07*	0.35
	Maximum	7.29	414.62	1226.11	2142.05	706.21	10.28	2.58	2.94	8.07	0.51
	Minimum	4.64	288.84	872.47	1504.82	437.45	7.15	1.97	1.98	5.65	0.24
	Mean	5.97	351.73	1049.29	1823.44	571.83	8.72	2.28	2.46	6.86	0.38
	Standard deviation	0.69	40.54	118.64	179.25	102.57	1.10	0.35	0.29	1.08	0.05
	Standard error	0.19	11.28	33.26	52.51	29.46	0.33	0.10	0.07	0.32	0.02
	Coefficient of variation (%)	12.14	10.48	11.20	10.46	17.22	14.58	15.27	11.46	13.92	17.31

Significant at p=5% level

B: Boron Mg: Magnesium P: Phosphorus K: Potassium Ca: Calcium Mn: Manganese Fe: Iron
Cu: Copper Zn: Zinc Mo: Molybdenum

mutants D4 (TNAU-HG-DM-004) and D1 (TNAU-HG-DM-001) could be further exploited as donors for photosensitivity, yield as well as nutrient improvement programs in horse gram.

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