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Agronomic Performance, Genotype X Environment Interaction and Stability of Black Cumin Genotypes Grown in Bale, Southeastern Ethiopia

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Abstract

Twenty Black Cumin genotypes were evaluated across locations to assess their agronomic performance, genotype by environment interaction and seed yield stability during 2011 and 2012 at Sinana, Goro and Ginir in randomized complete design with three replications. Except the number of capsules per plant, the analysis of variance indicated that there was highly significant variation (p<0.01) among the genotypes in days to flower, plant height, primary branches, days to maturity, biomass yield and seed yield. The combined analysis of variance indicated that the genotype x environment interaction was highly significant (p<0.01) indicating that there is a need to know which component of the interaction is contributing to the variation. The genotype by environment interaction explained contributed to the majority (79.16%) of the variation while the genotype and environment respectively explained 19.72 and 1.12% of the total sum of squares. The variation is majorly contributed by the genotype x environment interaction than genotype indicating that there was substantial difference in genotypic response across environments. AMMI stability analysis revealed that all the four AMMI components are highly significant. The first and second principal components contributed 70.85% and 17.0% of interaction sum of squares respectively. The PCA1 and PCA2 had sum of squares greater than that of genotypes and cumulatively contributed to 87.86% of the total GEI. Based on the calculated AMMI stability value, BC-DM-9 was the most stable genotypes followed by AC-BC-6 and AC-BC-19. On the other hand, genotype AC-BC-10 was the most unstable followed by MAB-057, AC-BC-8, Local and AC-BC-4. AMMI biplot of seed yield indicated that BC-DM-11 Xereta-1, AC-BC-9 and MAB-018 expressed a highly interactive behavior while genotype 394640-539 showed low interaction and thus stable in its seed yield (kg/ha).

Keywords: Black cumin; GXEI; Stability and agronomic performance

Introduction

Black Cumin (*Nigella sativa* L.) is an annual herbaceous plant belonging to the family Ranunculacea [1]. It has been used since antiquity for culinary, seasoning, medicinal and pharmacological purposes [2]. Its seed constituents have unique chemical properties with more than one hundred different chemical components [3]. It is also a valuable source of carbohydrates, proteins, essential fatty acids, vitamins, and minerals. Because of its characteristic properties, there is an increasing demand in the domestic and international markets [1]. Black Cumin is one of the seed spices grown in Ethiopia with a great capacity in income generation at local as well as international market. Owing to this, Black Cumin is included in the crops prioritized in the agricultural strategy and specialization program of Ethiopia with a potential of fulfilling the agriculture-led industry development policy of the country. Even though the crop is with a great potential contribution in the economic development of the country, its productivity and production was too low. One of the reasons that contributed to its low production and productivity is lack of stable improved cultivar with wider adaptability in the past for it has been neglected in the research system of the country. As a result, the country was not getting the benefit that would be incurred from the genetic potential and diversity the crop had. Since 2003, however, the crop was included in the crop improvement research of the country to evaluate

the available landraces and generate improved cultivars that are stable and have wide adaptability in their performance.

Crop performance depends on the genotype and environment as well as their interaction. Thus, testing genotypes over diverse environments is universal practice to ensure the stability of performance of the genotypes [4]. Generally, genotypes that perform well over a wide range of environmental conditions are preferred [5]. This can be achieved through the evaluation of performance of genotypes across locations and years [6]. However, identification and recommendation of superior genotypes is complicated and severely limited by genotype x environment interaction [7]. The reason is that, in the presence of GEI, yield is less predictable and cannot be interpreted based on genotype and environmental means alone [8,9] for GEI confound the genotypic performance with environmental effects [5,10-12].

Several statistical models and procedures have been developed and exploited for studying the GEI effect and stability of genotypes [6,7,10,13]. One of the models is the Additive Main effect and Multiplicative Interaction (AMMI). Additive Main Effect and Multiplicative Interaction (AMMI) is the model of first choice when main effects and interaction are both important to increase accuracy [12]. It is a powerful tool for effective analysis and interpretation of multi-environment data structure in breeding programs and is useful for understanding GEI [4,6]. This method integrates analysis of variance and principal component analysis (PCA) into a united approach [13]. Plant breeders frequently apply AMMI model for

explaining GEI and analyzing the performance of genotypes and test environments [14,15].

With the intention to meet the national agricultural development policy and the specialization program, Black Cumin genotypes were under evaluation at multi-location in order to identify stable genotypes with wider adaptability and better agronomic performance. Stability in performance is one of the most desirable properties of a genotype to be released as a variety for wide cultivation [16]. Most of the works so far done on Black Cumin, however, focused on its nutritional as well as medicinal properties. Thus, the information documented on its breeding aspect is scanty. Accordingly, this paper assesses agronomic performance, genotype x environment interaction (GEI) as well as seed yield stability of Black Cumin genotypes under Bale, Southeastern Ethiopia using joint regression analysis and AMMI analysis.

Materials and Methods

Twenty genotypes of Black Cumin were evaluated across locations in a randomized complete block design with replications at Sinana, Goro and Ginir during 2011 and 2012. Sinana is located at an altitude of 2400 m.a.s.l. Sinana has a range of mean annual rainfall of 563-1018 mm with minimum and maximum temperature of 7.9°C and 24.3°C, respectively. The soil type is dark-brown with slightly acidic reaction [17]. Goro and Ginir are located at altitudinal range of 1557-2032 m.a.s.l. and 1860-2337 m.a.s.l respectively. The genotypes were sown on a plot area of 2.4 m^2 having four rows which are 30 cm apart and 2 m long. Three times hoeing, and weeding were applied without any fertilizer and chemical applications (Table 1).

Genotype/ Variety name	Origin/ Source	Genotype/ Variety name	Origin/ Source
BC-DM-11	SARC	AC-BC-15	SARC
MAB-057	,,	AC-DM-4	,,
AC-BC-19	,,	MAB-065	,,
MAB-018	,,	AC-BC-10	,,
MAB-050	,,	AC-BC-6	,,
AC-BC-7	,,	MAB-042	,,
BC-DM-9	,,	AC-BC-8	,,
AC-BC-16	,,	AC-BC-9	,,
Local	,,	AC-BC-4	,,
Darbera	,,	Xereta-1	,,

Table 1: List of studied Entries and their Origin/Source. SARC=Sinana Agricultural Research Center.

Data collection: The variables were gathered from ive plants selected randomly from the middle rows from each replication at harvest.

Days to flower: Days to flower was recorded on plot basis when 50% of the plants get flowered.

Plant height (cm): Average height in centimeter measured from ground level to the tip.

Number of capsules per plant: Average number of seed bearing capsules from the five plants.

Numbers of primary branches: Average number of primary branches from the five plants.

Days to maturity: Number of days to reach physiological maturity, on plot basis, was recorded when capsules turned brown.

Biomass yield per plant: The average biomass yield in grams, including seeds per plant, from the 5 sample plants.

Seed yield per plant (g): Average seed yield in gram from the five plants.

Data analysis

The combined analysis of variance was performed across test environments of location and years on the average of the variables using SAS version 9.2 [18]. The Additive Main Effects and Multiplicative Interactions (AMMI) statistical model and biplot were produced using Irristat software [19]. Furthermore, AMMI's stability value (ASV) was calculated in order to rank genotypes in terms of stability using the formula suggested by Purchase [20] as shown below:

$$AMMI\ stability\ Value\ (ASV) = \sqrt{\left[\frac{SSIPCA1}{SSIPCA2}(IPCA1score)\right]^2 + (IPCAscore2)^2}$$

Where, SS=Sum of squares; IPCA1=interaction principal component analysis axis 1 and IPCA2=interaction principal component analysis axis 2.

Results and Discussion

Agronomic performances

The combined analysis of variance for agronomic traits and seed yield of Black Cumin genotypes evaluated across locations were indicated in Table 2. The analysis of variance indicated that there was highly significant variation (P<0.01) among the genotypes evaluated across location with respect to days to flower, plant height (cm), number of primary branches per plant, days to maturity, biomass yield (Kg/ha) and seed yield (kg/ha). On the other hand, non-significant variation was observed among the genotypes with respect to number of capsules per plant. The seed yield ranged from 731.77 kg/ha to 1238.81 kg/ha while the overall mean seed yield recorded was 1057.31 kg/ha. The minimum (731.77 kg/ha) and maximum (1238.81 kg/ha) mean seed was produced by Xereta-1 and BC-DM-11 respectively. The overall mean seed yield produced during the 2011-2012 at Sinana, Ginir and Goro respectively was 1466.37 kg/ha, 924.05 kg/ha and 790.37 kg/ha. Lowest mean seed yield at Goro was recorded due to the shortest rainfall period prevailing at this location as a result of which much of the flowers get aborted and hence resulted in minimum yield. The reverse is true for Sinana, where the rainy season is too long for each flower of the genotypes to set fruit bearing capsules. The minimum and maximum number of days needed to flower was 84 and 93 respectively while the mean number of days to flower was 88. The maximum mean plant height (58.68 cm) was recorded by the genotype AC-BC-9 while genotype MAB-050 was the shortest (41.83) while the overall mean value of plant height was 52.78 cm. The mean primary branch per plant ranged from 3.82 to 5.14 with the overall mean record

of 4.37. The mean number of capsules per plant ranged from 10.53 to 14.44 with the overall mean value of 12.81. The overall mean number of days required to reach maturity was 146. It took 142 and 150 days respectively for the early (MAB-018) and late (AC-DM-4) maturing genotypes to mature. The overall mean biomass yield of Black Cumin genotypes was 5199.61 kg/ha. The minimum and maximum biomass recorded was 3046.2 kg/ha and 7197.5 kg/ha respectively (Table 3). Similar result was also reported by Ermias et al. regarding seed yield, plant height, days to flower and days to maturity [21]. Ali et al.[22] also reported similar result on plant height, number of capsule per plant and number of primary branches.

Mean Square								
Source	DF	Days to flower	PH	PB	CPP	DM	BY	SY
ACC	19	115.35881***	625.233***	1.569***	19.576***	78.858***	16282837***	323853.70***
LOC	2	17228.29793***	36928.448***	44.165***	221.679***	59014.259***	2547849909***	15669609.72***
Year	1	357.16560***	145.339**	1.907**	29.221**	2429.442***	25539591***	114258.28***
ACC*LOC	38	1899.29413***	120.478***	1.141***	16.513***	37.867***	15494803***	517139.35***
ACC*Year	19	285.33106***	76.845***	0.601ns	6.807ns	26.311***	2191800***	116534.07***
LOC*Year	2	177.17120***	3252.476***	0.246ns	60.648***	712.765***	35044366***	1048417.44***
ACC*LOC*Year	38	570.66213***	51.049***	0.652***	5.163ns	32.414***	2410063***	71257.26***
LOC*Year*REP	12	784.96372***	541.299***	1.323***	10.342**	350.524***	648848ns	1570.15ns
Error	228	3.42024	22.7553	0.375386	5.021629	10.1467	460033	2222.44
R2		0.98	0.95	0.72	0.640849	0.982615	0.98	0.99
CV		2.09	9.04	4.0471	17.49854	2.184317	13.04	4.46
Mean		88.33	52.77	4.36	12.81	145.83	5199.6	1057.309

Table 2: Combined analysis of variance for agronomic traits and seed yield of Black Cumin genotypes evaluated across locations in Bale, Ethiopia. NB: PH=plant height, PB=primary branch, CPP=capsules per plant, DM=days to maturity, BY=biomass yield (Kg/ha) and SY=seed yield (Kg/ha). ns, ** and ***=non-significant, significant and highly significant at 0.05 and 0.01 level of significance, respectively.

ACC	Seed yield				Agronomic Characters					
	Ginir	Goro	Sinana	Over all mean	DF	PH	PB	CPP	DM	BY (Kg/ha)
BC-DM-11	718.61	594.07	2403.75	1238.81[a]	86.94[fghi]	42.70[f]	4.68[ab]	14.16[a]	145.08[cdef]	4806.6[fghij]
AC-BC-15	984.07	1085.51	1613.15	1227.58[a]	88.08[defg]	55.80[abc]	4.34[abc]	13.92[a]	148.39[abc]	5948.2[bcd]
MAB-057	947.58	810	1810.4	1189.33[ab]	85.41[hi]	44.27[ef]	4.33[abc]	13.23[abc]	143.06[ef]	4090.2[j]
AC-DM-4	757.18	729.99	1972.29	1153.14[bc]	91.58[ab]	59.42[a]	4.23[bc]	12.57[abc]	149.53[a]	5693.4[bcdef]
AC-BC-19	1149.26	781.81	1514.28	1148.45[bc]	91.08[abc]	56.51[abc]	4.57[abc]	13.48[abc]	148.08[abcd]	5824.6[bcde]
MAB-065	721.99	861.53	1770.83	1118.12[cd]	85.83[ghi]	50.80[bcd]	4.24[bc]	13.70[ab]	143.61[ef]	3046.2[k]
MAB-018	807.04	1093.72	1430.18	1110.31[cd]	84.50[i]	44.71[edf]	4.01[bc]	10.82[bc]	141.78[f]	4522.0[hij]
AC-BC-10	1122.92	844.96	1351.35	1106.41[cde]	90.69[bc]	57.83[a]	3.92[bc]	11.88[abc]	147.16[abcde]	4976.3[efghij]
MAB-050	927.46	742.22	1622.92	1097.53[cde]	84.50[i]	41.83[f]	4.51[abc]	11.72[abc]	146.19[abcde]	4380.0[hij]
AC-BC-6	923.33	676.25	1691.24	1096.94[cde]	89.73[bcde]	54.10[abc]	4.56[abc]	12.62[abc]	145.16[bcdef]	4681.4[ghij]
AC-BC-7	1002.5	535.79	1695.94	1078.08[de]	89.97[bcd]	56.76[ab]	4.28[bc]	12.67[abc]	146.53[abcde]	6544.1[ab]
MAB-042	952.96	732.88	1517.85	1067.89[def]	85.67[ghi]	44.96[edf]	4.41[abc]	12.36[abc]	143.78[edf]	4265.5[ij]
BC-DM-9	1037.08	638.83	1520.21	1065.38	90.14bcd	57.94[a]	5.14[a]	14.44[a]	146.36[abcde]	6233.9[bc]

AC-BC-8	902.92	812.78	1471.96	1062.55^{def}	88.97^{cdef}	56.71^{abc}	3.82^c	10.53^c	146.08^{abcdf}	7197.5^a
AC-BC-16	798.61	969.31	1369.08	1045.67^{ef}	89.16^{bcdef}	56.03^{abc}	4.51^{abc}	12.16^{abc}	147.28^{abcde}	5287.8^{defgh}
AC-BC-9	1233.47	971.57	823.9	1009.65^f	87.39^{efgh}	58.68^a	4.34^{abc}	13.2^{abc}	145.61^{abcdef}	4894.8^{fghij}
Local	881.25	814.86	1081.25	925.79^g	87.42^{efgh}	50.28^{cde}	4.02^{bc}	13.02^{abc}	143.89^{edf}	5538.3^{cdef}
AC-BC-4	1013.99	502.74	1193.32	903.35^g	90.42^{bcd}	54.81^{abc}	4.37^{abc}	13.79^{ab}	144.94^{cdef}	5921.8^{bcd}
Darbera	650.24	659.9	998.19	769.44^h	93.22^a	53.34^{abc}	4.58^{abc}	13.39^{abc}	149.42^{ab}	5137.1^{fghi}
Xereta-1	948.61	948.61	475.36	731.77^h	85.92^{ghi}	58.01^a	4.58^{abc}	12.47^{abc}	144.66^{cdef}	5002.5^{efghij}
Mean	924.05	790.37	1466.37	1057.31	88.33	52.78	4.37	12.81	145.94	5199.61

Table 3: Overall means for seed yield (Kg/ha) and agronomic characters of Black Cumin genotypes grown in Bale, Ethiopia during 2011-2012. Means with the same letter are not significantly different. NB: SY=seed yield (Kg/ha), DF=days to flower, PH=plant height, PB=primary branch, CPP=capsules per plant, DM=days to maturity and BY=biomass yield (Kg/ha).

Genotype x environment interaction

The combined analysis of variance indicated that the genotype x environment interaction was highly significant indicating that there is a need to undertake stability analysis to know which component of the interaction is contributing more to the variation. The genotype by environment interaction explained the majority (79.16%) of the total sum of squares while the genotype and environment respectively explained 19.72 and 1.12% of the total sum of squares. The variation is majorly contributed by the genotype x environment interaction than genotype. The magnitude of the genotype by environment sum of squares was four times larger than that of genotypes, indicating that there was substantial difference in genotypic response across environments.

AMMI stability analysis

The pooled analysis of variance for seed yield of Black Cumin indicated that all the four AMMI components are highly significant (p<0.01) (Table 4). The first principal component contributed 70.85% of interaction sum of squares. The second principal component, on the other hand, explained 17.01% of the interaction sum of squares. The PCA1 and PCA2 had sum of squares greater than that of genotypes and cumulatively contributed to 87.86% of the total GEI.

Source	DF	SS	MS	F	Explained (%)
Genotypes	19	1963897	103363		19.72
Environments	5	111834.5	22366.9		1.12
Genotypes X Environment	95	7884211.5	82991.7		79.16
AMMI Component 1	23	5586309	242883	7.610***	70.85
AMMI Component 2	21	1341406.5	63876.5	3.406***	17.01
AMMI Component 3	19	722847.4	38044.6	5.210***	9.17
AMMI Component 4	17	208716	12277.4	7.385***	2.65
GXE Residual	15	24938.6			
Total	119	9959943			

Table 4: Pooled analysis of variance for Additive Main effect and Multiplicative Interaction (AMMI) of seed yield of Black Cumin accessions grown at Bale, South eastern Ethiopia (2011-2012).

The mean, AMMI stability value was indicated in Table 5. Based on the AMMI stability value, BC-DM-9 was the most stable genotypes followed by AC-BC-6 and AC-BC-19. On the other hand, genotype AC-BC-10 was the most unstable followed by MAB-057, AC-BC-8, Local and AC-BC-4.

AMMI											
Variety	Mean	AMMI1	AMMI2	ASV	R	Variety	Mean	AMMI1	AMMI2	ASV	R

BC-DM-11	1238.81	27.51***	7.35 ***	3.139	12	AC-BC-7	1078.08	7.59	2.87	1.469	6
AC-BC-15	1227.58	-1.42***	-10.90 ***	1.061	4	MAB-042	1067.89	1.94***	2.94	2.02	9
MAB-057	1189.33	7.70***	-2.52	6.229	19	BC-DM-9	1065.37	1.63***	1.63	0.923	1
AC-BC-19	1148.45	-.96***	6.60 ***	1.039	3	AC-BC-8	1062.55	1.06***	6.67	5.965	18
MAB-065	1118.12	8.01***	-6.43	2.366	10	AC-BC-16	1045.67	-3.41	-8.78	3.078	11
MAB-018	1110.31	-4.77***	-21.39 ***	4.686	15	AC-BC-9	1009.65	-21.64	4.61	4.642	14
AC-BC-10	1106.41	-5.39***	4.71	6.495	20	Local	9279	-9.22***	5.27	5.622	17
MAB-050	1097.53	4.68***	8.71	3.504	13	AC-BC-4	899.14	-2.98	6.3	5.202	16
AC-BC-6	1096.94	7.13	0.93	0.953	2	Darbera	769.44	-7.14***	-6.37	1.633	7
AC-DM-4	1092.8	10.87	-5.88	1.282	5	Xereta-1	731.77	-23.41 ***	6.26	1.919	8

Table 5: Summary of overall mean yield (kg/ha), Additive Main effects and Multiplicative Interaction (AMMI) and the rank (R) orders for 20 Black Cumin genotypes tested in 6 environments at Bale, southeastern Ethiopia (2011-2012).

Both genotypes and environments differed in their interaction as well as main effects for seed yield (Figure 1). Genotype 19 (Xereta-1) and genotype 20 (BC-DM-11) were the lowest and highest in their seed yield respectively. Environment F was highly productive while environment D was poor in seed yield. Genotypes 20 (BC-DM-11), 7 (MAB-057), 8 (AC-BC-10), 4(AC-DM-4), 6 (AC-BC-6), 17 (AC-BC-7), 2 (BC-DM-9), 10 (MAB-042) and 9 (AC-BC-8) interacted positively with environment C and F. On the other hand, genotypes 1 (MAB-050), 3 (AC-BC-19), 5(AC-BC-16), 7 (MAB-057), 11 (AC-BC-9), 12 (AC-BC-4), 13 (AC-BC-15), 14 (Local), 15 (MAB-018), 16 (Darbera), 18 (MAB-065) and 19 (Xereta-1) interacted negatively with environments A, B, D and E. Genotype 16 and 19 found adaptable to poor environments. On the other hand, genotypes 20 and 13 were suitable to productive environments.

AMMI biplot of seed yield of the 20 accessions tested in six environments during 2011-2012 was indicated in Figure 1. The distance from the origin (0, 0) is indicative of the amount of interaction that was exhibited by genotypes either over environments or environments over genotypes (9). Genotype 20 (BC-DM-11), 19 (Xereta-1), 11(AC-BC-9) and 15(MAB-018) expressed a highly interactive behavior (positively or negatively) while genotype 2 (394640-539) show low interaction and thus stable in its seed yield (kg/ha) as indicated in the Figures 1 and 2.
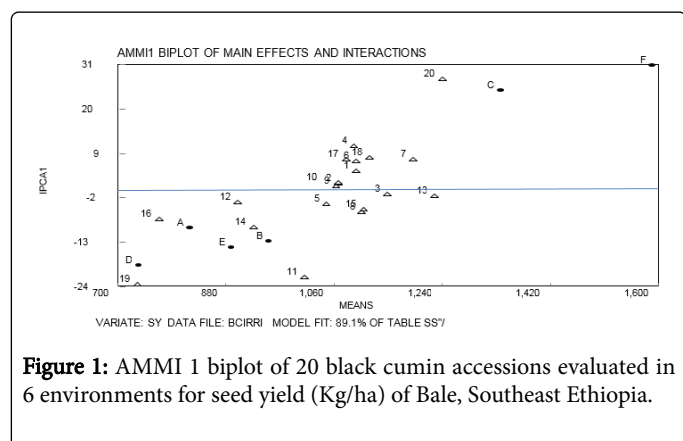

Figure 1: AMMI 1 biplot of 20 black cumin accessions evaluated in 6 environments for seed yield (Kg/ha) of Bale, Southeast Ethiopia.
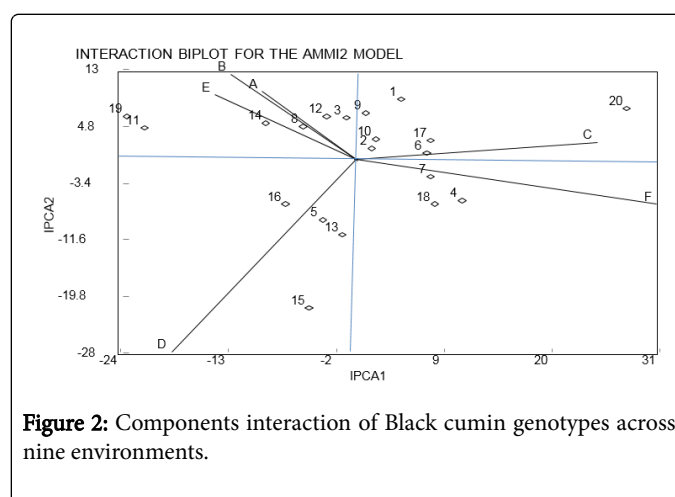

Figure 2: Components interaction of Black cumin genotypes across nine environments.

Genotypes: 1=MAB-050, 2=BC-DM-9, 3=AC-BC-19, 4=AC-DM-4, 5=AC-BC-16, 6=AC-BC-6, 7=MAB-057, 8=AC-BC-10, 9=AC-BC-8, 10=MAB-042, 11=AC-BC-9, 12=AC-BC-4, 13=AC-BC-15, 14=Local, 15=MAB-018, 16=Darbera, 17=AC-BC-7, 18=MAB-065, 19=Xereta-1 and 20=BC-DM-11.

Environments: A=ENV1, B=ENV2, C= ENV3, D=ENV4, E= ENV5 and F= ENV6.

Conclusion

The current study focused only on the agronomic performance evaluation. Thus, it is recommended to consider chemical characterization such as the fatty acids and oil content analysis in the future study. The present study indicated that the genotype showed excellent agronomic performance in the study areas implying that the areas are conducive for black cumin production. As AMMI analysis result revealed BC-DM-9 was the most stable genotypes followed by AC-BC-6 and AC-BC-19 and they can be released and used for production across locations.

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