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PARAMETERS OF AMMI MODEL TO ASSESS G×E INTERACTION OF MALT BARLEY GENOTYPES

Ajay Verma^{1*}, V Kumar, AS Kharab, GP Singh

¹ICAR-Indian Institute of Wheat & Barley Research, Karnal 132001 Haryana

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ABSTRACT

AMMI analysis of twenty three promising malt barley genotypes were evaluated at nine major locations of the country to interpret complex genotype by environment (GE) interactions. Combined analysis of variance indicated the larger and highly significant G×E interaction. Seven significant IPCA's were used to calculate AMMI based measures. Type 1 measures (EV1, ASTAB1, D1), considered G12, G8, G19, G20 as desirable genotypes and G9, G2 as of unstable performance; while type 2 (EV2, ASTAB2, D2 and ASV) considered G12, G10, G22, G15 as genotypes of choice and G9, G2 as unsuitable; type 3 (EV3, ASTAB3 and D3) pointed towards G22, G12, G23, G3 as of stable type along with G2, G9 of unstable type; type 5 measures (EV5, ASTAB5, SIPC5 and D5) selected G22, G12, G23, G3 genotypes and G2 & G9; type 7 utilized more than 97% of G×E interaction (EV7, ASTAB7, MASV and D7) identified G22, G3, G12, G6 as genotypes of recommendations and G2 & G9 were detected as the unstable genotypes. AMMI based measures recommended genotypes G12, G13, G22 and G3 had the moderate yield performance while G19 was of high yield. Association analysis among measures by multivariate hierarchical Ward's clustering approach grouped into three major clusters. Largest group clubbed as many as 16 measures while yield combined with IPCA2, and SIPC1, SIPC2, SIPC3, SIPC5, SIPC7 in second group.

* Corresponding author

E-mail: ajay.verma1@icar.gov.in (Ajay Verma)

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1 Introduction

Barley is cultivated worldwide mainly for malt and beer production (Kilic, 2014). G×E interaction governs the identification of the stable yield performer genotypes suitable for a specific environment or for several environments (Akbarpour et al., 2014). An efficient assessment of G×E interaction is very essential to determine the yield potential of genotypes along with stable yield performance (Dehghani et al., 2010). ANOVA analysis is useful to test the significance of interaction but this test fails to partition total variation into simple and cross over interactions (Flores et al., 1998). Partitioning and interpretation of G×E interaction is carried out by linear regression still this technique have inherent deficiencies for confounding of main effects (Tekdal & Kendal, 2018) as well as failure to account for non linear genotypic response (Yau, 1995). Other multiplicative model analysis based on principal component lacked to describe the additive main effects (Sabaghnia et al., 2013; Bocianowski et al., 2019a).

AMMI model (Additive main effects and multiplicative interaction model) observed as choice of researchers with emphasis on main effects and interactions both (Crossa et al., 1990; Mohammadi et al., 2015; Nowosad et al., 2018). Multi Environment trials of all crops pay same attention to efficient estimation of main and interaction effects (Kendal & Tekdal, 2016). Prime objectives of this study are application of different AMMI based measures and explore the association analysis among different measures in identifying adapted genotypes.

2 Materials and Methods

Twenty three promising malt barley genotypes were evaluated at nine major locations of the country during cropping season of 2017-2018 in field trials via randomized complete block design with four replications. Fields were prepared nicely and agronomic recommendations were followed to harvest good crop. Parentage details and environmental conditions had mentioned in table 1 for

Table 1 Parentage details of malt barley genotypes along with environmental conditions

Code	Genotype	Parentage	Code	Environments	Latitude	Longitude	Mean sea level
G 1	DWRB181	DWRUB52/DWRB77	E 1	Bawal	28 °10 ' N	76° 59 ' E	263
G 2	RD2986	DWR39/RD-2651	E 2	Durgapura	26°51 ' N	75° 47 ' E	390
G 3	KB1638	K551/NDB1295	E 3	Hisar	29°10 ' N	75° 46 ' E	215.2
G 4	DWRB183	DWR28/DWRUB52	E 4	SG Nagar	29 °90' N	73° 87' E	176
G 5	DWRB182	DWRUB52/DWRB78	E 5	Ludhiana	30° 54 ' N	75° 52' E	247
G 6	RD2988	DWRUB52/RD-2651	E 6	Bathinda	30° 21 ' N	74° 95' E	208
G 7	DWBR137	DWR28/DWRUB64	E 7	Mathura	27 ° 49' N	77° 67' E	187
G 8	DWRB160*	DWRB62/DWRB73	E 8	Pantnagar	29 °02 ' N	79° 48 ' E	237
G 9	DWRB184	DWRUB52/DWR81	E 9	Karnal	29 °43 ' N	76° 58 ' E	252
G 10	Andreia						
G 11	PL904	DWRUB64/RD2668					
G 12	RD2849 (c)	DWRUB52/PL705					
G 13	DWRB101 (c)	DWR28/BH581					
G 14	Explorer						
G 15	DWRB123 (c)	DWRUB54/DWR51					
G 16	RD2985	Clipper/RD-2668/DWR73					
G 17	BH902 (c)	BH495/RD2552					
G 18	KB1634	Lakhan/JB137					
G 19	DWRB187	RD2035/ RD2552					
G 20	ABI Voyager						
G 21	Danielle						
G 22	PL905	VJM 604/PL764					
G 23	RD2987	Clipper/EB921/RD-2668					

ready reference. More over grain yield was analyzed further to estimate the G×E interaction component by AMMI analysis. The description of widely used measures based on AMMI analysis was mentioned for completeness.

Zobel, 1994	EV1	EVF	$EV = \sum_{n=1}^N \lambda_{in}^2 / n$
Sneller et al., 1997	SIPC1	SIPCF	$SIPC = \sum_{n=1}^N \lambda_n^{0.5} \gamma_{in}$
Purchase, 1997	ASV		$ASV = \left[\frac{SSIPC}{SSIPC} \frac{1}{2} (PCI)^2 + (PC2)^2 \right]^{1/2}$
Annicchiarico, 1997	D		$D = \sqrt{\sum_{n=1}^N (\lambda_n \gamma_{in})^2}$
Rao & Prabhakaran, 2005	ASTAB		$ASTAB = \sum_{n=1}^n \lambda_n \gamma_{ni}^2$
Zali et al., 2012	MASV		$MASV = \sqrt{\sum_{n=1}^{N-1} \frac{SSIPC_n}{SSIPC_{n+1}} (PC_n)^2 + (PC_{n+1})^2}$

EV1 = EV for first IPCA; EVF = EV for seven IPCA & SIPC1 = SIPC for first IPCA, SIPC 2 = SIPC for first two IPCAs

AMMI model computations were performed by software MATMODEL version 3.0 (Gauch, 2007) and SAS software version 9.3.

3 Results and Discussion

The combined analysis of variance (ANOVA) showed highly significant differences between the genotypes (G), which supported the considerable variability with respect to grain yield in this study (Table 2). Significant differences were also observed among the environments (E). AMMI analysis of variance showed that environments, genotypes and G×E interaction effects accounted for 58%, 12% and 22.5% of the total variation, respectively. Variance explained by the G×E interaction effect was nearly two times that of genotype effects. This was further divided into seven significant interaction principal component axes (IPCA's). First four IPCA's contributed more than 80%. IPCA1 explained 31.1% of the variation affected by interaction, while IPCA2, IPCA3 and IPCA4 accounted for 22.7, 16.7 and 10.6%, respectively. Since the main effect of genotypes on grain yield was highly significant, mean yield was considered as the first parameter for assessing the yield potential of genotypes. In this respect, G7, G9, G19, G17 and G5 had the highest and genotypes G21, G14 and G10 had the lowest average yields across 09 environments.

Large magnitude of G×E interactions for yield found in this investigation are similar to those found in other crops (Sabaghnia et al., 2012; Mortazavian et al., 2014). The high significance of GE interactions is indicating the studied genotypes exhibited both crossover and non-crossover types of GE interaction. Total G×E (35116.26) was partitioned into G×E noise (3073.76) that is

Table 2 AMMI analysis of malt barley genotypes

Source	df	MS	Level of significance	% of Total SS	% of G×E SS	Cumulative % SS by PCA's
Treatments	206	704.6512	***	93.05		
Genotypes	22	888.6938	***	12.53		
Environments	8	11311.33	***	58.01		
G×E	176	199.5242	***	22.51		
IPC1	29	376.2301	***		31.07	31.07
IPC2	27	294.8774	***		22.67	53.74
IPC3	25	234.49	***		16.69	70.44
IPC4	23	161.5521	***		10.58	81.02
IPC5	21	135.5105	***		8.10	89.12
IPC6	19	89.42937	***		4.84	93.96
IPC7	17	82.85984	***		4.01	97.97
Residual	15	47.4968	***			
Error	621	17.46457				
Total	827	188.638				

8.75% and G×E signal (32042.49) of 91.25%. AMMI derived measures based on the use of significant IPCA's were calculated as EV1, ASTAB1, SIPC1, D1 measures (only first significant IPCA), while ASV, EV2, ASTAB2, SIPC2, D2 considered IPCA1 & IPCA2 both, measures EV3, ASTAB3, SIPC3 and D3 used three IPCAs, EV5, ASTAB5, SIPC5 & D5 (based on five IPCAs), whereas measures EV7, ASTAB7, SIPC7 and D7 utilized all significant IPCAs.

Explained variation of G×E interaction accounted by each of IPCA exploited by defined measures, as type-1 measures benefited 31.07%, type-2 measures utilized 53.74%, type 3 measures used up to 70.44%, type 5 measures benefited up to 89.1%, while type 7 measures accounted for most of variation and utilized to the extent of benefits 97.9% (Table 2). This justifies the

use of AMMI derived parameters based on the larger numbers of IPCAs results in the most usage of G×E interaction variations.

Minimum and maximum values of EV1 observed for G12, G8, G20, G19 and G9, G2 while corresponding to D1 were G12, G8, G20, G19 and G9, G2 absolute values of ASTAB1 for G12, G8, G20, G19 and G9, G2 and for SIPC1 were G17, G14, G21, G6 & G9, G2, genotypes G7, G9, G19, G17 were of high yield and G21, G14 of low yield performance (Tables 3 & 4).

Genotypes EV2 pointed towards G12, G10, G22 & G15 as desirable at the same time undesirable genotypes (G9, G2), for values of D2 genotypes were G12, G10, G22, G15 & G9, G2, whereas as per criterion of SIPC2 were G6, G14, G19, G16) & G9, G4 and of ASTAB2 were G12, G10, G22, G15 & G9, G2

Table 3 Principal components analysis of malt barley genotypes

		Yield	IPCA 1	IPCA 2	IPCA 3	IPCA 4	IPCA 5	IPCA 6	IPCA 7	ASV	MASV
G 1	DWRB181	47.94	1.2854	0.8653	-0.5628	-0.3128	1.5982	-0.1224	0.2926	1.74	3.47
G 2	RD2986	47.36	3.0039	-1.4643	2.5807	0.9765	-0.7550	-0.5527	-0.7724	3.81	6.29
G 3	KB1638	48.44	-1.4427	0.3568	0.4008	-0.7619	0.8400	0.7669	1.0419	1.73	3.03
G 4	DWRB183	49.89	1.1253	1.9575	-0.0542	-0.1159	0.5759	0.6493	-0.7277	2.36	3.63
G 5	DWRB182	52.39	1.8720	-0.0352	-2.8564	0.1709	0.6254	1.4882	-0.6779	2.19	5.68
G 6	RD2988	42.33	-1.7043	-1.7110	-1.0213	1.7796	-1.7807	0.8318	0.3624	2.63	5.57
G 7	DWBR137	58.86	-0.7372	2.0129	-0.7513	-1.2641	-0.3383	-2.1201	0.9557	2.19	5.16
G 8	DWRB160*	52.17	-0.2517	2.1653	-1.6704	0.2797	-1.8901	-0.9560	-0.5142	2.19	5.51
G 9	DWRB184	55.89	3.6077	0.2804	-0.4140	0.0493	-1.1730	-0.9440	0.0440	4.23	4.91
G 10	Andreia	42.06	0.8325	-0.4839	1.5361	-3.0298	-0.1470	0.5405	-0.2680	1.09	5.43
G 11	PL904	45.64	1.1752	1.8465	1.6417	0.7087	-0.5830	1.2382	0.8821	2.30	4.81
G 12	RD2849 (c)	49.61	0.0146	0.5695	0.3343	0.9487	0.9424	0.6381	-2.0675	0.57	3.27
G 13	DWRB101 (c)	51.64	-1.1996	-0.6031	0.5299	1.1783	1.9515	-0.4832	-0.3605	1.53	4.19
G 14	Explorer	41.22	-1.8659	-1.1477	-0.3131	-1.0421	0.2506	-0.3066	-1.5544	2.47	3.66
G 15	DWRB123 (c)	50.14	-0.6921	-0.9681	1.2982	0.0220	1.6458	-1.3177	0.1152	1.26	4.28
G 16	RD2985	47.47	-1.1497	-0.8806	0.9640	1.7789	-1.2227	-1.3075	-0.1385	1.61	4.60
G 17	BH902 (c)	54.17	-1.9871	2.1003	0.2214	0.8491	0.2077	0.3033	-0.6879	3.13	4.29
G 18	KB1634	53.83	-0.6737	1.1680	1.7332	0.7157	0.3759	0.5201	1.6729	1.41	4.07
G 19	DWRB187	55.14	0.5322	-1.3341	-2.5779	0.8436	1.2020	-0.7114	0.9174	1.47	5.40
G 20	ABI Voyager	43.25	0.3041	-3.0918	-0.2031	-1.0428	-0.2507	0.0654	0.1875	3.11	5.05
G 21	Danielle	40.83	-1.8094	0.1373	-0.0162	-2.0856	-1.3070	0.0342	-0.7561	2.12	4.44
G 22	PL905	49.08	0.6852	-0.8120	-0.7115	-0.5930	0.2742	-0.0411	1.3160	1.14	2.50
G 23	RD2987	45.97	-0.9247	-0.9280	-0.0882	-0.0529	-1.0421	1.7867	0.7368	1.43	3.70

IPCA, principal component of interaction, ASV = AMMI stability value, MASV = Modified AMMI Stability value

Table 4 AMMI based estimates of malt barley genotypes

	EV1	EV2	EV3	EV5	EV7	D1	D2	D3	D5	D7
DWRB181	0.0158	0.0121	0.0094	0.0156	0.0115	13.14	15.47	16.24	20.14	20.17
RD2986	0.0864	0.0552	0.0658	0.0447	0.0353	30.70	33.67	40.54	41.62	41.82
KB1638	0.0199	0.0107	0.0078	0.0092	0.0128	14.74	15.13	15.53	17.72	18.57
DWRB183	0.0121	0.0275	0.0184	0.0123	0.0123	11.50	21.78	21.79	22.21	22.67
DWRB182	0.0336	0.0168	0.0467	0.0296	0.0306	19.13	19.14	31.48	31.83	33.28
RD2988	0.0278	0.0303	0.0247	0.0371	0.0294	17.42	23.77	25.39	31.73	32.19
DWBR137	0.0052	0.0253	0.0193	0.0173	0.0314	7.53	20.46	21.49	23.78	27.50
DWRB160*	0.0006	0.0266	0.0299	0.0316	0.0267	2.57	20.62	25.28	28.88	29.55
DWRB184	0.1246	0.0627	0.0426	0.0307	0.0250	36.87	36.97	37.14	38.12	38.60
Andreia	0.0066	0.0046	0.0134	0.0382	0.0286	8.51	9.66	16.55	28.90	29.11
PL904	0.0132	0.0257	0.0289	0.0202	0.0227	12.01	21.18	25.59	26.53	27.78
RD2849 (c)	0.0000	0.0018	0.0017	0.0073	0.0229	0.15	5.38	6.13	11.82	13.52
DWRB101 (c)	0.0138	0.0089	0.0072	0.0231	0.0178	12.26	13.52	14.29	22.18	22.41
Explorer	0.0333	0.0240	0.0165	0.0137	0.0193	19.07	21.94	22.11	23.63	24.02
DWRB123 (c)	0.0046	0.0075	0.0124	0.0176	0.0186	7.07	11.56	16.21	20.18	21.88
RD2985	0.0127	0.0107	0.0112	0.0227	0.0222	11.75	14.40	16.69	23.48	24.93
BH902 (c)	0.0378	0.0436	0.0293	0.0201	0.0165	20.31	28.40	28.46	29.26	29.38
KB1634	0.0043	0.0098	0.0196	0.0140	0.0216	6.89	13.01	19.98	20.93	21.59
DWRB187	0.0027	0.0113	0.0365	0.0296	0.0261	5.44	13.73	26.41	28.60	29.05
ABI Voyager	0.0009	0.0540	0.0362	0.0255	0.0184	3.11	29.38	29.44	30.60	30.60
Danielle	0.0313	0.0158	0.0105	0.0270	0.0215	18.49	18.54	18.54	26.46	26.52
PL905	0.0045	0.0059	0.0062	0.0051	0.0103	7.00	10.39	12.11	13.12	13.52
RD2987	0.0082	0.0089	0.0060	0.0077	0.0186	9.45	12.89	12.92	15.00	18.97

EV = Eigenvector, AMGE = Sum across environments of GEI, SIPC = Sum of the value of the IPC Scores, D = Parameter of Annicchiarico

(Tables 4 and 5). In recent studies, agronomic concept of stability would be more preferred instead of static concept of stability (Karimizadeh et al., 2016). Using first two IPCAs in stability analysis could benefits dynamic concept of stability in identification of the stable high yielder genotypes.

ASV recommended G12, G10, G22 & G15 as of stable performance and unsuitable were G9, G2 (Table 3). Considering first two IPCAs in ASV measure used 53.7% of G×E interaction. The two IPCAs have different values and meanings and the ASV parameter using the Pythagoras theorem and to get estimated values between IPCA1 and IPCA2 scores to produce a balanced measure between the two IPCA scores (Purchase, 1997). Also, ASV parameter of this investigation used advantages of cross

validation due to computation from first two IPCAs. Results put forward by ASV measure have many similarities with the other AMMI stability parameters which calculated from the first two IPCAs scores (Carlos & Krzanowski, 2006).

Minimum values EV3 preferred G12, G23, G22, G13 as well of unstable performance of G2, G5 while SIPC3 pointed towards G6, G19, G14, G20 and G11, G2 whereas D3 for G12, G22, G23, G13 & G2, G9; ASTAB3 measure considered G12, G22, G23, G13 & G2, G9 (Table 4). G22, G12, G23, G3 preferred by least values EV5 and maximum values found for G2, G10, measure SIPC5 identified G21, G6, G20, G14 and G11, G2 whereas D5 considered G12, G22, G23, G3 as suitable & G2, G9 as unsuitable ones; ASTAB5 selected G12, G22, G23, G3 as suitable & G2, G9 as unsuitable genotypes.

Table 5 Further AMMI based estimates for GxE interaction analysis

	SIPC1	SIPC2	SIPC3	SIPC5	SIPC7	ASTAB1	ASTAB2	ASTAB3	ASTAB5	ASTAB7
DWRB181	1.29	2.15	1.59	2.87	3.04	16.89	23.96	26.74	46.15	46.77
RD2986	3.00	1.54	4.12	4.34	3.02	92.22	112.48	170.76	182.36	187.98
KB1638	-1.44	-1.09	-0.69	-0.61	1.20	21.27	22.47	23.88	33.56	44.00
DWRB183	1.13	3.08	3.03	3.49	3.41	12.94	49.15	49.18	51.70	57.65
DWRB182	1.87	1.84	-1.02	-0.22	0.59	35.82	35.83	107.22	110.30	127.34
RD2988	-1.70	-3.42	-4.44	-4.44	-3.24	29.69	57.35	66.48	114.36	119.61
DWBR137	-0.74	1.28	0.52	-1.08	-2.24	5.55	43.84	48.78	62.10	96.55
DWRB160*	-0.25	1.91	0.24	-1.37	-2.84	0.65	44.95	69.37	96.06	103.54
DWRB184	3.61	3.89	3.47	2.35	1.45	133.02	133.76	135.26	145.33	151.06
Andreia	0.83	0.35	1.88	-1.29	-1.02	7.08	9.30	29.94	101.80	104.11
PL904	1.18	3.02	4.66	4.79	6.91	14.11	46.33	69.92	76.32	90.93
RD2849 (c)	0.01	0.58	0.92	2.81	1.38	0.00	3.07	4.04	17.56	46.37
DWRB101 (c)	-1.20	-1.80	-1.27	1.86	1.01	14.71	18.15	20.60	59.25	61.54
Explorer	-1.87	-3.01	-3.33	-4.12	-5.98	35.58	48.03	48.88	57.82	73.24
DWRB123 (c)	-0.69	-1.66	-0.36	1.31	0.10	4.90	13.75	28.50	48.28	59.51
RD2985	-1.15	-2.03	-1.07	-0.51	-1.96	13.51	20.84	28.97	64.60	75.69
BH902 (c)	-1.99	0.11	0.33	1.39	1.01	40.35	82.04	82.47	88.41	91.91
KB1634	-0.67	0.49	2.23	3.32	5.51	4.64	17.53	43.82	48.85	67.74
DWRB187	0.53	-0.80	-3.38	-1.33	-1.13	2.89	19.71	77.86	93.97	102.37
ABI Voyager	0.30	-2.79	-2.99	-4.28	-4.03	0.95	91.28	91.64	100.59	100.83
Danielle	-1.81	-1.67	-1.69	-5.08	-5.80	33.46	33.64	33.64	80.08	83.59
PL905	0.69	-0.13	-0.84	-1.16	0.12	4.80	11.03	15.46	18.75	29.38
RD2987	-0.92	-1.85	-1.94	-3.04	-0.51	8.74	16.88	16.95	24.90	48.72

SIPC1 = SIPC for first IPCA, SIPC 2 = SIPC for first two IPCAs, ... for

According to D7 minimum values G12, G22, G3, and G23 were genotypes of stable yield while G2 and G9 as undesirable; SIPC7 observed G14, G21, G20, G6 as of stable & G11, G18 of unstable yield (Tables 4 and 5). EV7 pointed towards G22, G1, G5, G4 & G2, G7. Measure ASTAB7 identified G22, G3, G12, G1 as desirable and G2, G9 for unstable behavior over the studied environments. Composite measure MASV selected G22, G3, G12, G1 as of stable performance and G2, G5 not recommended for cultivation due to unstable yield behavior.

Finally type 1 of AMMI measures (EV1, ASTAB1, D1), considered G12, G8, G19, G20 as desirable genotypes and G9, G2 as of unstable performance; based on the type 2 (EV2, ASTAB2, D2 and ASV) G12, G10, G22, G15 were genotypes of choice and

G9, G2 as unsuitable; as per type 3 (EV3, ASTAB3 and D3), G22, G12, G23, G3 were stable genotypes and G2, G9 of unstable type; according to the type 5 of AMMI parameters (EV5, ASTAB5, SIPC5 and D5), genotypes G22, G12, G23, G3 and G2 & G9; lastly based on the type 7 (EV7, ASTAB7, MASV and D7), genotypes G22, G3, G12, G6 and G2 & G9 were detected as the unstable genotypes. Considering all of the AMMI based measures, only genotypes G12, G13, G22 and G3 had the moderate yield performance while G19 was of high yield.

To better understand the relationship among the AMMI based estimates along with yield, principal component analysis (PCA) was performed. The relationship among these estimates is graphically displayed in a plot of PC1 versus PC2. AMMI based measures along with yield could be divided into three major

Figure 1 Biplot representation of AMMI based estimates

clusters (Figure 1). Largest group I clubbed 16 measures as ASV, MASV, D1, D2, D3, D5, D7, with EV1, EV2, EV3, EV5, EV7, as well as ASTAB2, ASTAB3, ASTAB1, ASTAB7. Group II contains yield with IPCA2, and SIPC1, SIPC2, SIPC3, SIPC5, SIPC7, whereas IPCA5 was lying far away. Group III contains IPCA3, IPCA4, IPCA6, IPCA7 whereas SIPC1 and IPCA1 were observed as outliers.

Each of the AMMI stability parameters relates to a different concept of yield stability and may be useful to plant breeders attempting to select genotypes with high, stable and predictable yield across environments (Mohammadi et al., 2015). However, it seems that there is no need to consider all of these measures simultaneously, and a few of them should be used in as per maximum usage of G×E interaction sum of squares. AMMI analysis has been observed as useful for exploring complex G×E interaction, improving selections and increasing experimental efficiency (Sabaghnia et al 2013; Bocianowski et al., 2019b).

Conflict of interests

There is no conflict of interest.

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