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Soybean (*Glycine max* L) Genotype and Environment Interaction Effect on Yield and Other Related Traits

Tony Ngalamu[1*], Muhammad Ashraf[1] and Silvestro Meseka[2]

[1]Department of Agricultural Sciences, College of Natural Resources and Environmental Studies, University of Juba, P.O. Box 82, Juba, South Sudan.
[2]International Institutes of Tropical Agriculture, PMB 5320, Oyo Road, Ibadan, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author TN designed the study, laid out the experiment, compiled the study results, and wrote the protocol, first and final draft of the manuscript. Author MA was the main supervisor of the study. Author SM (the co-supervisor) helped the corresponding author from the inception of the study, performed the statistical analysis and also did proof read and restructured the first draft of the manuscript. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Aims: To evaluate genetic variability of five soybean genotypes, and assess genotype × environment effect on seed yield and yield related traits.
Study Design: Split-plot, replicated three times. Genotypes were fixed effect while plots (main 60 m² and subplot 12 m²) were random effects. The sub-plot consists of 4 rows 5 m long with 60 cm and 10 cm inter and intra-row spacing.
Place and Duration: El Gantra, Range and Pasture Farm in Sennar State of the Sudan during 2009 and 2010 cropping season.
Methodology: Five soybean genotypes NA 5009 RG; TGx 1904-6F, TGx 1740-2F, TGx 1937-1F and Soja were evaluated. A strain of *Rhizobium japonicum* was used for inoculation at a rate of 10 g per kg of soybean seed using a sugary solution in 2009. Inoculation was not carried out due to the assumption that the field had the remnant of inoculum effect in 2010. All the recommended soybean agronomic practices were equally applied. Number of days to 50% flowering was recorded on plot basis when almost half of the sub-plot flowers. Ten plants were randomly selected on plot basis to quantify these traits: Plant height was measured as from ground surface to the base of meri-stem of the mother plant. Number of branches was computed as an average count of branches per plant. Leaf area was computed using Iamauti [12] empirical relationship. The first pod height was measured at full bloom. Number of seeds per pod was counted at physiological

**Corresponding author: Email: lingarigwa@yahoo.co.uk;*

maturity of the crop. 100-seed weight was determined randomly from a seed bulk using a digital weighing machine. Seed yield was quantified after harvest and converted into kg/hectare.
Results: The effect of genotype (G), environment (E) and G × E interactions on pod number per plant; plant height, first pod height, number of branches per plant, leaf area, number of days to 50% flowering and seed yield were found significant at P=0.05. The highest mean seed yield was obtained from TGx 1937-1F (0.98 t/ha). Beside TGx 1740-2F, TGx 1904-6F and Soja were significantly higher than NA 5009 RG in all environments for seed yield. TGx 1937-1F was an intermediate maturing and best in terms of number of pods per plant, number of branches per plant, and leaf area. Correlation coefficient for seed yield showed significant association with days to 50% flowering and leaf area.
Conclusion: The best genotype for seed yield across the environments was TGx 1937-1F and TGx 1740-2F, TGx1904-6F and Soja were intermediate and NA 5009 RG was the least. Thus, partitioning G × E into adaptability and phenotypic stability will positively address the information gap on association of traits to yield.

Keywords: Soybean; genotype (g) × environment (e) interaction; genetic variability and yield.

1. INTRODUCTION

Soybean (*Glycine max* L) is one of the oldest world grown crops. It contains 20 to 22% essential amino acids, 40% protein and 18–22% oil of which 85% is cholesterol free [3,18]. The crop is an important legume with multifarious uses. Its cost effectiveness is ensured through biological nitrogen fixation and rotation with exhaustive crops. It replenishes and maintains soil fertility.

In the Sudan, soybean trials started as early as 1925 at Gezira Research Farm where a low yield of 500 kg/ha was obtained. This low yield was attributed to lack of cultivars adaptable to the Sudan agro-ecological conditions. Thus, researchers at the stations were reluctant to work on soybean. Nevertheless, in early 1980’s several attempts were made, one at Agadi Experimental Farm where a yield of 500–1000 kg/ha was obtained [8]. Furthermore, he reported that in Damazin an area of 1260 hectares was used for commercial production, but the crop failed to meet the desired objective of the project. Lack of adaptable cultivar to the Sudan agro-ecological conditions has enormously contributed into the existing information gap on association of traits with seed yield. This association is of great importance to define selection criteria for yield improvement.

Seed yield is a complex trait determined by several traits having positive or negative effects on yield. As such, it is important to examine the contribution of each of the traits in order to give more attention to those having the greatest influence on seed yield. According to Soldati [24] the expression of the traits is determined by genetic and environmental factors and their interaction. Therefore, to determine both qualitative and quantitative traits variability caused by genetic, environmental and genotype × environment interaction under Sudan agro-ecological condition; the current study was undertaken to:

i. Evaluate the genetic and environmental variability of the genotypes and
ii. Assess the genotype × environment effect on yield and other related traits

2. MATERIALS AND METHODS

Five soybean genotypes namely: TGx 1740-2F, TGx 1904-6F and TGx 1937-1F, obtained from International Institute of Tropical Agriculture (IITA) Nigeria and NA 5009 RG and Soja from ORNAS Company in Khartoum, were studied under five different sowing dates over two years at El – Gantra, in Range and Pasture Farm of Sennar State. Sennar State lies between latitude 14°24' N and longitude 33°29' E. The soi l is best described as heavy clay (60%) with low organic content of 0.5%, 0.05% nitrogen, and 2.8 mg/kg available phosphorus with a pH of 8.2. The land was disc ploughed, levelled and ridged before sowing. The site was pre-irrigated three days prior to experimentation.

The design of the study was Split-plot replicated three times. Planting dates: 10th August; 24th August; 7th September; 28th September and 12th October in 2009; 12th July; 26th July; 9th August; 23rd August and 6th September in 2010 were the main plot factor and genotype was a subplot. The sizes of the main and subplots were 12 m × 5 m and 2.4 m × 5 m. These subplots consisted of 4 rows 5 m long with 60 cm and 10 cm inter and intra-row spacing. In addition, all soybean cultural practices were equally applied across the five sowing dates over two years. Two seeds were planted per hill on the ridged then thinned to one after three weeks. The seed was inoculated once in 2009 with *Rhizobium japonicum* strain at a rate of 10 g per 1 kg of soybean seed using a sugary solution of 250 g sugar per liter of water to ensure the sticking of the strain on the seed surface to initiate nodulation upon establishment. The experiment was repeated in the same site without further inoculation in 2010 because it was assumed to have remnant of inoculum effect. Number of days to 50% flowering was recorded on plot basis when almost half of the sub-plot had flowered. Each of the 75 sub-plots had a plant count of 200 plants. Ten plants were randomly selected on sub-plot basis to quantify these traits. Plant height was measured as from ground surface to the base of meri-stem of the mother plant. Number of branches was computed as the average count of branches per plant. Leaf area was computed using Iamauti [12] empirical relationship. The first pod height was measured at full bloom. Number of seeds per pod was counted at physiological maturity of the crop. 100-seed weight was determined randomly from a seed bulk using a digital weighing machine. Seed yield was quantified after harvest and converted into kg/hectare.

All data collected were subjected to Statistical Analysis System [23] package for computing analysis of variance (ANOVA) and mean performance of genotypes were compared using Duncan's Multiple Range Test (DMRT) by Ashraf [2]. In ANOVA, each sowing date in year was considered as an environment. Genotype was considered as a fix effect while plots (main and sub-plots), and replications as random effects. Correlation coefficient analysis was estimated using (Pearson’s simple correlation) according to Fishers’ significance test using SAS [23] package.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Combined analysis of variance for agronomic and yield traits

Combined ANOVA for soybean seed yield and agronomic traits across the two years [2009 and 2010] obtained from this study are presented on (Table 1). Almost all traits showed significant interactions between genotype × year except for first pod height, number of seeds per pod and 100-seed weight, but G × S had significant differences at (P=0.05) for all traits with exception of first pod height, number of branches per plant, number of seeds per pod, 100-seed weight (Table 1).

The mean seed yield of the genotypes across the ten environments, showed that the first sowing dates (environment) in both 2009 and 2010 had the highest yield (1.19 t/ha) and (1.03 t/ha) and the fifth environment in both seasons registered the lowest seed yield of 0.30 t/ha and 0.32 t/ha respectively. Similar trend was observed in relation to 100-seed weight with heaviest 100-seed weight in 10th August 2009 and 12th July 2010 (Table 2).

The mean performance of the genotypes across the environments showed that TGx 1937-1F had the highest number of branches per plant (4.6) and NA 5009 RG registered the lowest (2.0). NA 5009 RG had the heaviest 100-seed weight (14.10 g) and TGx 1904-6F had the lightest (12.60 g). TGx 1937-1F had the highest number of pods per plant (61.8) and NA 5009 RG was the least (24.9). Soja had the highest number of seeds per pod (2.2) and NA 5009 RG was the lowest (2.0). TGx 1937-1F was best performer (0.98 t/ha) and NA 5009 RG was the lowest yielder (0.48 t/ha) across ten environments (Table 3). In addition the mean value of the traits across were: plant height (30.0 cm), first pod height (5.6 cm), number of branches (3.1), number of pods per plant (43.0), number of seeds per pod (2.1), leaf area (99.7 cm^2), days to 50% flowering (35.4), 100-seed weight (13.4 g) and seed yield (0.74 t/ha). Hence, the compared mean of the traits across the five sowing dates over two years revealed that all traits of the genotypes responded differently and this signified TGx 1937-1F performance (Table 3).

3.1.2 Correlation coefficients

Correlation coefficient measured among traits presented on (Table 4) showed that plant height had significant correlation with number of seeds per pod and non-significant correlation with all the other traits. First pod height was positively associated with 100-seed weight and negatively associated with leaf area, number of pods per plant, number of branches per plant and seed yield. It was non-significantly correlated with number of days to 50% flowering, number of seeds per plant and plant height. The number of branches per plant was significantly correlated with number of days to 50% flowering, leaf area and number of pods per plant. It had a negative correlation with first pod height, 100-seed weight and number of seeds per pod. This trait showed a non-significant correlation with plant height and seed yield. Leaf area had strong association with number of pods per plant, number of branches per plant, 100-seed weight, and number of days to 50% flowering. It was negatively correlated with number of seeds per pod and had non-significant correlation first pod height and plant height.

Number of days to 50% flowering had a strong association with leaf area, number of pods per plant, number of branches per plant and seed yield and negatively correlated with number of seeds per pod. This trait was non-significantly correlated to first pod height and plant height. Number of pods per plant showed significant correlation with number of branches per plant, 100-seed weight, number of days to 50% flowering and leaf area. It had a negative correlation with first pod height and number of seeds per pod. The trait showed non-significant correlation with plant height and seed yield. Number of seeds per pod showed a significant correlation with plant height and had negative correlation with number of days to 50% flowering, leaf area, number of pods per plant. The trait had non-significant correlation with first pod height, 100-seed weight and seed yield.

The correlation coefficient for 100-seed weight showed strong association with leaf area, number of pods per plant, and first pod height. It also had negative correlation with number of branches per plant. 100-seed weight also registered non-significant correlation with number of days to 50% flowering, plant height and number of seeds per pod. Seed yield was highly significant and positively correlated with leaf area and days to 50% flowering and negatively correlated with first pod height. The trait also revealed non-significant correlation with 100-seed weight, number of seeds per plant, number of pods per plant, number of branches per plant and plant (Table 4).

Table 1. Mean square values of combined analysis of variance of five genotypes across sowing dates averaged over two years

Source of variation	DF	Plht (cm)	1stpdht (cm)	Branchpp (no.)	Podpp (no.)	Seedppd (no.)	Larea (cm²)	Dflower (day)	Tswgt (g)	Seedyld (t/ha)
Replication (R)	2	0.1	3.9	0.07	169.6	0.02	368.5	5.6	2.0	0.03
Sowing date (S)	4	734.8**	6.5**	14.56**	3334.3**	0.11 *ns*	5929.0**	174.1**	7.9 *ns*	3.59*
Year (Y)	1	1143.4**	72.8**	60.42**	9964.0**	1.13**	53069.0**	0.1 *ns*	988.2**	0.39 *ns*
S × Y	4	66.1**	14.1*	3.45**	529.8**	0.04 *ns*	4784.0**	34.8**	10.1 *ns*	0.15 *ns*
R × Y × S	18	8.9 *ns*	5.7**	0.52 *ns*	44.9 *ns*	0.04 *ns*	260.4 *ns*	5.6 *ns*	4.8 *ns*	0.16 *ns*
Genotype (G)	4	1591.0**	28.0**	38.64**	7435.4**	0.09 *ns*	22246.5**	917.9**	23.7 *ns*	0.93**
G × Y	4	177.9**	1.3 *ns*	2.7**	634.1**	0.05 *ns*	830.2**	61.0**	6.9 *ns*	1.42*
G × S	16	16.9 *ns*	1.1 *ns*	0.68 *ns*	318.33**	0.07 *ns*	545.0**	34.6**	9.6 *ns*	0.11 *ns*
G × Y × S	16	45.7**	2.1 *ns*	1.34**	194.1**	0.06 *ns*	676.1**	29.8**	17.1 *ns*	0.29**
Pooled error	80	12.8	1.5	0.47	58.8	0.04	182.8	5.6	10.0	0.11

***: Significant at P≤0.01 level, *: Significant at P≤0.05 level and ns: Not Significant*

Table 2. Mean of 100 seed weight and seed yield (t/ha) of various sowing dates along with their significance ranking (DMR) in 2009 and 2010 seasons

Code	Planting date (PD)	100-seed weight (g)			Seed yield (t/ha)		
		1st Season	2nd Season	Mean	1st Season	2nd Season	Mean
PD1	10th August 2009 and 12th July 2010	**11a**	16.6b	13.8	**1.19a**	**1.03a**	1.1
PD2	24th August 2009 and 26th July 2010	10.7b	**17.07a**	13.9	0.77b	0.93b	0.9
PD3	7th September 2009 and 9th August 2010	10.7b	16.6b	13.7	0.70b	0.56c	0.6
PD4	28th September 2009 and 23rd August 2010	10.9b	14.8c	12.9	0.50c	0.46d	0.5
PD5	12th October 2009 and 6th September 2010	10.9b	14.8c	12.9	0.30d	0.32df	0.3
C.V.		20.4	24.36		53.62	35.8	
S.E.		2.2	3.89		0.37	0.28	
Genotype x sowing date		Ns	ns		*	ns	

Means followed by the same letters do not differ significantly

Table 3. Performance of five soybean genotypes across five sowing dates average over two years

Genotype	Plht (cm)	1stpdht (cm)	Branches (no.)	Podpp (no.)	Seed ppd (no.)	Larea (cm²)	Dflower (day)	Tswgt (g)	Seed yield (t/ha)
NA5009 RG	21.0d	4.1c	2.0c	24.9d	2.0a	68.7d	27.7d	14.10a	0.48c
TGx 1740-2F	40.3a	6.8a	3.3b	50.8b	2.1a	90.8c	37.7b	12.77b	0.76b
Soja	33.4b	6.0a	2.0c	28.4c	2.2a	84.0cd	31.4c	14.60a	0.74b
TGx 1937-1F	28.6bc	5.5b	4.6a	61.8a	2.1a	135.5a	40.0a	12.97b	0.98a
TGx 1904-6F	26.9c	5.5b	3.7b	49.2b	2.1a	119.7b	40.0a	12.60b	0.74b
C.V	11.9	22.1	22.0	17.8	9.6	13.6	6.7	23.61	44.49
S.E.	3.6	1.2	0.7	7.7	0.2	13.5	1.6	3.17	0.33
Mean	30.0	5.6	3.1	43.0	2.1	99.7	35.4	13.41	0.74

Means followed by the same letters do not differ significantly

Table 4. Correlation coefficients among measured traits of five soybean genotypes across five sowing dates averaged 2009 and 2010

	SEEDYLD	TSWG	DFL	LA	# Seed/Pd	# Pods/P	#Br/P	FPdht	Plht
SEEDYLD	1.0								
TSWG	0.11	1.0							
LA	0.45**	0.61**	0.66**	1.0					
# Seed/Pod	0.21	0.22	-0.28	-0.03	1.0				
# Pods/P	0.23	0.55**	0.71**	0.79**	-0.1	1.0			
# Br/P	0.05	-0.22	0.55**	0.74**	-0.14	0.85**	1.0		
FPdht	-0.02	0.47**	0.02	-0.35	0.34	-0.23	-0.35	1.0	
Plht	0.33	0.16	0.09	0.16	0.44*	0.32	0.18	0.19	1.0

***: Significant at P≤0.01 level *: Significant at P≤0.05 level ns: Not Significant*

***Key:-Plht**: Plant height, FPdht: First pod height, # Br/P: Number of branches/plant, # Pods/P: Number of pods/plant, #Seed/Pd: Number of seeds/pod, LA: Leaf area, DFL: Days to 50% flowering, TSWG: 100-seed weight & SEEDYLD: Seed Yield*

3.2 Discussion

Apparently, the mean square of analysis of variance showed significant difference at (P=0.05) among the genotypes and sowing date for all traits except for number of seeds per pod, 100-seed weight and first pod height over the two years (Table 1). The genotype (year and sowing date) interaction clearly demonstrated that genotype and environment interaction across the environment clearly plays a significant role in breeding adaptable genotypes to the wide environment. This interaction was validated by the highly significant difference at (P=0.05) for plant height, number of pods per plant, number of branches per plant, leaf area, number of days to 50% flowering and seed yield. Genotype and environment interaction was also highly significant at (P=0.05) for number of pods per plant, leaf area, days to 50% flowering whereas it was non-significant for plant height, first pod height, number of branches per plant, number of seeds per pod, 100-seed weight and seed yield (Table 1). These results confirm the findings of Gebeyehu and Assefa [10] who reported that selection based on the highest yielding genotypes appeared less stable than the average of all lines. Furthermore, they reported that selection solely for seed yield could result in rejection of several stable genotypes. TGx 1937-1F out yielded others because of its yield components such as, number of pods per plant and number of seeds per pod and some other growth traits like leaf area, days to 50% flowering that do contribute to the highest yield (Table 1). In contrast, Arslanoglu and Aytac [1] reported contrary finding on the effect of genotype (G), environment (E) and G x E interactions on pod number per plant, whereby plant height, seed yield and 1000-seed weight were found to be significant at (P=0.01). Furthermore they reported that among the experiment locations, the pod number per plant ranged between 87.34 - 33.87, plant height 100.41 - 68.71 cm, 1000-seed weight 210.06-133.66 g and seed yield between 379.49- 211.85 kg/ha. The non-significant variation exhibited by genotype and environment interaction on various other traits indicates their response to climatic condition, and planting date do influence seed yield. From the findings of this study, (Table 2) it was very evident that seed yield and 100-seed weight declined in the same trend. Thus, early planting was observed to be essential in the efficient crop husbandry. Salem [22] confirmed the finding by reporting that date plays an important role in the crop productivity as the seed yield of genotypes decreased with delayed sowing date. The mean performance analysis revealed that high yielding genotypes across the sowing dates over the two years were: TGx 1937-1F (0.98 t/ha) and TGx 1740-2F (0.76 t/ha) whereas TGx 1904-6F and Soja registered (0.74 t/ha for each) and NA 5009 RG was the lowest yielder (0.48 t/ha). Thus, the outstanding performance by TGx 1937-1F in terms of yield and yield related traits made it the best performer across five sowing dates over two years (Table 3). These conform to Egli [7] explanation for soybean performance that yield variation across environments and years was associated with changes in number of seeds per unit area. A contrary explanation is that an ideal soybean cultivar was one that achieves the greatest yield across many environments [9]. The exhibited non-significance by these traits: first pod height, 100-seed weight, seed per pod, plant height, number of branches per plant on G × E interaction was confirmed by [4] who defined the non-significant difference as failure of genotypes to achieve the same relative performance in different environment. Thus, the G × E interaction might have made it difficult for breeder to identify the best genotypes, during selection and recommendation.

The positive correlation estimated between seed yield and days to 50% flowering and leaf area agrees with the findings of Malik et al*.,* [18]. This implies that selections aimed at increasing seed yield would invariably select for higher leaf area and earliness to flower and against first pod height, 100 seed weight, number of seeds per pod, number of branches per plant and plant height. This finding was in agreement with several scientists [13 and 20].

Bekheit [5] study revealed that the crop yield variation associated with change in the seed per unit area and crop performance was strongly influenced by weather condition. Other yield related traits: 100-seed weight had significant correlation with leaf area (0.61**), number of pods per plant (0.55**) and first pod height (0.47**). This positive correlation reported agrees with Maesri et al., [17]. Whereas, Rajanna et al*.,* [21] were of the view that 1000-seed weight had negative association with number of seeds per plant. The positive correlation of number of seeds per pod with plant height obtained conformed to [20] study in Turkey. But Haliloglu et al., [11] reported a contradictory result that the number of pods per plant indicated a positive association with number of seeds and seed yield. On the other hand, the positive correlation estimated between number of branches per plant and days to 50% flowering, leaf area, number of pods per plant agrees with the Malik et al., [19]. Thus, the correlation estimation in this study clearly defines the contribution of various other traits such as days to 50% flowering, leaf area, number of branches and number of pods per plant to yield .The highest and the lowest seed yields level attained by the five genotypes were mostly due to number of pods per plant, number of seeds per pod, leaf area and number of branches.

From the study it could be cited that the correlation coefficient of the five genotypes across the two years indicated that plant height had significant correlation with number of seeds per pod (0.44**) and non-significantly correlation with other traits. This finding conformed to the reports of several researchers [16 and 21]. The first pod height across the ten environments had significant correlation with 100-seed weight (0.47**). Although it correlated non-significantly with other traits but showed negative trend with leaf area, pods per plant, and seed yield.

Leaf area and days to 50% flowering were significantly associated with seed yield (0.37* and 0.45**). This indicates that with the larger leaf the more interception and efficient utilization of solar radiation could be achieved. And the more number of days to 50 % flowering area the higher number of pods produced. Besides the seed yield, the leaf area was highly significantly correlated with days to 50% flowering and 100-seed weight, the traits which in turn were correlated with branches and pods per plant. Like all other traits, leaf area showed similar trend in both seasons and the genotype, the leaf area was highly correlated with days to 50% flowering (0.66**), 100-seed weight (0.61**) and seed yield (0.45**). High leaf area is a good indication of high 100-seed weight and seed yield. The finding was in agreement with Kumudini et al*.,* [15] who explained that the greater leaf area improved the yield due to increased intercepted solar radiation and enhanced carbon exchange rate. This high variability among the genotypes was due to their response to climatic changes in the ten environments. It accentuates with Kang [14] findings that environment played major role in phenotypic expression of agronomic traits. The close correlation of seed yield with days to 50% flowering and leaf area is expected since these traits positively correlate to yield components number of pods per plant and number of branches per plant. The close association of seed yield with leaf area contributes to seed yield through the manufacture of assimilates by photosynthesis (source) and depositing it to the seed yield (sink). Therefore the close relations between leaf area and days to 50 % flowering would be useful indices for selection and improvement.

To overcome G × E effect, Cucolotto et al*.,* [6], partitioned G × E interaction into two: adaptability and phenotypic stability. These researchers defined adaptability as the capability a genotype has to make use of the environmental effects that warrants a high yield level; and phenotypic stability was related to yield maintenance or yield predictability in diverse environment. However, in the present study, G × E was not partitioned. Phenotypically, all the studied genotypes followed similar trend of performance over two years. The non-significant difference posed by G × E interaction was confirmed by Faisal [8] and he reported that delaying sowing date to late July do influence performance and yield per unit area reducing it to 0.5 t/ha or even less.

4. CONCLUSION

Partitioning genotype and environment into adaptability and phenotypic stability would have checked the adaptability of the genotypes. However, it could be concluded that genotype and environment interaction had a highly significant association with number of pods per plant, leaf area and number of days to 50% flowering. The mean separation ranked TGx 1937-1F as the highest yielder across the ten environments. These results too suggested that high seed yield potential was associated with number of branches per plant, number of productive pods per plant and leaf area. These strongly associated traits could be exploited in crop improvement and as selection criteria in breeding programmes. One more year trial is required to validate the trend of performance of genotypes across the environments.

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COMPETING INTERESTS

Authors have declared that no competing interests do exist.

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