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True Potato Seed Production and its Economic Analysis as Influenced by Supplemental Nitrogen and Planting Density

[1]Tuhin Suvra Roy, [2]Takashi Nishizawa and [1]Mohammed Hazrat Ali
[1]Faculty of Agriculture, Sher-e-Bangla Agricultural University,
Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh
[2]Faculty of Agriculture, Yamagata University, Tsuruoka 997-8555, Japan

Abstract: A field experiment was carried out to evaluate True Potato Seed (TPS) production and its relative economic return as influenced by supplemental nitrogen (N) at a range of 0-250 kg ha^{-1} and planting density at a range of 8-16 haulms m^{-2} in potato mother plants (*Solanum tuberosum* L.) using a cross of MF-II (♀) and TPS-67 (♂). The single effect of supplemental N application and planting density on the yield of berries and TPS was significant. Number of berries $plant^{-1}$, mean berry weight, number of TPS $berry^{-1}$ and yield of TPS showed maximum values when 0-150 kg N ha^{-1} was applied, but the values decreased thereafter as supplemental N application increased, irrespective of the size of the harvested berries. Although only the weight of 100-TPS showed a maximum value at 250 kg N ha^{-1} application, the value was similar to that at 200 kg N ha^{-1} application. Mean berry weight, number of seeds $berry^{-1}$ and weight of 100-TPS showed the maximum values at the lowest (8 haulms m^{-2}) planting density and the values decreased thereafter as the planting density increased, irrespective of the size of harvested berries. A positive effect of higher planting density was detected only in the number of berries $plant^{-1}$ and yield of TPS. The combination effect of supplemental N application and planting density on the yield of berries and TPS was also significant. Although the total yield of TPS was the highest at the combination of 150 N kg ha^{-1} and 16 stems m^{-2}, the yield of large size TPS, which is regarded as high quality TPS, was the highest at the combination of 200 N kg ha^{-1} and 12 stems m^{-2}. This was also true for the other characteristics of harvested TPS under different supplemental N applications and planting densities; i.e., number of berries $plant^{-1}$, number of TPS $berry^{-1}$ and weight of 100-TPS showed the maximum values at the combinations of 0-150 N kg ha^{-1} and 8-16 stems m^{-2} or 200 kg N ha^{-1} and 8 stems m^{-2}, but not at 200 N kg ha^{-1} and 12 stems m^{-2}. The benefit cost ratio, which was estimated from total cost of production and gross return also showed that the combination of 200 kg N ha^{-1} and 12 stems m^{-2} were the optimal growth conditions to harvest high quality TPS from the potato mother plants.

Key words: Berry, supplemental nitrogen, planting density, seed quality, TPS

INTRODUCTION

The most important component to achieve True Potato Seed (TPS) production commercially is to produce high quality TPS economically. Reports on potato production from TPS have emphasized that the success of this technology largely depends on the production of high quality TPS at low cost (Upadhya *et al*., 2003; Islam *et al*., 2000). These two factors will ensure that farmers in developing countries, who are expected to benefit from this alternative method of potato production, not only get the TPS at cheaper prices but also assure maximum production. Therefore, an appropriate field practice for the production of TPS should be established following the introduction of advanced technologies for potato production from TPS (Golmirzaie and Ortiz, 2004; Simmonds, 1997).

The production of high quality seed is strongly influenced by fertilizers (Almekinders and Wiersema, 1991; George and Varis, 1980). Among them, nitrogen (N) is the most important for improving the yield and quality of TPS (Roy *et al*., 2007b; Kanzikwera *et al*., 2000; Pallais and Espinola, 1992). In our previous studies (Roy *et al*., 2007a, b), we applied N fertilizers to potato mother plants (MF-II) in 4 installments at 10 day intervals from 30 Days After Planting (DAP) at the range of 0-200 kg N ha^{-1} and showed that the quality of harvested TPS was correlated positively with increasing N application. However, yield

Corresponding Author: Dr. Takashi Nishizawa, Faculty of Agriculture, Yamagata University, Tsuruoka, 997-8555, Japan
Tel: + 81-235-28-2828 Fax: +81-235-28-2812

components such as number of berries plant^{-1} and mean berry weight, often correlated negatively with increasing N application when N was applied as 4 separate applications during flowering through to seed developmental stages. This was probably mainly due to a competition for N absorption between tubers and inflorescences (Kinet *et al*., 1985), because 8.3-9.6 t ha^{-1} of tubers was also produced in our previous studies (data not shown). A similar trend of TPS and tuber production has also been reported by Pallais *et al.* (1987) and Dayal *et al.* (1984). Thus, 4 separate applications of N at 10 day intervals from 30 DAP is not optimal for the production of high quality TPS. On the other hand, tuberization was inhibited without preventing the steady growth of shoots and roots when N was applied to potato plants at 7 day intervals (Banik, 2005; Maingi *et al*., 1994), suggesting that competition for N uptake between tubers and inflorescences could be avoided by more frequent N applications.

Planting Density (PD) also affects the production of TPS. Almekinders (1991) showed that higher stem density increased the number of berries plant^{-1} and TPS yield but decreased 100-TPS weight. Therefore, the best combination of supplemental N and PD for TPS production should be clarified.

However, such an optimal combination that is obtained by studies of different combinations of supplemental N and PD on the yield and quality of TPS will not be accepted commercially if the combination ignores its economical benefit. Therefore, economic return must be considered as well as clarifying the effect of the combination.

Therefore, the objective of the present study was to evaluate how supplemental N fertilizer and PD affect the yield and quality of TPS. The results were also evaluated for the economic aspects.

MATERIALS AND METHODS

The experiment was conducted at the experimental field of the Tuber Crops Research Center (TCRC), Bangladesh Agricultural Research Institute, Gazipur, Bangladesh, during 2006-2007. The soil characteristics were pH 6.8 (Jackson, 1962) with 1.65% organic matter, 0.096% N, 0.001% available P, 0.131 me% exchangeable K and 0.00123% available S.

On 19 October 2006, sprouted tubers (50-60 g) of the female parent (MF-II) were planted in the experimental plots of TCRC at a depth of 5 cm. In contrast to the standard procedures for growing potato mother plants (Roy *et al*., 2007a), the experimental plots were not hilled to prevent tuberization. The above ground stolons were pruned soon after emergence for better growth of the main shoots. Two to four haulms per tuber were allowed to grow to obtain small, medium and high PD (8, 12 and 16 potato haulms m^{-2}, respectively and hereafter described as PD_8, PD_{12} and PD_{16}, respectively). Each haulm was supported on trellises. Considering the findings of our previous studies (Roy *et al*., 2007a, b), N:P:K:Gypsum:$ZnSO_4$:Borax(150:120:125:120:12:6kgha^{-1}) and farmyard manure (10 t ha^{-1}) were applied 3 days before planting as a basal fertilizer.

Four different levels of N (0, 21.4, 28.6 and 35.7 kg ha^{-1}, respectively) were applied supplementary at a depth of 3-5 and 10-15 cm apart from the mother plants, when the first flower bud commenced (27 DAP). This supplemental N application was conducted 7 times at 7 day intervals as described above. Therefore, the total amount of supplemental N application was 0, 150, 200 and 250 kg N ha^{-1} for each treatment (hereafter described as N_0, N_{150}, N_{200} and N_{250} kg N ha^{-1}, respectively).

The experiment was conducted in a split-plot design with 3 replications. Supplemental N was assigned to main-plots and PD to sub-plots. The distance between two rows was 1 m and each seed potato was planted at a distance of 0.25 m apart in a row. The sub-plot was a single row 3 m long and each consisted of 12 plants.

On 12 October 2006, the male parent (TPS-67) was planted in separate plots to harmonize their flowering with the female parent. Only the first and second inflorescence on a stem was allowed to develop for pollination and each inflorescence was pruned to 6 flower buds of similar maturity to equalize the date of anthesis. Berries were harvested when they became soft (approximately 6-7 weeks after pollination) and classified into large- (> 10 g) and small-(<10 g) berries. Ten berries from each weight class were selected per replication. All other practices and procedures of production, extraction and drying of TPS were same as those described in the previous report (Roy *et al*., 2007a). After proper drying, TPS were separated into three sizes of small-(<1.18 mm), medium-(1.18-1.4 mm) and large-(>1.4 mm) seeds using testing sieves (Tokyo Screen, Japan).

The Benefit Cost Ratio (BCR) of TPS production under different combinations of supplemental N and PD was estimated from the cost of production, gross return and net return according to standard labor/material costs of Bangladesh (BADC, 2006).

The analysis of variance was carried out using MSTAT-C statistical software (MSTAT, 1991). Means were compared using the Least Significant Differences (LSD) test at a 5% probability level.

RESULTS AND DISCUSSION

Single effect of supplemental N and planting density on plant growth and TPS production: Plant height increased significantly ($p \leq 0.01$) with increasing supplemental application of N fertilizer (Table 1). The highest plant height (117.9 cm) was obtained at N_{250}. Supplemental N application significantly ($p \leq 0.01$) affected all characteristics of berry and TPS (Table 1). Among them, number of berries plant^{-1} (28.4 and 14.1 for small and large berries, respectively), mean berry weight (10.9 g), number of seeds berry^{-1} (175 and 267 for small and large berries, respectively) and yield of TPS (148 kg ha^{-1}) showed maximum values at N_{0-150}, but the values decreased thereafter as N application increased, irrespective of berry size. Only mean weight of 100-TPS showed a maximum value at N_{250}, irrespective of berry size (84.4 and 85.1 mg for small and large berries, respectively), but the value did not change significantly between N_{200} and N_{250}.

PD also significantly ($p \leq 0.01$) affected the plant height and all berry and TPS characteristics (Table 1). Plant height at 70 DAP was the highest (115.7 cm) at PD_8, but it decreased thereafter as PD increased. Among the characteristics of berries and TPS, mean berry weight (10.9 g), number of seeds berry^{-1} (187 and 265 for small and large berries, respectively), weight of 100-TPS (81.4 and 82.1 mg for small and large berry, respectively) and mean weight of 100-TPS (81.7 mg) showed the maximum values at PD_8, but these values decreased thereafter as PD increased. Only the number of berries plant^{-1} (36.6 and 14.3 for small and large berries, respectively) and yield of TPS (137.6 kg ha^{-1}) showed maximum values at PD_{12} or PD_{16} and the values tended to decrease as PD decreased.

Although the weight of 100-TPS changed significantly as supplemental N application or PD changed, irrespective of berry size, the values did not differ apparently between small and large berries.

Combined effect of supplemental N application and planting density on plant growth and TPS production: The combination of different levels of supplemental N and PD significantly ($p \leq 0.01$) affected plant height (Table 2). Highest plant height (125.7 cm) was recorded at $N_{250}PD_8$.

Table 1: Single effect of supplemental N application or planting density on plant height and berry and TPS characteristics in MF-II x TPS-67

Treatments	Plant height at 70 DAP	NBPP^z Small berry	NBPP^z Large berry	Mean berry wt. (g)	NSPB^y Small berry	NSPB^y Large berry	Wt. of 100-TPS (mg) Small berry	Wt. of 100-TPS (mg) Large berry	Mean wt. of 100-TPS (mg)	Yield of TPS (kg ha^{-1})
Supplemental N application (kg ha^{-1})										
0	92.2^d	28.4^a	6.0^c	9.4^c	145^c	240^b	67.9^c	68.2^c	68.1^c	93.3^c
150	108.8^c	20.0^c	14.1^a	10.9^a	175^a	267^a	83.4^b	84.0^b	83.7^b	148.0^a
200	114.1^b	21.0^{bc}	13.4^{ab}	10.3^b	172^a	247^b	84.2^a	84.8^a	84.5^a	141.6^a
250	117.9^a	22.3^b	12.1^b	9.1^c	152^b	214^c	84.4^a	85.1^a	84.8^a	122.1^b
Planting density (number of potato haulms m^{-2})										
PD_8 (2)^x	115.7^a	12.7^c	10.9^b	10.9^a	187^a	265^a	81.4^a	82.1^a	81.7^a	93.3^c
PD_{12} (3)	108.4^b	20.6^b	14.3^a	10.1^b	155^b	251^b	80.1^b	80.8^b	80.6^b	133.2^b
PD_{16} (4)	100.7^c	36.6^a	9.0^c	8.8^c	140^c	238^c	78.4^c	78.8^c	78.7^c	137.6^a
Significance										
N	**	**	**	**	**	**	**	**	**	**
PD	**	**	**	**	**	**	**	**	**	**
N×PD	*	*	ns^w	*	*	*	*	*	*	**

^{z}: No. of berries plant^{-1}, ^{y}: No. of seeds berry^{-1}, ^{x}: No. in parenthesis indicates the number of potato haulms tuber^{-1}, *,**: Significant at $p \leq 0.05$ and 0.01, respectively. Different letter(s) within columns indicate a significant difference by LSD test at $p \leq 0.05$, ^{w}ns: Not-significant

Table 2: Combined effect of supplemental N application and planting density on plant height and berry and TPS characteristics in MF-II x TPS-67

Treatments combination	Plant height at 70 DAP (cm)	No. of berries plant^{-1} Small berry	No. of berries plant^{-1} Large berry	Mean berry wt. (g)	No. of TPS berry^{-1} Small berry	No. of TPS berry^{-1} Large berry	Mean No. of TPS berry^{-1}	Wt. of 100-TPS (mg) Small berry	Wt. of 100-TPS (mg) Large berry	Mean of 100-TPS wt. (mg)	Yield of TPS (kg ha^{-1})
N_0 PD_8	101.00	17.7	6.0	10.40	156.0	251.0	203.0	69.6	70.2	69.9	74.6
N_0 PD_{12}	95.30	28.7	6.3	9.60	143.0	238.0	191.0	67.5	68.1	68.4	95.2
N_0 PD_{16}	80.30	39.0	5.7	8.00	136.0	232.0	184.0	66.5	66.4	66.7	110.3
N_{150} PD_8	115.30	11.0	13.0	11.70	205.0	294.0	249.0	84.3	85.2	84.6	138.8
N_{150} PD_{12}	109.00	16.3	18.7	10.80	167.0	259.0	233.0	83.9	84.6	84.3	155.3
N_{150} PD_{16}	102.00	32.7	10.7	10.30	151.0	248.0	219.0	81.7	82.0	81.9	160.1
N_{200} PD_8	120.70	10.3	13.0	11.30	202.0	270.0	236.0	85.5	86.1	85.8	120.1
N_{200} PD_{12}	113.30	18.0	17.3	10.50	165.0	240.0	223.0	84.2	85.0	84.9	151.3
N_{200} PD_{16}	108.30	34.7	10.0	9.00	147.0	229.0	208.0	82.9	83.2	83.1	153.3
N_{250} PD_8	125.70	11.7	11.7	10.10	186.0	243.0	214.0	86.0	86.4	86.2	108.3
N_{250} PD_{12}	116.60	19.3	15.0	9.40	145.0	208.0	193.0	84.6	85.5	85.1	126.3
N_{250} PD_{16}	112.00	36.0	9.7	7.90	126.0	190.0	173.0	82.6	83.4	82.9	131.7
LSD (0.05)^z	4.83	2.2	2.6	0.66	15.8	13.0	11.3	0.6	0.7	0.7	8.3

N_0 to N_{250} and PD_8 to PD_{16} indicate that supplementary nitrogen was applied at the rate of 0 to 250 kg ha^{-1} and potato haulms were allowed to grow 8 to 16 m^{-2}, respectively. See Table 1 for details. ^{z}LSD ($p \leq 0.05$) for comparing means in columns

Table 3: Combined effect of supplemental N application and planting density on the yield of TPS of different sizes

Treatments combination	Yield of different size TPS[z] ($kg\ ha^{-1}$)		
	< 1.18 mm	1.18-1.4 mm	> 1.4 mm
N_0 PD_8	48.70	17.70	8.20
N_0 PD_{12}	63.80	21.90	9.50
N_0 PD_{16}	77.20	23.70	9.40
N_{150} PD_8	37.30	53.90	47.80
N_{150} PD_{12}	37.40	67.30	50.60
N_{150} PD_{16}	49.40	70.70	40.00
N_{200} PD_8	15.90	55.60	48.60
N_{200} PD_{12}	26.40	68.40	56.50
N_{200} PD_{16}	36.50	67.40	49.40
N_{250} PD_8	11.80	49.10	47.40
N_{250} PD_{12}	17.50	60.10	49.10
N_{250} PD_{16}	25.90	60.20	45.60
LSD (0.05)[y]	5.74	3.35	3.66

[z]: Seed size < 1.18 mm, 1.18-1.4 mm and > 1.4 mm were counted as small, medium and large size TPS, respectively. N_0 to N_{250} and PD_8 to PD_{16} indicate that supplementary nitrogen was applied at the rate of 0 to 250 $kg\ ha^{-1}$ and potato haulms were allowed to grow 8 to 16 m^{-2}, respectively. See Table 1 for details. [y]LSD ($p \leq 0.05$) for comparing means in columns

The maximum values of the number of berries $plant^{-1}$ (39.0 and 18.7 for small and large berries, respectively), mean berry weight (11.7 g), number of TPS $berry^{-1}$ (205 and 294 for small and large berries, respectively) and mean number of TPS $berry^{-1}$ (249) were obtained with the combinations of N_{0-150} PD_{8-16}, irrespective of berry size (Table 2). On the other hand, the maximum values of the weight of 100-TPS were obtained with the combination of N_{250} PD_8 (86.0, 86.4 and 86.2 mg for small, large berries and mean weight of 100-TPS, respectively).

Combined effect of supplemental N application and planting density on the yield of TPS: Total yield of TPS higher than 150 $kg\ ha^{-1}$ was obtained with the combination of $N_{150-200}$ PD_{12-16} (Table 2). However, among different TPS sizes, the maximum yield was obtained with the combination of N_{200} PD_{12} for large TPS, N_{150} PD_{16} for medium TPS and N_0 PD_{16} for small TPS (56.5, 70.7 and 77.2 $kg\ ha^{-1}$, respectively) (Table 3).

Economic analysis: The cost and return analysis made under different treatment combinations demonstrated that the total cost of production was the most expensive in N_{200} PD_{12} (US\$ 15,052 ha^{-1}), whereas the cheapest was at N_0 PD_8 (US\$ 14,038 ha^{-1}) (Table 4). The highest gross return, net return and benefit cost ratio (BCR) (US\$ 28,552 ha^{-1}, US\$ 13,500 ha^{-1} and 1.90, respectively) were also obtained with the combination of N_{200} PD_{12} and this combination was found to be more profitable than the other treatment combinations (Table 4). The calculations based on the present information showed that under Bangladesh conditions of land and labor, the cost of production of one kg of hybrid TPS would be US\$ 120.5 (Table 4).

The number of large berries $plant^{-1}$, mean berry weight, number of TPS $berry^{-1}$ and yield of TPS showed maximum values when lower than N_{200} was applied as supplemental dressing, irrespective of berry size (Table 1). Although only plant height and mean weight of 100-TPS increased with increasing supplemental N, the weight of 100-TPS was similar between N_{200} and N_{250} (Table 1). Application of N also accelerates the tuberization in potato plants when it is discontinued (Kraus, 1978) and the growth of aerial parts including shoots and fruits is often prevented by the rapid tuberization because of the competition for N uptake (Zrust, 1992; Pallais, 1987). On the other hand, rapid tuberization can be prevented when N is applied inter-spatially, because of successive growth of above-ground parts (Maingi *et al*., 1994; Kraus, 1978). In our experiment, N was applied in 7 installments at 7 day intervals from 27 DAP to prevent high competition between above-ground parts and tubers for N uptake, but the role of supplemental N application was maximal at N_{200} or lower (Table 1). These results suggest that the decrease in reproductive growth at N_{250} might be due to a competition for N uptake among aerial parts such as shoots and fruits (Kanzikwera *et al*., 2001). Thus, N_{250} can be concluded as supra-optimal to obtain maximum reproductive growth.

Although high PD (>12 m^{-2}) resulted in the maximum number of berries $plant^{-1}$ and TPS yield, all other harvesting factors were better at the lowest PD (8 m^{-2}), irrespective of berry size (Table 1). Almekinders (1991) also showed a similar relationship between berry/seed size and PD. Effects of PD are generally attributed to the competition for light, water and nutrients. In our experiment, nitrogen supply and soil moisture were adjusted, but still a competition for light between stems would occur because stem internodes became longer as PD increased (data not shown).

Although 100-TPS weight increased with increasing supplemental N, irrespective of berry size, the values were similar between large and small TPS (Table 1). This result indicates that small berries contain fewer but heavier TPS than large berries, irrespective of PD and supplemental N level. Thus, the assumption that smaller berries must possess lighter TPS is not supported.

The combination effect of supplemental N application and PD showed that the maximum yield of TPS was obtained with the combination N_{150} PD_{16} (Table 2). However, in the previous report (Roy *et al*., 2007c) we showed that the yield of large TPS was crucial for obtaining seedlings with excellent growing performance after germination. In this aspect, the combination of $N_{150-200}$ PD_{12} will be better, because the maximum yield of large TPS was obtained with these combinations (Table 3).

Table 4: Estimation of cost and return in hybrid TPS production in Bangladesh as influenced by different levels of supplemental N and planting density

Treatments combination	Cost of N fertilizer and seed treating chemicals used for the treatments (US \$ ha^{-1})^z	Total cost of production (US \$ ha^{-1})^y	Yield of marketable TPS (kg ha^{-1})^x	Gross return^w (US \$ ha^{-1})	Net return^v (US \$ ha^{-1})	Benefit cost ratio^u (BCR)
N_0 PD_8	170.0	14037.8	25.9	5920.0	-8117.8	-0.42
N_0 PD_{12}	201.1	14079.8	31.4	7178.0	-6901.8	-0.51
N_0 PD_{16}	210.7	14092.7	33.1	7566.7	-6526.0	-0.54
N_{150} PD_8	631.4	14862.5	101.7	23248.6	8386.1	1.56
N_{150} PD_{12}	723.3	14986.0	117.9	26951.9	11965.9	1.79
N_{150} PD_{16}	682.6	14931.1	110.7	25306.0	10374.9	1.69
N_{200} PD_8	655.1	14894.1	104.2	23820.1	8926.0	1.60
N_{200} PD_{12}	772.2	15052.0	124.9	28552.1	13500.1	1.90
N_{200} PD_{16}	726.4	14990.2	116.8	26700.5	11710.3	1.78
N_{250} PD_8	621.0	14848.1	96.5	22059.9	7211.8	1.49
N_{250} PD_{12}	692.3	14944.2	109.1	24940.3	9996.1	1.67
N_{250} PD_{16}	673.6	14919.0	105.8	24185.9	9266.9	1.62

N_0 to N_{250} and PD_8 to PD_{16} indicate that supplementary nitrogen was applied at the rate of 0 to 250 kg ha^{-1} and potato haulms were allowed to grow 8 to 16 m^{-2}, respectively. See Table 1 for details, ^{z}: Price of N fertilizer (Urea) and seed treating chemicals (GA_3, HCl, KOH and Clorox), ^{y}: Total cost of production = Total input cost + Miscellaneous cost (5% of the total non-material and material cost) + Over head cost (interest on running capital, depending on the amount input cost @ 14% per year for 6 months) + Total cost of production of 0.02 ha of Male parent, ^{x}: Marketable TPS yield means > 1.18 mm size TPS, ^{w}: Gross return = Yield of marketable TPS x price of TPS (sale rate fixed by BADC US \$ 228.6 kg^{-1}), ^{v}Net return = Gross return – total cost of production, ^{u}: BCR = Gross return (US \$ ha^{-1})/Total cost of production (US \$ ha^{-1})

The result of combination effect of supplemental N application and PD (Table 2) revealed that $N_{0\text{-}150}$ $PD_{8\text{-}16}$ and N_{250} PD_8 were the best combinations when the objective of TPS production was focused on number of berries plant^{-1} or number of TPS berry^{-1} and weight of 100-TPS, respectively, irrespective of the size of harvested TPS. However, from the economic point of view, the combination of N_{200} PD_{12} was found to be most profitable compared to other treatment combinations in respect of gross returns, net returns and BCR values (Table 4). This combination was also produced the maximum yield of marketable TPS (> 1.18 mm size). The price of hybrid TPS is still high (US \$ 228.6 kg^{-1}) and not within the reach of majority farmers. It would be reduced either by increasing the yield of quality TPS or by applying appropriate crop management practices.

Therefore, in the commercial aspect 200 kg N ha^{-1} of supplemental N application in 7 separate installments at 7 day intervals starting from 27 DAP and 3 stems tuber^{-1} (12 stems m^{-2}) is the most suitable combination to produce high quality TPS from ♀MF-II x ♂TPS-67.

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