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Revolution in Wheat Production and Total Factor Productivity in Gujarat: The Contribution of Research Investment

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Abstract **– This paper has analyzed the growth in TFP of wheat crop and its sources in Gujarat state from 1990-91 to 2011-12. The Tornqvist Theil Index has been used to calculate the total output index, total input index and TFP index. Two outputs and ten inputs have been used to construct output and input indices. The results reveals that during 2000s the area, production and yield of wheat were increased at remarkable rate of 11.62, 14.68 and 2.74 per cent per annum in Gujarat, followed by Madhya Pradesh and Rajasthan. It has also registered moderate growth rates of output indices and TFP indices about 1.53 and 1.05 per cent per annum, respectively in 2000s.**

This was contributed by the release of *viz.,* GW-496 and GW-503 in 1989, GW-273 in 1997, GW-322 in 2002, GW-366 in 2006, including proper agronomical practices as well plant protection measures by the then GAU and SAUs in the state, remarkably increased the productivity of wheat in first decade of 21st century.

The Investment on wheat research generated 29 percent IRR found to be a highly paying proposition in study period. The sources of productivity growth indicated that government expenditure on agricultural research and education, balance use of fertilizers and development of ground water as well as canal irrigation in the state, and good monsoon has positive and significant impact on TFP. It essential that growth in TFP needs to be sustaining, through varietal improvements and irrigation developments.

Keywords **– Wheat, TFP Growth, Research, Investment, Return, Gujarat.**

I. Introduction

The wheat *(Triticum estivum L.)* is cultivated in about 120 countries of the world. The major wheat producing countries are EU, China, India, USA, Russian Federation, Canada, Australia, *etc*. Importance of wheat world wide as main food can be understood by use of stylized wheat spike as a symbol of FAO. Although, as many as 25 species of wheat have been recognized in the world, only three species of wheat namely; *T. estivum Linn* (Bread wheat), *T. durum* (Macaroni wheat) and *T. dicoccum* (Emmer wheat) are commercially grown in India. Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhya Pradesh and Bihar are the major wheat producing states in India. India has made tremendous progress in production of wheat. During the year 1950-51, its production was merely 64.6 lakh tonnes, which increased to 958.50 lakh tonnes in 2013-14. Due to sustained efforts made by policy makers, agricultural scientists, extension workers and receptive farmers, the production of wheat dramatically increased manifold on account of adoption of modern production technology.

Gujarat is one of the leading states in agricultural production in the country. The Government has allocated a significant proportion of its resources to agricultural research in the state. Gujarat agricultural has recorded the fastest growth (above 9.6%) among all Indian states, since 2000. This is more than three times agricultural growth (2.9% per annum during 2000-01 to 2007-08) at all India level (Gulati, *et al.*, 2009). Therefore, it is imperative to look at current research efforts and their accuracy in order to address emerging regional research needs. The most comprehensive measure of aggregate or sectoral productivity is Total Factor Productivity (TFP).

In view of the above, the present study was undertaken with the following specific objectives *viz.,* to measure the temporal changes in area, production and productivity of wheat crop of Gujarat; to estimate the growth of input and output indices of wheat crop, and to estimate the growth of Total Factor Productivity and its sources, and returns to investment for wheat crop research in Gujarat.

II. Methodology and Data Source

In the present study, TFP is estimated taking into account two outputs and ten inputs. Output index includes main product and by-product. The ten index comprises, seed (kg/ha), manure (tone/ha), fertilizers (kg/ha), human labour (man days/ha), bullock labour (pair days/ha), Irrigation (Rs/ha), insecticide/ pesticide (Rs/ha), miscellaneous cost (Rs/ha), depreciation (Rs/ha) and rental value of owned land (Rs/ha). The data on input, output and prices has been compiled from the Department of Agricultural Economics, Junagadh Agricultural University, Junagadh Campus, Junagadh collected under cost of cultivation scheme. The other required data were obtained from various publication sources.

Analytical Framework

Total factor productivity (TFP) refers to that part of growth in output, which cannot be explained by growth in factor inputs like land, labour and capital. Index of Total factor productivity (TFPI) measured the growth of net output per unit of total factor input. The TFP is defined as the ratio of an index of aggregate output to an index of aggregate input. Theil Tornqvist discrete approximation to the Divisia index is a most useful method for TFPI computation. The use of TFP indices gained prominence since Diewert (1976, 1978) proved that Theil Tornqvist discrete approximation to the Divisia index was consistent in aggregation and superlative to linear homogeneous translogarithmic production function. The Tornqvist index is exact for the homogenous translog production function.

The Divisia indices have two important attractive properties: (i) they satisfy the time reversal and factor reversal test for index numbers, and (ii) it is a discrete of the components, so that aggregate could be obtained by the aggregation of sub-aggregates (Kumar et al, 2008). An index of total factor productivity (TFP) compares changes in output with changes in aggregate inputs.

In the present study also, the Tornqvist Theil index was used for computing the total output index, total input index and total factor productivity index. These indices were calculated as follows:

Total Output Index (TOI)

Total output indices were constructed using the Tornqvist Theil index approach as follows:

$TOI_t / TOI_{t-1} = \prod_j (Q_{jt} / Q_{jt-1})^{(R_{jt} + R_{jt-1}) ½}$

Total Input Index (TOI)

$TII_t / TII_{t-1} = \prod_j (X_{it} / X_{it-1})^{(S_{jt} + S_{it-1}) ½}$

Where,

Q_{jt} = Output of j^{th} crop in t^{th} year.

R_{jt} = Output share of j^{th} crop in total revenue in t^{th} year.

X_{it} = Quantity of i^{th} input used in j^{th} crop in t^{th} year.

S_{it} = Share of input 'i' in total input cost in t^{th} year.

t is the time period

In the case of TFP for a single crop, revenue share refers to the share of main product and by-product in total revenue from the crop, while output includes main product and by-product. Thus, total output and total input chaining indices for wheat crop were prepared taking 1990- 91 as the base year.

Total Factor Productivity Index (TFPI)

Total factor productivity indices was computed as the ratio of total output index (TOI) to total input index (TII).

$TFPI_t = (TOI_t / TII_t) X 100$

The estimation of input, output and TFP growth rates for any specified was done by fitting an exponential (or semi-log) trend equation to the three-yearly moving averages of input, output and TFP indices, respectively.

Sources of TFP Growth

The changes in the variables, that produce growth in TFP, have vital importance to estimate how much each of these sources contributes to the growth of TFP. As an input to public investment decisions, it is useful to understand the relative importance of these productivity-enhancing factors in determining productivity growth. Following Chand *et al.* (2011) to examine the determinants of TFP, a multiple regression technique in double log functional form was carried out. In order to assess the determinants of TFP, the TFP index was regressed against the following variables:

RES_STOK (research stock per ha of crop area);

EXT_STOK (extension stok per ha);

LIT_R (the proportion of rural population which is literate);

NPRATIO (ratio of N to P_2O_5 nutrients used);

CI (cropping intensity, %);

IRR_GW (groundwater irrigated area to total irrigated area, *i.e.* GWIA/GIA);

ELECT_AG (electricity consumption per ha of crop area); and

IRR_INTEN (gross irrigated area to net irrigated area *i.e.* GIA/NIA);

IRR_POTEN (ratio of irrigation potential created to utilization *i. e.* U/P);

KH_RAIN is average total rainfall per year in state, and

IRR_CANAL (canal irrigated area to total irrigated area, *i.e.* CANAL/GIA).

Regression analysis was attempted using the above variables and by clubbing together variables related to natural resources and infrastructure (NARI). Three variables representing natural agricultural resources were clubbed together by taking their average as:1/3 CI + 1/3 NPRATIO + 1/3 IRR_GW.

Similarly, infrastructural index (INF) was computed from infrastructural variables as:

0.6 RAIL + 0.1 ELECT_AG + 0.3 IRR_INTEN)

[the weights 0.6, 0.3 and 0.1 were based on the experts judgement, as stated by Chand *et al*. (2011)].

Model 1 below uses NARI and INF indices to estimate the effect of various factors on TFP. All major individual variables representing natural resources and infrastructure were incorporated in model 2. Accordingly, the specification of regression equations was stated as:

Model 1: TFP = f (RES_STOK, EXT_STOK, LIT_R, NARI, INF,)

Model 2: TFP = g (RES_STOK, EXT_STOK, LIT_R, CI, NPRATIO, IRR_GW, ELECT_AG, IRR_INTEN, IRR_POTEN, KH_RAIN, IRR_CANAL)

Estimation was undertaken using a fixed effect approach for the pooled cross-section time seris state-level dataset, with corrections for serial correlation and heteroskedasticity (kmenta, 1981). Following Evenson *et al.* (1999), the research stock variable was constructed by summing up research investment of five years by assigning weights as 0.2 in the year t-2, 0.4 in the year t-3, 0.6 in the year t-4, 0.8 in the year t-5 and 1.0 in the year t-6. The extension stock variable was constructed by summing up three years' extension investment by assigning weights as 0.2 in the year t-1, 0.4 in the year t-2, and 1.0 in the year t-3.

Returns to Research Investments

The value of marginal product for research is estimated as per below Equation:

$$EVMP (RES\_STOK) = b_i (V/ RES\_STOK)$$

Where, V is the value of crop production associated with TEP (value of output for crop multiplied by the same share of TFP in total output), RES_STOK is the research stock and b_i is the TFP elasticity of research stock estimated from TFP models 1 and 2. The benefit stream was generated under the assumption that the investment made in research in the year t-i will start generating a benefit after a lag of five years, at an increasing rate during the next six years, will remain constant for the next six years and thereafter, it will start declining (one can also take the lag structure of 6,6,6 or 9,9,9). Following Evenson and Pray (1991), an investment of one rupee in the year t-i will generate a benefit equal to 0.1 EVMP in the year t-i+6, 0.2 EVMP in the year t-i+7,....... so on till t-i+11, and it will 0.9 EVMP in the year t-i+12. After this, the benefit will be equal to EVMP up to the year t-i+18. Then, the benefit from the year t-i+19 onwards will again star declining and will be equal to 0.9 EVMP in the year t-i+19, and 0.8 EVMP in the year t-i+20, and so on. This benefit stream can be discounted at the rate, say 'r', at which the present value of benefit is equal to one. Thus, 'r' was considered as the marginal internal rate of return to public research investment.

III. Results and Discussion

Wheat is a major cereal in India after rice contributes about 40 per cent of total cereals production. India has made tremendous progress in production of wheat (Table 1). Uttar Pradesh is the highest producer of wheat contributing around 28 per cent in the national production, followed by Punjab, Madhya Pradesh and Haryana. In last two decades the production of wheat in all major states including Gujarat has shown increasing trends.

Table 1: Major state wise production of wheat in India (lakh tonnes)

States	**1990-91**	**1995-96**	**2000-01**	**2005-06**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**
Gujarat	12.96	12.32	6.49	23.19	50.13	40.72	29.44	47.13	30.59
Bihar	35.60	42.39	44.38	32.39	40.98	47.25	53.57	47.38	39.87
Haryana	64.40	72.91	96.69	88.57	116.30	126.86	111.17	118.00	103.54
Madhya Pradesh	58.33	66.67	48.69	59.58	76.27	115.39	131.33	129.37	171.04
Punjab	121.55	125.18	155.51	144.93	164.72	172.80	165.91	176.20	150.50
Rajasthan	43.09	54.93	55.47	58.65	72.14	93.20	92.75	86.63	98.24
Uttar Pradesh	186.00	218.16	251.68	240.74	300.01	302.93	303.02	298.91	224.17
All India	**551.35**	**620.97**	**696.81**	**693.55**	**868.74**	**948.82**	**935.06**	**958.50**	**865.27**

Source: Directorate of Economics and Statistics, GoI.

It can be seen from Table 2 that the area, production and yield of wheat in India were significantly increased at the rate of 0.84, 1.97 and 1.13 per cent per annum, respectively during last two decades (*i.e.* from 1990-91 to 2011-12). During 1990s and 2000s the area, production and yield were by and large increased significantly in all major states. However, the rate of increase in area, production and yield, were slowdown in Bihar, Punjab, and Uttar Pradesh in 2000s. In Gujarat during 1990s the area and production were decreased by 3.0 and 2.29 per cent per annum but the yield was increased 0.73 per cent per annum, whereas during 2000s the area, production and yield were increased at remarkable rate of 11.62, 14.68 and 2.74 per cent per annum followed by Madhya Pradesh and Rajasthan. The Gujarat registered significantly the highest growth rate in area, production and yield of wheat during last two decades about 4.08, 5.70 and 1.55 per cent per annum, respectively.

Table 2: Compound annual growth rates of area, production and yield of wheat in major producing states in India (per cent)

Particular	**Period**	**Area**	**Production**	**Yield**
Gujarat	1990-91 to 2000-01	-3.00 (0.0111)	-2.29 (0.132)	0.73 (0.0032)
	2001-02 to 2011-12	**11.62**** (0.0069)	**14.68**** (0.0117)	**2.74**** (0.0043)
	1990-91 to 2011-12	**4.08**** (0.0047)	**5.70**** (0.0057)	1.55** (0.0014)
Bihar	1990-91 to 2000-01	0.72** (0.0008)	2.93** (0.0029)	2.19** (0.0025)
	2001-02 to 2011-12	0.32 (0.0012)	1.82 (0.0050)	1.50 (0.0040)
	1990-91 to 2011-12	0.27** (0.0004)	0.33 (0.0018)	0.06 (0.0015)
Haryana	1990-91 to 2000-01	2.40** (0.0012)	4.02** (0.0020)	1.58** (0.0011)
	2001-02 to 2011-12	1.17** (0.0005)	3.09** (0.0024)	1.89** (0.0022)
	1990-91 to 2011-12	1.54** (0.0005)	2.77** (0.0009)	1.21** (0.0006)
Madhya Pradesh	1990-91 to 2000-01	1.20 (0.0047)	2.56 (0.0079)	1.35 (0.0036)
	2001-02 to 2011-12	2.16** (0.0043)	**4.88**** (0.0069)	**2.66**** (0.0040)
	1990-91 to 2011-12	0.28 (0.0016)	1.33* (0.0028)	1.04** (0.0014)
Punjab	1990-91 to 2000-01	0.36** (0.0006)	2.43** (0.0022)	2.06** (0.0018)
	2001-02 to 2011-12	0.37** (0.0003)	1.37** (0.0018)	1.00** (0.0018)
	1990-91 to 2011-12	0.44** (0.0007)	1.35** (0.0008)	0.90 (0.0007)
Rajasthan	1990-91 to 2000-01	3.76** (0.0038)	**4.91**** (0.0068)	1.11 (0.0049)
	2001-02 to 2011-12	3.12** (0.0039)	**4.52**** (0.0041)	1.36** (0.0018)
	1990-91 to 2011-12	0.94* (0.0019)	2.55** (0.0022)	1.59** (0.0013)
Uttar Pradesh	1990-91 to 2000-01	0.81** (0.0005)	3.01** (0.0031)	2.19** (0.0015)
	2001-02 to 2011-12	0.69** (0.0007)	2.37** (0.0025)	1.67** (0.0020)
	1990-91 to 2011-12	0.41** (0.0003)	1.78** (0.0009)	1.36** (0.0007)
All India	1990-91 to 2000-01	1.32** (0.0012)	3.10** (0.0017)	1.75** (0.0013)
	2001-02 to 2011-12	1.43** (0.0021)	2.98** (0.0022)	1.53** (0.0016)
	1990-91 to 2011-12	0.84** (0.0005)	1.97** (0.0009)	1.13** (0.0006)

Note: ** and *Significant at 1 per cent and 5 per cent levels, respectively.
Figures in the parentheses indicate standard error.

Growth in Input, Output and TFP Index

The first set of growth rates in Table 3 is based on three years moving average of indices of inputs, outputs and TFP. The second set is based on annual values. The compound annual growth rates of total input and output indices were decreased at the rate of 0.57 and 0.27 per cent respectively, but TFP growth increased at the rate of 0.30 per cent in 1990s. Whereas in 2000s input growth was stagnant, but growth in output and TFP were moderate about 1.53 and 1.05 per cent per annum, respectively. The overall growth rate of inputs remained stagnant while its output and TFP indices increased at the rate of 0.70 and 0.61 per cent per annum, respectively, from 1990-91 to 2011-12. The same trend was continued still 2014-15.

Table 3: Annual growth rate in input use, output, TFP and real cost of production (RCP) for wheat crop in Gujarat: 199091 to 2011-12 (in per cent)

Period	Input growth	Output growth	TFP growth	RCP growth	Share of TFP in output growth
Based on three- year moving averages					
1990-91 to 2000-01	-0.57	-0.27	0.30	0.83	--
2001-02 to 2011-12	0.48	1.53	1.05	0.06	68.60
1990-91 to 2011-12	0.09	0.70	0.61	0.10	87.22
1990-91 to 2013-14	0.19	0.78	0.59	0.13	75.18
Based on "normal" year values					
1990-91 to 2000-01	-1.18	0.23	1.42	-0.39	--
2001-02 to 2011-12	0.49	1.55	1.06	-0.13	68.17
1990-91 to 2011-12	0.15	0.77	0.62	-0.06	80.10
1990-91 to 2013-14	0.27	0.80	0.53	0.13	65.93

Note**:** Normal years excludes years of extreme drought and poor weather: 2000-01.

The contribution of TFP to output growth was high about 87 per cent for wheat in Gujarat. Chand *et al.* (2011) in their TFP analysis of wheat in India, revealed that during 1975-05 the TFP indices for wheat has shown an annual growth rate of 1.77 per cent in Uttar Pradesh followed by 1.6 per cent in Gujarat and about 1 per cent in Punjab and Haryana. Thus, among the non-traditional wheat-growing states, Gujarat has shown an outstanding performance of TFP growth in wheat, though the state is frequently constrained by short of irrigation water and high temperature at maturity stage during February-March.

This is credited to the release of wheat varieties *viz.,* GW-89 in 1984, GW-496 and GW-503 in 1989, GW-273 in 1997, GW-322 in 2002, GW-366 in 2006, released by the then Gujarat Agricultural University in the state, remarkably increased the productivity of wheat in first decade of 21st century. This has largely helped to reduce cost of production, although the input prices including labour charges increased remarkably during recent years.

Among these released wheat varieties in the state, the GW-496 has been largely adopted by the farmers due to its superiority in yield, best quality, resistant to rust and high adaptability in the soil and climate of the state. The variety GW-366 is also gaining popularity having attractive bold grain size and high yield. The Lok-1variety of *Lokbharti* institution, released in 1979 is also performing well in the state. Among these released wheat varieties, the farmers have wide chance for selection as early, timely and in late sown conditions.

This is a clear evidence explained by TFP analysis, that the research expenditure incurred in 1980s and 1990s for evolving better varieties of wheat crop in the state had played a greater role for increasing productivity, as well as keeping lower cost of production, in the state.

Sources of Total Factor Productivity

A rise in production can be attributed to a growth in inputs or growth in total factor productivity. Productivity growth encompasses changes in efficiency as well as changes in the best practice. As far as sources of productivity change are concerned, the technical change component assumes greater significance. The changes in the variables, that produce growth in TFP, have vital importance to estimate how much each of these sources contributes to the growth of TFP. An attempt has been made to further analysis in terms of contribution of various factors to TFP growth.

Estimates of regression coefficients which measure the effect of various sources of TFP, were used to compute elasticity of TFP with respect to research stock and to assess the impact of research has been presented in Table 4. It indicates that government expenditure on agricultural research and education, balance use of nitrogen and phosphoric fertilizers (the ratio of phosphoric to nitrogen nutrients) and development of canal irrigation, good monsoon in the state has positive and significant impact on TFP. The coefficients associated with cropping intensity, ground water utilization ratio and electricity consumption per ha have also positive effect on TFP of wheat. This indicates that public expenditure on agricultural research and education, development of irrigation and bringing more area under canal irrigation assumes a greater role in accelerating productivity in agriculture, particularly for wheat crop in Gujarat.

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Table 4: Determinants of TFP for wheat crop in Gujarat (1990-91 to 2011-12)
(Dependant variable: TFP index of wheat at state level)

Variable	Regression coefficient	Standard error	't' statistics	Level of significance
Model 1				
Constant	1.2813	0.7021	1.8250	--
RES_STOK	0.1602*	0.0922	1.7373	0.1028
EXT_STOK	0.0114	0.0243	0.4670	0.6472
LIT_R	-0.0206*	0.0102	-2.0144	0.0623
NARI	0.4511**	0.1022	4.4123	0.0005
INF	0.1724*	0.0850	2.0279	0.0607
IRR_CANAL	0.1720*	0.0806	2.1342	0.0497
Adjusted R-Squared	**0.6509**			
Model 2				
Constant	-0.0845	1.5879	-0.0532	--
RES_STOK	0.1776**	0.0640	2.7746	0.0196
EXT_STOK	0.0247	0.0189	1.3053	0.2210
LIT_R	-0.0199*	0.0090	-2.2065	0.0519
NPRATIO	0.2089**	0.0729	2.8635	0.0169
CI	0.0005	0.0037	0.1250	0.9030
IRR_GW	0.0261	0.1441	0.1808	0.8602
ELECT_AG	-0.0385	0.0545	-0.7063	0.4961
IRR_INTEN	-0.0028	0.0025	-1.1419	0.2801
IRR_POTEN	0.4909	0.4493	1.0926	0.3002
KH_RAIN	0.2312**	0.0782	2.9583	0.0143
IRR_CANAL	0.1845*	0.0784	2.3526	0.0405
Adjusted R-Squared	**0.9104**			

Note: ** and *Significant at 1 per cent and 5 per cent levels, respectively. All variables specified in logarithms, except those variables defined in percentage terms.

Whereas, rural literacy was found to be negative, as the migration of rural literates to urban areas due to availability of increased non-farm employment opportunities and distress like conditions in agriculture sector might be the reason for negative effect of rural literacy and extension education.

From Table 4 it can be further revealed that TFP elasticity with respect to research stock ranged from 0.1602 (model 1) to 0.1776 (model 2) for wheat. The inverse of this elasticity gives research stock flexibility which represents the required increase in research stock to increase in TFP by 1 per cent. This estimates show that to achieve 1 per cent increase in TFP, the minimum investment in research need to be increased by 5.92 per cent.

Returns to Investment on Gram Research

The estimated value of marginal product (EVMP) of research investment has been presented in Table 5 revealed that additional investment of rupee one in wheat crop research generated an additional output worth Rs. 5.33 during 1990-91 to 2011-12 in Gujarat.

The internal rate of return (IRR) to research investment for wheat crop of which research stock coefficient in TFP decomposition equation was statistically significant has been estimated following the assumption given in the methodology section. The result indicated that during the period 1990-91 to 2011-12, the overall rate of return to public agricultural research investment turned out to be 29 per cent for wheat crop in Gujarat.

Table 5: Estimated value of MVP and IRR to research investment for wheat crop in Gujarat

Period	**Value of marginal product** (in Rupees)	**Internal rate of return** (in per cent)
1990-91 to 2011-12	6.45	29.00

IV. Conclusion

The Gujarat state has good infrastructure for agriculture research and professional staff. However, the current period of economic transition and policy reform is accompanied by budget constraints that motivate careful rationing of public investment funds, making it increasingly important to assess the economic rates of return to agricultural research and other public investments. The study has used farm-level data collected under the Cost of Cultivation Scheme for the period from 1990-91 to 2011-12 and analysed using Tornqvist-Theil Index for constructing aggregate output and aggregate input of the crop.

The analysis of growth in TFP of wheat in Gujarat shows it has registered a low productivity growth during the nineties. Vitally increased, during 2001-02 to 2011-12 and registered positively significant growth in TFP throughout last two decades, though it is frequently constrained by adverse weather and moisture stress. This largely contributed to release of high yielding varieties in the state *viz.*, GW-89 in 1984, GW-496 and GW-503 in 1989, GW-273 in 1997, GW-322 in 2002, GW-366 in 2006 including proper agronomical practices as well plant protection measures. Further, the analysis of determinants of wheat TFP indicates that the government expenditure on crop research and education, balanced use of nutrients, moisture storage from *kharif* rain and development of ground water as well as canal irrigation in the state are the important drivers of wheat crop productivity in Gujarat. Returns to investment on wheat crop research have been found to be a highly paying proposition. It is essential that more public and private investments on technology improvement and development of irrigation infrastructure in the state through a favourable policy environment to sustain and further increase in TFP growth.

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