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Some Physiological Parameters and Sugar Concentration Changing of Sugar Beet (*Beta vulgaris* L.) Under Controlled Climatical Conditions

[1]A. Yadollahi and [2]Z. Shojaei Asadiyeh
[1]Department of Agricultural Engineering, Payame Nour University,
P.O. Box 81465-617, Kohandej, Isfahan, Iran
[2]School of Agriculture, Shahrekord University, P.O. Box 115, Shahrekord, Iran

Abstract: This research was conducted to investigate the impact of night temperature and light intensity on growth indices and sugar content of sugar beet (Triploid Multigerm Iran-Karaj 1 variety, type N-E) in a Mediterranean climate (North West of Iran) at Moghan Agro-industry and Livestock Co. from April 2001 to February 2002. Its lower sugar contents were reported than those normally grown in other sugar beet growing regions. Sugar beet crops were cultivated with full automatic controlled environment (night temperature and light intensity) facilities in an experimental farm. Data were collected 80 days after planting using a completely randomized block design with four replications using 7 treatments. The treatments consisted of night temperature 15°C (T_1) and 10°C (T_2), increase of light intensity (L), night temperature 15°C and increase of light intensity (T_1L), night temperature 10°C and increase of light intensity (T_2L), a greenhouse control (C_1) and a control without greenhouse (C_2). The total dry matter and leaves area of sugar beet were measured to calculate the growth indices including shoot crop growth rate, total crop growth rate, leaf area index and net assimilation rate from 20 days after planting. After 140 days, some samples were taken from the roots of sugar beet and pulp in order to determine the sugar content. This sampling procedure was carried out every 10 days up to 210 days after planting. Model development showed that the best equation, $Y = ae^{bx}$ (Y is the sugar content, e, the napery logarithm, a and b are coefficient and x is one of the growth indices), was obtained from data regression. The growth indices were negatively correlated well ($p<0.001$) with sugar content. Hence, the low sugar content could be due to the warm nights and slight light intensity during days.

Key words: Growth indices, night temperature, light intensity, controlled environment, Mediterranean climate

INTRODUCTION

It is well docnmented that the quality and quantity of economic plants such as sugar beet (*Beta vulgaris* L.) has increased noticeably due to improvements in agronomy and genetic (Fabeiro *et al*., 2003). One of major concerns for agricultural plants is to study growth physiology of crop yield (Freeckleton *et al*., 1999; Scott and Jeggard, 2000) and physiological growth patterns (Bedell *et al*., 2006). The relationship between growth indices and sugar content of sugar beet in a controlled environment temperature and light intensity has been studied (Ulrich, 1952). Ulrich (1952) found the sugar content of Sugar beets was 15.4% at 17°C and 18.3% at 10 and 4°C night temperature. Multi factors such as climate, soil texture, nutrient availability and the occurrence of pests and diseases and their interactions can affect crop growth (Jones *et al*., 2003; Sivakumar, 2006;

Corresponding Author: A. Yadollahi, Department of Agricultural Engineering, Payame Nour University, P.O. Box 81465-617, Kohandej, Isfahan, Iran

Qi *et al*., 2005; Kenter and Hoffmann, 2006). To date, various attempts have been carried out to study impacts of temperature changes, solar radiation and water input on the growth and development of sugar beet (Abdollahian-Noghabi and Froud-Williams, 1998; Kenter *et al*., 2006). No general conclusions of crop growth can be obtained from individuals to match other climatic regions. For example, temperature has an effect on the early growth of sugar beet in Central Europe (Durr and Boiffin, 1995) and there was a relationship between the crop growth rate and absorbed solar radiation after canopy closure in the UK (Scott and Jaggard, 1993). Most recent works has been done to quantify the influence of temperature, solar radiation and water supply on sugar beet growth (Clover *et al*., 2001; Kenter and Hoffman, 2006). Even though published data exist on the effects of agronomic ways such as irrigation and fertilization on sugar beet quantitative and qualitative analysis of the roots (Fabeiro *et al*., 2003), there is still limited data on sugar beet physiology (Yadollahi, 1998). Yet, the prime factor for sugar yield of sugar beet is low sugar content of roots in warm Mediterranean climate such as north West of Iran-Moghan. Yadollahi (1998) studied the effects of night temperature and light intensity on producer molasses in warm Mediterranean climate. It was found that the producer molasses decreased since the night temperatures were adjusted within 10-15°C in nights and light intensity, 30000 Lux in days. Sugar beets cultivating under warm Mediterranean climate in Iran-Moghan Plain has real problem as low sugar content (8-10%) which is unacceptable in crop management.

MATERIALS AND METHODS

A two-year experiment (2001-2002) was carried out in a commercial farm located in the North West of Iran with a warm Mediterranean climate. Some agronomic characteristics of the farm were consisted of the geographical location (50 m above sea level), site (39° 23'-39° 42' N and 47° 25'-48° 23'E), fertilization (300 kg t^{-1}, phosphate ammonium and urea, 100 kg t^{-}), mean temperature (°C) (T_{min}, 8.6 and T_{max}, 20.7), mean (T_{max}-T_{min}) (12.1°C), total cloudy day (141 days). The other characteristics were light intensity (15000-25000 Lux), mechanized planting systems, farm position (research site), irrigation (from Arras river) and soil (clay). A variety of triploid Multigerm Iran-Karaj 1, type N-E was selected for planting in the experimental farm (area, 70×60 m^2). Seeds were planted in 4 rows from 60 cm apart and the distance between the plants was 15 cm. Thereafter, the farm was watered. The date of planting in 2001 was 6th April and the second year was 6th February. Enough fertilization was used as basal and top-dressing (Table 1). After establishment of experimental plots, 24 greenhouses (volume: 75 cubic meter) were made to control night temperature and increase the light intensity after 80 DAP. A ventilation apparatus was installed in each greenhouse. The frame of greenhouse was made of galvanized pipes which can be easily set up. There was used 16 cooler (0-General 18000, USA) with thermostat and automatic timer set up in order to control night temperature. For increasing the light intensity (approximately 30000 Lux), supplementary lightning was provided using 12 reflective fluorescent tubes above crops (1.20 m) from 7 am to 7 pm. To

Table 1: Summary of statistical evaluation of sugar yield data in year 2002; ANOVA, a Duncan's test

Parameters ($t\ ha^{-1}$)	Date of sampling: 1st September	11th September	21st September	1st October
T_1	7.32a	8.75a	8.65a	8.17a
T_2	6.78ab	7.33b	7.50b	7.06b
L	6.33b	6.74c	6.52d	5.94cd
T_1L	6.38b	6.89bc	7.07c	6.35c
T_2L	6.33b	6.74c	6.73cd	6.10c
C_1	4.93d	5.53d	5.42f	4.97e
C_2	5.67c	6.01d	5.98e	5.43de

Means of four replicates in the same column followed by different letter(s) are significantly different according to Duncan's test at $p<0.01$

supply electricity with automatic timer set up in the greenhouses, digging channels and setting cables (35×16) in 1.2 m depth between blocks of design were done and then install the main electricity transformer. After 80 days, the controlled of night temperature was applied as well as increasing light intensity during day time. Sampling procedure was carried out to obtain experimental data including 20 DAP (for dry matter, area of leaves in relation to crop growth rate of shoot (CGR-Shoot), CGR-Total, Leaf Area Index (LAI) and Net Assimilation Rate (NAR), 140 DAP (for obtaining sugar concentration from roots and pulps of sugar beet). This sampling procedure (at the date of 140 DAP) was repeated every 10 days till 210 DAP. Each sample was taken from 1 m of middle rows. The shoots were cut from the roots and were washed and made up pulps with the weight of 100 g for each treatment. The sugar beet pulps were kept in a freezer (-20°C) to use for all analysis subjects to this research in the modern sugar beet laboratory in Ministry of agriculture, Tehran-Karaj. A completely randomized block design with four replications and seven treatments were used to obtain data after 80 Days After Planting (DAP).

Measuring Sucrose Concentration

Determination of sugar beet root quality was conducted using a Betalyser (Dr. Wolfgang Kernchen GMBH, Seelz, Germany). The pulp, 26 ±0.05 g, was added to 177 mL of Aluminium Sulphate (Sigma Alderich, UK). The solution was centrifuged (12000-15000 rpm for 3 min) and the supernatant was extracted for measuring sugar content by direct polarization at 20°C (Method GS6-3, 1994).

Determination of Sugar Yield

Sugar yields are as a result of root yield and sucrose concentration (Werker and Jaggard, 1998). Therefore, to calculate sugar yield, net sugar content (sugar) of crop is obtained from Eq. 1:

$$\text{Sugar} = \text{Pol} - \text{MS} \quad (1)$$

where, the MS expresses sugar concentration of molasses and Pol indicates sugar concentration of root measuring using a Polar meter. Then sugar yield can be calculated by Eq. 2:

$$\text{Sugar yield} = (\text{sugar}/\text{pol}) \times 100 \quad (2)$$

Model Description

A formal model as reported by Rafiei (1995) illustrates well the crop growth rate. Hence, the crop growth rate of the sugar beet is calculated using the Eq. 3.

$$Y = \exp\,(a + bx^{1/2} + cx + dx^2) \quad (3)$$

where, Y is the weight of Dry Matter (DM) and x express DAP and a, b, c and d represent coefficients of Eq. 3. The RGR is a relative growth rate and can be obtained from Eq. 4:

$$\text{RGR} = (\log w_2 - \log w_1)/(t_2 - t_1) \quad (4)$$

where, $\log w_2$ and $\log w_1$ are the weight of crop (in logarithm scale) at the harvesting time (t_1) and when the crop was dried (t_2), respectively. Other parameters such as CGR and NAR were given as below:

$$\text{CGR} = \text{RGR} \times \text{DM} \quad (5)$$

$$NAR = CGR/LAI \quad (6)$$

The LAI is defined as the total leaf area of a crop per unit area of soil surface ($m^2\ m^{-2}$). A direct method has been used to measure LAI using a LAI-2000 Plant Canopy Analyzer (Li-cor).

Statistical Analysis of Data

Statistical analyses were performed with SPSS 13.0 (SPSS, Inc., New Jersey, USA). The experimental design was a randomized complete block with four replicates. Data was subjected to ANOVA using a Duncan's test to analyze differences between seven treatments (at four dates consisting of 1st, 11th, 21st September and 1st October 2002).

RESULTS AND DISCUSSION

The results of statistical evaluation (ANOVA, a Duncan's test, Table 1) showed that significant differences were found between seven treatments in the four dates consisting of 1st, 11th, 21st September and 1st October 2002. The T_1 treatment had maximum sugar concentration of root, 8.65 t ha^{-1}. Careful consideration of data analysis indicates that sugar yield data were greatest for majority of treatments in 21st September, whereas the two treatments, C1 and C2, had lowest values of sugar yield. As a result, higher sugar yield could be achieved when shoot crop growth rate values will be more negative.

Correlation Between Growth Indices and Sugar Content of Sugar Beets

CGR-Shoot and Sugar Content

The relationship between CGR-Shoot and sugar concentration is shown in the Fig. 1 in 2001. The regression equation in the common form of $y = ae^{-bx}$ was obtained from regression analysis of two sets of data, experimental and theoretical data as follows:

$$SP = 0.940\ e^{-1.1394CGR_{sh}} \quad (6)$$

where, SP is a sucrose concentration (in percentage), e is a napery logarithm and CGR_{sh}, is a shoot CGR ($g\ m^{-2}\ day^{-1}$). The coefficient correlation (R^2) was found 0.86 (significant at the $p<0.001$ level).

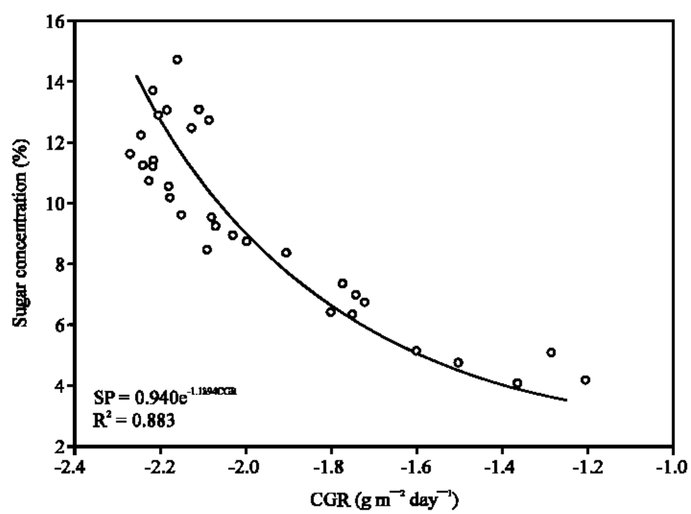

Fig. 1: Relationship between CGR values and sugar concentrations in 2001

The CGR-Shoot values inversely correlated with sucrose concentrations in 2001. It was obtained 14.7 for sucrose concentration with 2.2 g m^{-2} day^{-1} CGR shoot occurrence. The relationship between CGR-Shoot and sugar concentration (Fig. 2) in 2002, shows a negative correlation between CGR and sugar content of shoot in 2002 (based on the equation 7) and The R^2 was obtained 0.8 (significance level $p<0.001$).

$$SP = 2.046\ e^{-0.8465CGR_{sh}} \quad (7)$$

Correlation Between the CGR-Total and Sugar Content

Figure 3 showed that the relationship between total crop growth rate and sugar content in 2001.

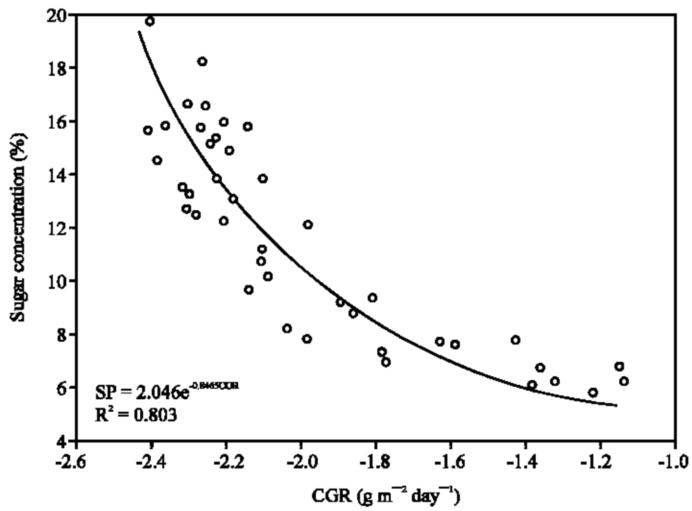

Fig. 2: The relationship between sugar concentration and CGR in 2002

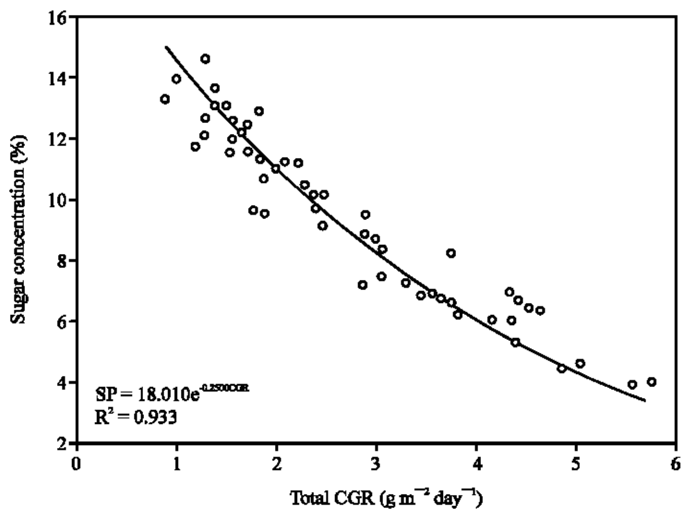

Fig. 3: Total CGR data were plotted versus sugar concentration in 2001

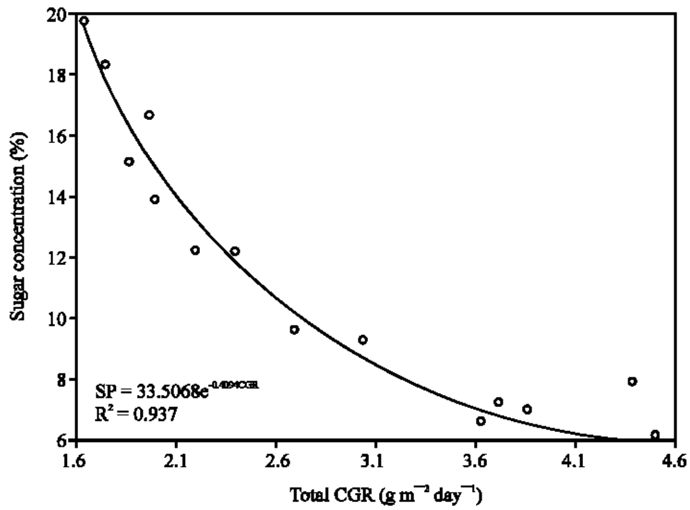

Fig. 4: Total CGR data were plotted versus sugar concentration in 2002

The best regression equation was found to be as given below:

$$SP = 18.01e^{-0.25CGR_t} \quad (8)$$

The R^2 was obtained 0.9 (significance level $p<0.001$) with a negative correlation. The sugar content of 14.7 with total CGR 1.5 g m^{-2} day^{-1} was obtained for the first year. In the second year, the relationship between total CGR and sugar content was similar to that of the first year (Fig. 4) with an equation as given below:

$$SP = 33.50687e^{-0.25CGR}t \quad (9)$$

Figure 4 shows the negative relationship between CGR shoot and sugar percentage ($R^2 = 0.9$ at $p<0.001$) in 2002. The sugar concentration was 19.7 with total CGR 1.6 g m^{-2} day^{-1}. While the total crop growth rate was found 1.5 g m^{-2} day^{-1} with a sugar content of 14.7 in the experimental farm, the total growth rate of Isfahan area (Rafiei, 1995) was reported -20 g m^{-2} day^{-1} with sugar concentration of 20. Therefore, to gain higher sugar content, it is required to maintain the total CGR low in August and September. This is consistent with the findings of Tsukada and Takada (1988) who confirmed a negative relationship between total growth rate and sugar concentration of sugar beet based on the qualitative evaluation of sugar beet.

Correlation Between LAI and Sugar Content

The negative relationship between LAI and sugar content (2002) was shown in Fig. 5. From the regression analysis, the best equation was obtained as follows:

$$SP = 39.391e^{-0.2838LAI} \quad (10)$$

In Eq. 10 the coefficient was 0.80 which was significant at $P< 0.001$ level. This imply that the LAI values around 3-4 would be suitable to gain higher sugar content. This is in agreement to the findings of Ulrich (1961) who reported LAI 4 and high sugar content 17.2 in a controlled system. Others concluded that the normal LAI 6-7 resulted in sugar content of 8-12 (Yadollahi, 1998). As a result, the appropriate variety of sugar beet and suitable farming methods may decrease LAI to a desirable level (i.e., 4).

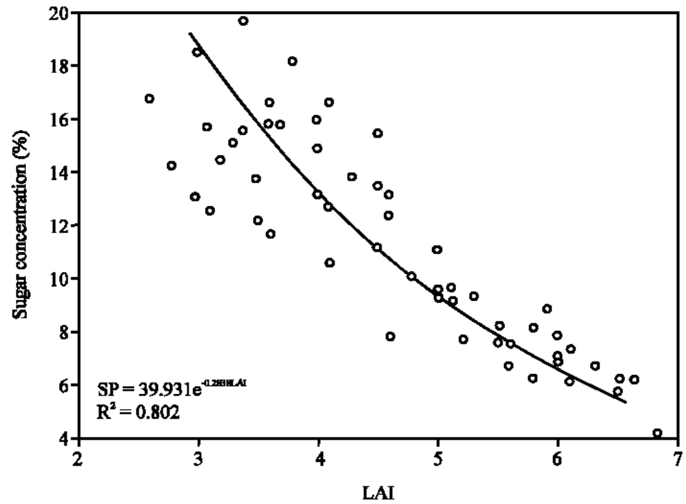

Fig. 5: Observed LAI values and sugar concentration (%)

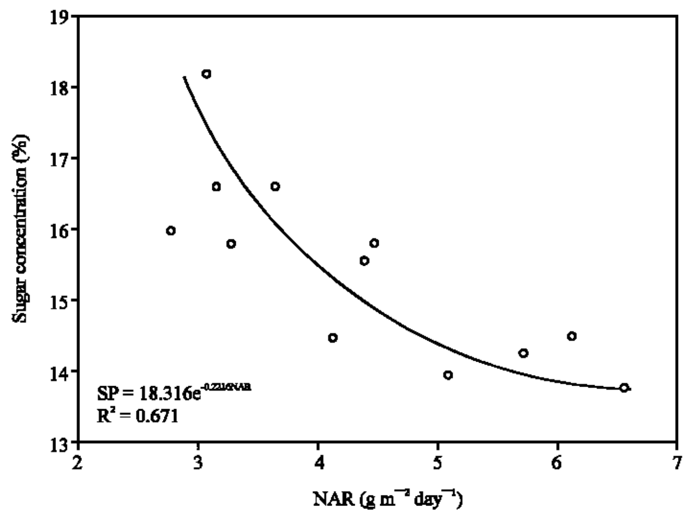

Fig. 6: Observed NAR values and sugar concentration (%)

NAR and Sugar Content

The relationship between net assimilation rate and sugar content after 140 till 210 DAP in 2002 was shown in Fig. 6. The regression relationship between net assimilation rate and sugar content was calculated as given below (Eq. 11, $R^2 = 0.7$ at $p<0.001$):

$$SP = 18.316e^{-0.2216NAR} \quad (11)$$

There is reverse correlation between NAR values and sugar content which suggests that when NAR values increase, sugar concentrations will reduce. The greatest value of NAR is about 0.4-0.6 g m^{-2} day^{-1} which is similar to the literature values (Ulrich, 1952; Miyazawa *et al*., 2004; Javaheri *et al*., 2004).

DISCUSSIONS

The sucrose concentration of sugar beet increased from 14.7 (CGR-Shoot, -2.2 g m^{-2} day^{-1}) in 2001 to 19.7 (CGR-Shoot, -2.4 g m^{-2} day^{-1}) in 2002. To achieve higher sucrose concentration, it seems that the CGR-Shoot is of prime importance. The highest sugar concentration 14.7 in year 2001 was related to CGR -2.2 g m^{-2} day^{-1} obtained from a treatment with night temperature of 15°C (T_1) 190 DAP (11th of September in 2001) also in year 2002, the highest sugar concentration was 19.7 related to CGR -2.4 g m^{-2} day^{-1} obtained from a treatment with night temperature of 15°C (T_1) 190 DAP (11th of September in 2002). The results showed that the CGR_{sh}×day values (when CGR values become negative), has not gone up more than -108 g m^{-2}. Nevertheless, the report by Rafiei (1995) pointed out that the CGR_{sh}×day values reached to -20 g m^{-2} since CGR values become negative until the time of crop harvesting, obtaining sugar concentration of 20. Although there is a relationship between negative CGR and, yellowing and falling of leaves and leaf stalk, transportation of carbohydrates from shoot to root causes an increase of the CGR. The period of CGR_{sh} would decrease with additional constituents of the CGR_{sh} product. Thus, if the time of crop harvesting delays, the sugar content decrease. It should be noted that by using growth inhibiting substrates (Ulrich, 1952) the shoot CGR in months August and September of crop harvesting decrease before crop harvesting. Consequently, the root yield and sucrose concentration have an effect on sugar yields (Werker and Jaggard, 1998). In addition to that, applying some furring method such as raining irrigation produces lower night temperature. The more negative CGR would be better condition for higher sucrose accumulation in roots. Possibly varieties that physiologically have negative CGR could be a good substitute to obtain higher sugar content. Moreover, the extent of light intensity could be accountable for modification of sugar concentration.

CONCLUSION

Sugar beet is capable and temperate crop readily settled in different environmental conditions. On the other hand, the properties of sugar beet roots are influenced by climatic conditions (Ritcher *et al*., 2001). For instance, good quality roots in terms of high sugar content can be generated if the plant is cultivated with favourable climatic such as temperate and sunlight, sugar production is directly proportioual to the sunlight interception over time by the leaf canopy (Ulrich, 1961). The result obtained from this research which done in the real farm with facilities of controlled area systems for temperate and sunlight over the canopy, exactly confirmed by the above research and model evaluations under temperate and sunlight conditions in this research showed that growth indices values were inversely correlated well to sugar concentration of sugar beet on the warm Mediterranean climate. According to this result, there is possible to increase sugar content in warm Mediterranean climate with the employs of some techniques to bring down the night temperate 80 days after planting and increase light intensity in the same period in day time.

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