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Research Article

Analysis of Sugarcane Juice Quality Indexes

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The analysis of the quality indexes of sugarcane juice plays a vital role in the process of refining sugarcane, breeding, cultivation, and production management. The paper analyzes the dynamic laws of five quality indexes (i.e., brix, purity, polarization, sucrose content, and reducing sugar) combined with graphs over time along the course of crushing season (December–March) in Guangxi province of China. During this time, the sugarcane is in the mature stage and hypermature stage. At the beginning of December to early January, during which sugarcane is in the later stage of maturity, the nutrients are accumulating, causing brix, purity, polarization, and sucrose content increase. At the beginning of January to mid-February, due to low temperature and insufficient light, it is not conducive to accumulation of nutrients. However, there is the so-called "sugar back" phenomenon and reducing sugar rises gradually in March, leading to deterioration of the quality of sugarcane juice. The results show that timely harvest of sugarcane is beneficial for sugar making. The regression analysis results show that some of quality indexes have strong correlation between them and the regression models are extremely significant, indicating that the prediction results are ideal.

1. Introduction

Sugarcane is an ancient agroindustrial crop, which contributes to more than ninety percent of the sugar production in China. Recently, this industry produces about 13 million tons of sugar and many other products such as pulp, paper, alcohol, yeast, xylitol, chemicals, drinking cane juice, biomanure, feed, and electricity (Li and Yang [1]). It is very important to analyze the quality of sugarcane juice in the role of refining sugarcane, breeding, cultivation, and production management. The mixed juice characteristics, along the course of crushing season, are influenced by variations in cane variety, changes in the agroclimatic conditions, and fluctuations in the process parameters (Ghosh and Balakrishnan [2]). Kumar and Chand [3] applied the response surface method and experimental design to optimize independent variables for clarification of sugarcane juice. In this study, regression model is established for the quality index of multi-input and single output. Kouzi [4] studied the effects of different cane conditions in the field on dextran level in cane juice (e.g., burning, chopping, delay between cutting and milling, and type of ratoon) and factors affecting levels of dextran during processing. The most important five criteria are, namely, polarization (Pol), apparent purity, pH, viscosity, and commercial cane sugar (CCS) of the cane juice; besides dextran content of juice has been used to measure the cane deterioration. Lingle et al. [5] provided evidence that sugarcane juice quality in late-harvested sugarcane has been increased by six cycles of recurrent selection for sucrose but that a limit may have been reached for further improvement. Wang et al. [6] analyzed the change rules of the cane juice purity, the polarization, and the reduction sugar and built the simple regression model between sucrose content (Suc) and the other five quality indexes, namely, reduction sugar (Rs), polarization (Pol), brix (Bx), apparent purity (Ap), and gravity purity (Gp). Nawi et al. [7] applied the Vis/SWNIR spectroscopy combined with PLS models to predict sugarcane quality (brix and polarization) from both clear and raw sugarcane juices. Sheikh [8] evaluated juice quality parameters ((percentage of cane), pol, brix, . . . , etc.)) and the level of colouring materials in crushed cane (green or burned) and evaluated the effect of low doses of separan on juice

quality and colour. Wang et al. [9] analyzed the changing law of the sugarcane juice purity by using seven main sugarcane varieties in the Zhanjiang area. The results show that when the ratio of the apparent purity and gravity purity is very close to 1, the sugar content almost reaches its apogee. Golabi et al. [10] evaluated the effect of irrigation water electrical conductivity on three varieties of sugarcane juice quality. Nawi et al. [11] identified the optimum sample form for predicting sugarcane quality using a low-cost and portable spectrometer. Mat et al. [12] explore the potential of spectroscopic method to predict sugarcane quality parameters by directly scanning the internode samples. Nawi et al. ([7, 13]) used visible and short-wave near infrared (Vis/SWNIR) spectroscopy to predict soluble solids content and sucrose content from sugarcane juice samples. The overall results indicated that Vis/SWNIR spectroscopy combined with PLS models could be applied to predict sugar content in both clear and raw sugarcane juices.

In the previous research, the author of this paper has successfully applied regression method to the field of mechanical processing (Xiao et al. [14]), in which the regression model is used to establish the relationship between the cutting parameters (spindle speed, feed rate and depth of cut) and the surface roughness. Because the regression model is universal in the field of quality control and prediction, this paper extends the application of regression method to the field of sugarcane juice quality indexes. After analyzing the dynamic laws of five quality indexes (i.e., brix, purity, polarization, sucrose content, and reducing sugar) combined with graphs over time, the paper establishes the relationship between the quality indexes of sugarcane juice by using regression method.

2. Data Sources

In this study, the data are derived from the measurement results of the indexes of sugarcane juice in Guangxi of China along the course of crushing season (December–March). The quality indexes of sugarcane juice studied in the paper include the following: (a) sucrose content (Suc); (b) brix (Bx); (c) polarization (Pol); (d) apparent purity (Ap); and (e) gravity purity (Gp). Matlab software system [15] is used to analyze the data in the discussion below.

3. Results and Discussion

3.1. The Change Rules of Every Index of Mixed Juice. Samples of sugarcane juice were tested about every two weeks along the course of crushing season (December–March), that is, sampling from eight days.

It can be clearly seen from Figure 1 that brix decreases in the early stage of maturity and then increases in the late stage of maturity. Because the daytime temperature is low and sunlight is not enough from mid-January to mid-February in Guangxi area, nutrients produced by photosynthesis are relatively few. The temperature of daytime rises and sunlight is enough in March, which leads to the relative increase of nutrients produced by the enhanced photosynthesis. However, day-and-night temperature difference is large and the intensity of respiration decreases due to low night temperature; thus consumption of nutrients is relatively small, which is conducive to the accumulation of nutrients. However, there is a positive correlation between brix and nutrients, which leads to the curve changing laws showed in the figure.

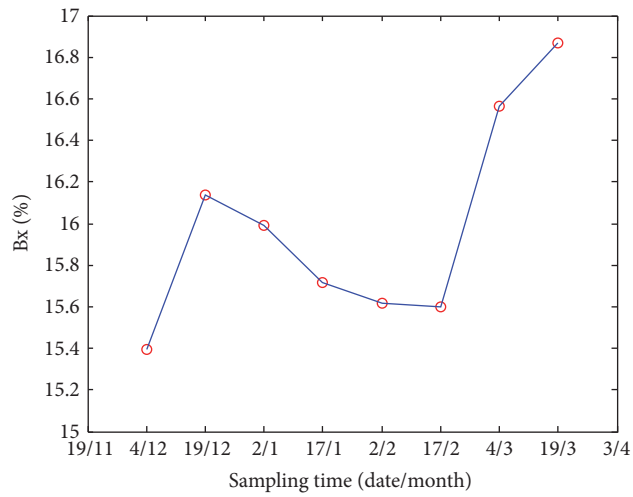

Figure 1: The change of brix over time for mixed juice samples.

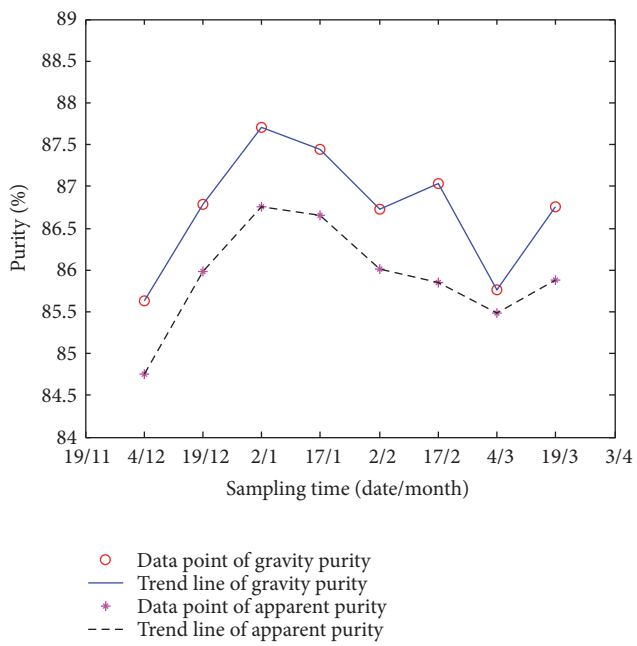

Figure 2: The change of purity over time for mixed juice samples.

Figure 2 shows the change of purity with time. It clearly shows that the changing trends of gravity purity and apparent purity are similar: there is an increase in purity from early December to the following early January and after that the purity tends to decrease in spite of small fluctuations. The purity, especially the gravity purity, can represent the numerical values of dry solid materials of sugarcane [9]; therefore, it can be seen that the sugar content is the highest in early January during crushing season. The results show that the sugarcane has begun to "sugar back" in February, so the purity of sugarcane juice has the trend of decreasing.

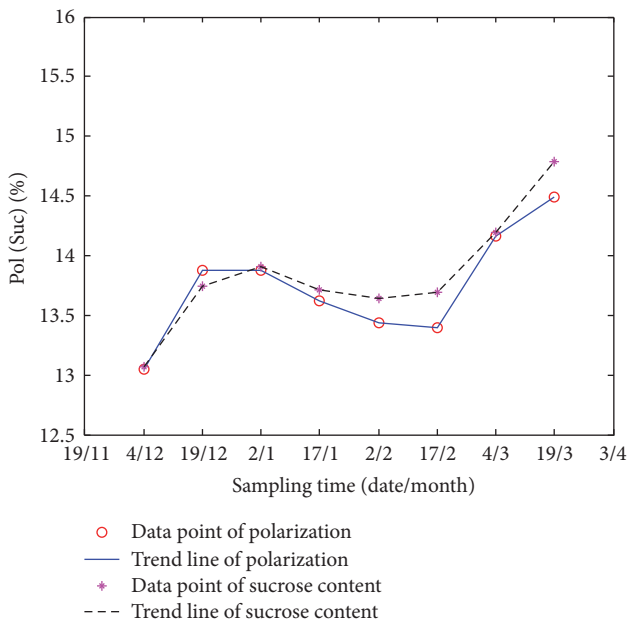

Figure 3: The change of polarization (Pol) and sucrose content (Suc) over time for mixed juice samples.

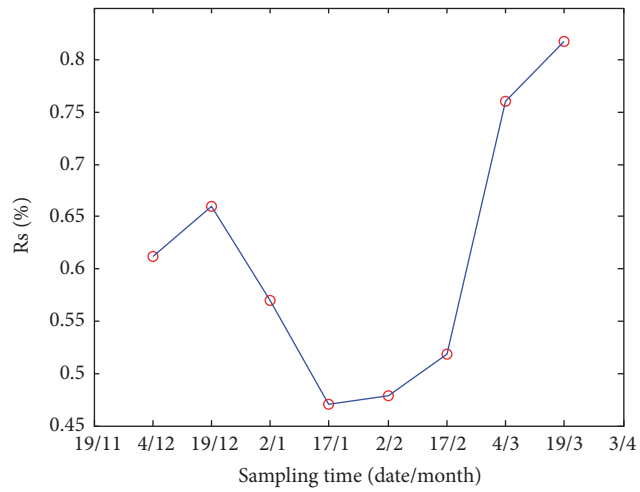

Figure 4: The change of reducing sugar (Rs) over time for mixed juice samples.

Therefore, the purity of sugarcane juice of timely harvest of sugarcane is relatively high, benefitting for sugar making.

Figure 3 indicates that the change trend of polarization is consistent with the change trend of sucrose content in juice, which shows a strong correlation between them. The comparison of Figures 1 and 3 shows that the laws of the curves are similar. The reasons for the change are similar to those discussed in Figure 1. At later stage of maturity, the photosynthetic products are mainly accumulated in the form of sucrose but are rarely used as a form of monosaccharide for growth, so growth is stagnant and sugar accumulation is much.

It can be concluded from Figure 4 that reducing sugar is low when the sugarcane is ripe and reducing sugar is high when the sugarcane is immature or overripe; especially when the quality of sugarcane juice tends to be worse, reducing sugar increases significantly. The results show that, during the period of the growth and maturity of sugarcane, after sucrose produced by sugarcane leaves is transported to the cane and then decomposed again, the ratio for growth in the form of reducing sugar decreases gradually. Reducing sugar is again constantly used for growth and synthesized to sucrose in the cane. Coupled with the consumption of respiration, so reducing sugar is decreasing with the increasing of plant age. However, sucrose begins to be transformed, showing the so-called "sugar back" phenomenon because of increased temperatures and increased rain after March in the subtropical climate of Guangxi, so the content of reducing sugar begins to rise again. Therefore, the constantly dropping content of reducing sugar of sugarcane during maturation stage is an important characteristic of maturity. The lower the content of reducing sugar is, the better the quality of cane juice is. According to the above analysis, the sugar will be consumed quickly after harvest.

3.2. Simple Linear Regression Analysis. Simple linear regression analysis [16] is carried out by 665 samples of sucrose content (Suc) and brix (Bx). The regression equation is as follows:

$$\text{Suc} = 1.3159 + 0.7851 \cdot \text{Bx}. \quad (1)$$

It is proved by the strong correlation ($R^2 = 0.924535$) between sucrose content (Suc) and brix (Bx). The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$). The results show that there is a strong correlation between brix and sucrose content. In addition, the way of measurement of brix is simple, quick, and convenient. Therefore, sucrose content could be calculated by measuring the brix of sugarcane juice.

681 samples are taken to set up a regression model between sucrose content (Suc) and polarization (Pol). The model is as follows:

$$\text{Suc} = 0.0634 + 1.0039 \cdot \text{Pol}. \quad (2)$$

The model was significant ($p < 0.05$) with F value of $1.054781e + 05$. The data present the strong correlation ($R^2 = 0.993604$) between polarization (Pol) and sucrose content (Suc), which implies that the model accounts for 99.3604% variability in the data. Lack of fit is insignificant, so the model is considered adequate as it had a high R^2 value and significant F value. According to (2), sucrose content can be expressed approximately by polarization.

Because factors that affect sucrose content (Suc) include the apparent purity (Ap) and brix (Bx), multiple linear regression analysis is performed as follows:

$$\text{Suc} = 12.9679 + 0.1525 \cdot \text{Ap} + 0.8578 \cdot \text{Bx}. \quad (3)$$

The coefficient of determination of (3) is 0.993684, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant

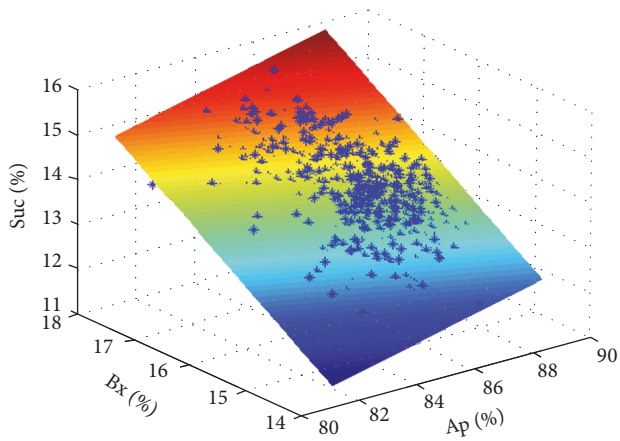

Figure 5: 3D response surface of the detected data (apparent purity, brix, and sucrose content).

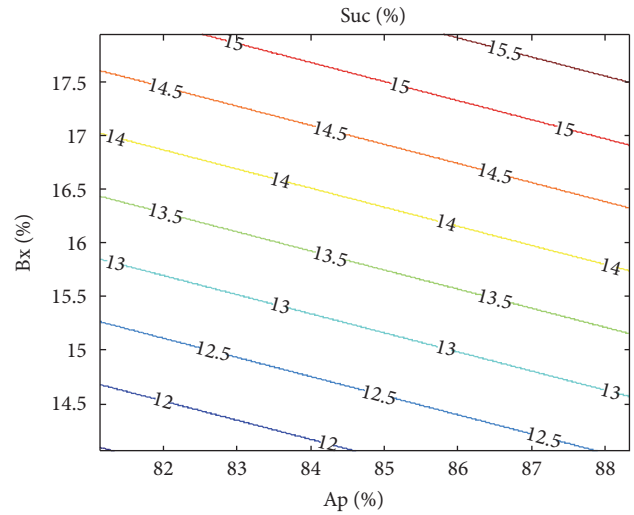

Figure 6: Contour plot between apparent purity and brix.

level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$). The results show that the prediction accuracy of (3) is very high.

The effect of apparent purity (Ap) and brix (Bx) on sucrose content (Suc) can be concluded from Figures 5 and 6. Sucrose content (Suc) is increasing with increasing apparent purity (Ap) and brix (Bx). The result shows that there is a positive correlation between Ap, Bx, and Suc, which can also be deduced obviously from (3).

Because factors that affect sucrose content (Suc) include polarization (Pol) and brix (Bx), multiple linear regression analysis is performed as follows:

$$\text{Suc} = 0.0700 + 0.9479 \cdot \text{Pol} + 0.0476 \cdot \text{Bx}. \quad (4)$$

The coefficient of determination of (4) is 0.994023, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$). Sucrose content (Suc) is increasing with increasing polarization (Pol) and the effect of brix (Bx) on Suc is very weak.

Because factors that affect sucrose content (Suc) include the apparent purity (Ap) and polarization (Pol), multiple linear regression analysis is performed as follows:

$$\text{Suc} = 0.8553 + 0.0092 \cdot \text{Ap} + 1.0037 \cdot \text{Pol}. \quad (5)$$

The coefficient of determination of (5) is 0.994035, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$). The effect of polarization (Pol) on sucrose content (Suc) is significantly greater than that of apparent purity (Ap). Sucrose content (Suc) is increasing with increasing polarization (Pol) and apparent purity (Ap)'s effect on sucrose content (Suc) is very weak.

The simple linear regression model between sucrose content (Suc) and the apparent purity (Ap), polarization (Pol) and brix (Bx) is as follows:

$$\text{Suc} = 9.0829 - 0.1055 \cdot \text{Ap} + 1.5980 \cdot \text{Pol} - 0.5079 \cdot \text{Bx}. \quad (6)$$

The coefficient of determination of (6) is 0.994108, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$).

The effect of polarization (Pol) and brix (Bx) on sucrose content (Suc) keeping apparent purity = 81.16% is shown in Figures 7 and 8. Increasing the positive terms will increase the response; however, increasing the negative terms will decrease the response. Therefore, sucrose content (Suc) is increasing with increasing polarization (Pol) and decreasing with increasing brix (Bx) according to model (6).

The effect of apparent purity (Ap) and brix (Bx) on sucrose content (Suc) keeping polarization = 15.31% shows that sucrose content (Suc) is decreasing with increasing apparent purity (Ap) and brix (Bx).

The effect of apparent purity (Ap) and polarization (Pol) on sucrose content (Suc) keeping brix = 14.07% shows that sucrose content (Suc) is increasing with increasing polarization (Pol) and sucrose content (Suc) is decreasing with increasing apparent purity (Ap). 3D response surfaces and contour plots of the latter two cases have been omitted in the article, the drawing methods of which are similar to Figures 7 and 8.

From the above analyses, sucrose content (Suc) can be predicted by single or multiple quality indexes.

Because factors that affect the gravity purity (Gp) include sucrose content (Suc) and brix (Bx) (Wang et al. [6]), multiple linear regression analysis is performed as follows:

$$\text{Gp} = 86.2640 + 6.1654 \cdot \text{Suc} - 5.3175 \cdot \text{Bx}. \quad (7)$$

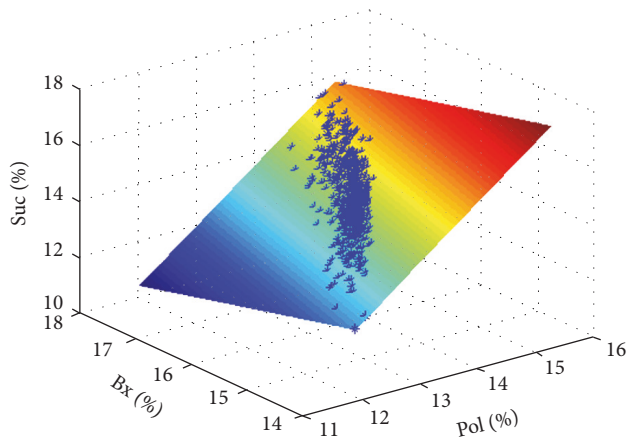

Figure 7: 3D response surface of the detected data (polarization, brix, and sucrose content) at apparent purity = 81.16%.

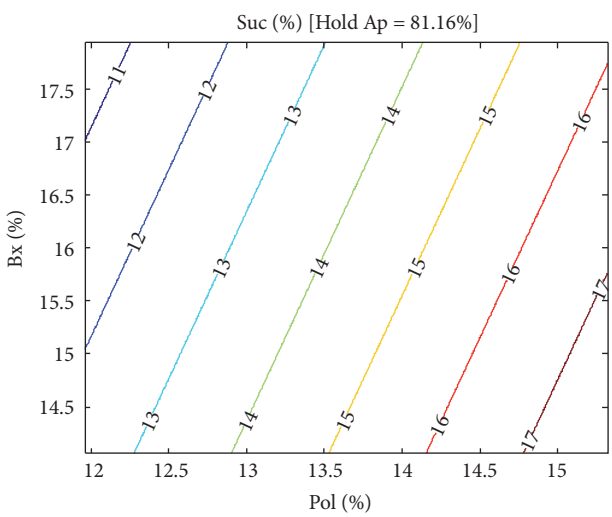

Figure 8: Contour plot between polarization and brix at apparent purity = 81.16%.

The coefficient of determination of (7) is 0.998411, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$).

The effect of sucrose content (Suc) and brix (Bx) on gravity purity (Gp) shows that by increasing the positive term the response will increase and by increasing the negative term, the response will decrease. Gravity purity (Gp) is increasing with increasing sucrose content (Suc) and decreasing with increasing brix (Bx).

Because factors that affect the apparent purity (Ap) include polarization (Pol) and brix (Bx) (Wang et al. [6]), multiple linear regression analysis is performed as follows:

$$\mathrm{Ap} = 85.3876 + 6.1733 \cdot \mathrm{Pol} - 5.2702 \cdot \mathrm{Bx}. \quad (8)$$

The coefficient of determination of (8) is 0.998245, which indicates high degree of fitting, namely, high reliability of the trend. The simple regression model reaches a very significant level ($p < 0.01$). In addition, the regression coefficient and regression intercept have reached a significant level ($p < 0.01$). It can be known clearly that apparent purity (Ap) is increasing with increasing polarization (Pol) and decreasing with increasing brix (Bx).

4. Conclusions

This work has dynamically analyzed five quality indexes of sugarcane juice along the course of crushing season (December–March) in the Guangxi province of China. Simple linear regression analysis showed that the following quality indexes have strong correlation between them and the regression models are extremely significant ($p < 0.01$): (a) sucrose content (Suc) and brix (Bx); (b) sucrose content (Suc) and polarization (Pol); (c) apparent purity (Ap), brix (Bx), and sucrose content (Suc); (d) polarization (Pol), brix (Bx), and sucrose content (Suc); (e) apparent purity (Ap), polarization (Pol), and sucrose content (Suc); (f) apparent purity (Ap), polarization (Pol), brix (Bx), and sucrose content (Suc); (g) sucrose content (Suc), brix (Bx), and gravity purity (Gp); and (h) polarization (Pol), brix (Bx), and apparent purity (Ap). This is an extended application of regression method in quality indexes forecast field, which is studied in the previous research of the author of this paper.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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