



# **EVALUATION OF SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF FORASTERO COCOA (*Theobroma cacao* L.) BEANS REQUIRED FOR ITS PROCESSING**

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## **Abstract**

**T**he physical and mechanical properties of cocoa beans are indispensable in its processing. However, larger percentages of cocoa production are exported in the raw form due to limited literature information regarding the physico-mechanical properties required for its

handling. This study evaluates selected physical and mechanical properties of forastero cocoa beans required for its processing. The axial

**Keywords:** coco beans, fermentation, cocoa nibs, and axial physical property dimensions.

dimensions (major, intermediate and minor diameters), sphericity, aspect ratio surface area and volume of the coco sample and the force required for cracking the coco sample were assessed at  $7.49 \pm 1.5$  %wb moisture content. The compression test indicated that the breaking force required along the major bean diameters were lower to the force required along the intermediate bean diameters.

## Introduction

Cocoa (*Theobroma cacao* L.), a member of the family *Sterculiaceae* family and the genus *Theobroma* is one of the main cash crops in Nigeria (Prabhakaran-Nair, 2010) and in other producing and consuming countries and as well as the main input material in many food processing industries around the world. The bean is the major raw material for the manufacturing industries of chocolate and other cocoa-based products. The cocoa beans powder is the base-material for all cocoa based confectioneries, beverages, chocolates, candies, cookies, sweets, butter, ice cream, soft drinks, flavoring agents, pharmaceutical products and cosmetics (Ogunsina *et al.*, 2017).

More than 70% of the world's cocoa production is reported to take place in West and Central African countries with Cote d'Ivoire, Ghana, Nigeria and Cameroon listed as the main producing countries in the region (Afoakwa *et al.*, 2011). The remaining production is from the equatorial regions of Central and South America, the West Indies and tropical areas of Asia (Kongor *et al.*, 2016). Nigeria is ranked in the fifth position after Côte d'Ivoire, Ghana, Cameroon and Indonesia in the world cocoa production ranking with around 2.8 metric tonnes of cocoa beans in the year 2022/2023 (Shahbandeh, 2021). The main producing states in the South-Western Nigeria include Ondo, Oyo, Osun, Ogun and Ekiti states.

Cocoa processing operations are divided into primary processing operations involving pod opening, extraction of seeds, fermentation and drying of fermented seeds resulting in the production of dried raw cocoa beans from the harvested cocoa pods normally carried out in the producing areas by the growers. And the secondary processing operations resulting in the production of cocoa liquor, cocoa butter and cocoa powder (Dillinger *et al.*, 2000) from fermented and dried cocoa beans has been concentrated in the importing and consuming countries. Large quantities of cocoa produced in West Africa, including Nigeria are exported in the raw form to the developed countries due to low level and or lack of processing technology (Amponsah *et al.*, 2019). To increase the involvement of the producing West Africa countries in the processing of cocoa beans to export value, these countries have to be able to develop and increase their capability to meet the quality of the world cocoa standards.

The physical and mechanical properties of cocoa beans, the same as for other grains and seeds are indispensable in the handling, processing, design and fabrication of equipment for the beans. A number of researches have been carried out on the physical and mechanical properties of cocoa beans among others were: Clement *et al.* (2018) studied experimental determination of modulus of elasticity of oven dried cocoa-beans varieties, Jayeoba *et al.*, (2016) studied moisture-dependent physical properties of cocoa (*Theobroma cacao*) pods, Nicolas *et al.* (2014) carried out physical and chemical assessment quality of cocoa beans in the south and center regions of Cameroon, Bart-Plange *et al.* (2012) carried out comparative study of some physical properties of large and medium size cocoa beans from Ghana. Hartuti *et al.* (2019) studied characteristics of dried cocoa beans color using response surface methodology. Many other researches done on development of cocoa processing machine were: Huy-Bich *et al.* (2019) carried out a study on the breaking and winnowing machine for cocoa beans at small industrial scale in Vietnam. Akinnuli *et al.* (2015) carried out design concepts towards cocoa winnowing mechanization for nib's production in manufacturing industries. Harsha *et al.* (2019) carried out design and fabrication of portable cocoa bean separation machine. Iyanda (2018) carried out design, fabrication and testing of cocoa depodding machine. Nigeria as one of the main cocoa producing countries in the world export larger percentages of her cocoa production in the raw form. This may be due to limited scientific literature information regarding the physico-mechanical properties of cocoa beans required for the handling, processing, design and fabrication of equipment for the beans. Therefore, the aim of this study is to assess the physical and mechanical properties and energy required for breaking forastero cocoa beans of Nigerian origin.

## **Material and Methods**

### **Materials collection and preparation**

Matured and ripped harvested cocoa pods of the forastero variety were procured from the Cocoa Research Institute of Nigeria (CRIN) Ibadan, Oyo state. The primary processing of the pods involving splitting of pods and extraction of seeds from pods and heap fermentation and sun drying of the

fermented seeds were carried out following the methods prescribed by Amponsah *et al.* (2019). The breaking of the pods using a blunt cutlass to split the pods into two halves to expose the bean seeds and scooping of beans from the pods and separation of placenta were done manually. Thereafter, the extracted seeds were heaped on plantain leaves and rapped by the leaves and allowed to ferment for a fermentation periods of eight (8) days (Figure 1a).

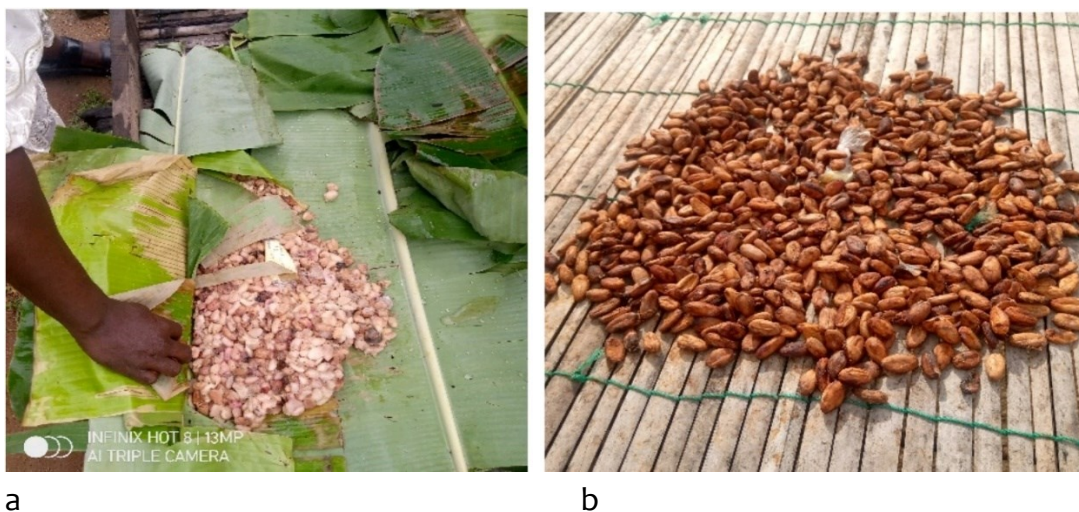


**Plate 1:** (a) Fermentation process, (b) Drying of cocoa beans

This was followed up by the turning of the cocoa beans every two days to ensure even fermentation until the end of the eighth day. After the fermentation, sun drying of the fermented beans was carried out by spreading of the beans on a raffia mat raised above the ground on a table (Figure 1b). The drying process continued for 14 days until the moisture is reduced to acceptable level, while the beans were periodically stirred during the drying periods to ensure uniform drying.

### Measurement of physical properties of cocoa Beans

The moisture content of the cocoa beans sample on wet basis ( $MC_{wb}$ ) was determined by the oven drying method in accordance with ASAE Standard S358.2 described by Prasanna (2017). Sample weights of the beans sample were oven dried at 105 °C temperature until three consecutives equal weights were obtained and recorded (AOAC, 2019). The weights of sample before ( $w_i$ )

and after ( $w_f$ ) drying were recorded and the procedure replicated thrice. The  $MC_{wb}$  of the cocoa sample was calculated from the recorded data using Equation 1.

The three principal axial dimensions; major (L), intermediate (W) and minor (T) diameters of fifty (50) randomly selected cocoa sample were measured using a digital Vernier Caliper (0.001 mm accuracy) and the values obtained recorded. The Geometric mean diameter ( $G_{md}$ ), Arithmetic mean diameter ( $A_{md}$ ), Square mean diameter ( $S_{md}$ ) and Equivalent diameter ( $E_{qd}$ ) of the sample were calculated from the mean values of the measured axial dimensions recorded using Equations 2, 3, 4 and 5, respectively as reported by El-Fawal *et al.* (2009). The Sphericity ( $\phi$ ) and Aspect ratio ( $A_R$ ) at natural flat positions were calculated from the geometric mean and major diameters using equations 6 (Mohsenin (1986); Vengaiah *et al.* (2021) and 7 (Sahin and Sumnu, 2006), respectively. The Surface area ( $S_A$ ) and Volume (V) of the cocoa sample were calculated by analogy with a sphere of the same geometric mean diameter using Equations 8 and 9 (Siqueira *et al.*, 2013), respectively.

The weight value of the cocoa sample was measured using the procedure described by Sandoval *et al.* (2019). One hundred (100) randomly selected samples of the cocoa were weighed on an electronic balance and the weight values recorded. The bulk density ( $\rho_b$ ) of the sample was determined using the method described by Thompson *et al.* (2021). An empty cylinder of height,  $h$  and diameter,  $d$  was filled with the cocoa sample. Same sample was emptied into an empty container of known weight and weighed using an electronic weighing balance (0.001 g accuracy). The mass,  $M$  of the bean sample recorded was used to evaluate the bulk density using the relation in Equation 10.

The angle of repose on steel surface was determined following the method of Busari and Olaoye (2016). An open-end cylindrical container was placed on a galvanized steel surface. The cylinder was filled with the cocoa bean to the brim and the container was emptied gradually on the steel surface to form a conical heap with the seeds. The angle of repose ( $\theta$ ) was calculated from the height ( $h$ ) and base radius ( $r$ ) of the heap using Equation 11. The coefficient of friction of cocoa bean samples was determined on mild steel surface. The mild steel surface was fixed on a tilting table and the cocoa beans were poured into a cardboard paper ring of diameter 10 cm by 2 cm deep until the ring was full.

The ring was raised slightly and carefully so that it did not touch the surface. The table was then slowly tilted by a screw device until movement of the cocoa beans mounted against the edge of the tilting table. The tangent of the angle of friction was measured and recorded as the angle of tilt ( $\alpha$ ). Coefficient of friction for the cocoa bean sample was measured as the beans begin to slide from a protractor attached to the inclined plane. The tangent of angle of inclination was the coefficient of static friction ( $\mu$ ) is given by Equation 12 as reported by Babatunde et al. (2018).

$$\begin{aligned}
 MC_{wb} &= \frac{w_i - w_f}{w_i} \times 100 & 1 \\
 G_{md} &= (LWT)^{\frac{1}{3}} & 2 \\
 A_{md} &= (L + W + T)^{\frac{1}{3}} & 3 \\
 S_{md} &= \sqrt{LW + WT + LT} & 4 \\
 E_{qd} &= [Amd + Gmd + Smd]/3 & 5 \\
 \phi &= \frac{(LWT)^{1/3}}{L} \times 100 & 6 \\
 A_R &= \frac{W}{L} \times 100 & 7 \\
 S_A &= \sqrt[2]{\pi G_{md}} & 8 \\
 V &= \left(\frac{\pi}{6}\right) LWT & 9 \\
 \rho_b &= \frac{4M}{\pi d^2 h} & 10 \\
 \theta &= \tan^{-1} \left(\frac{h}{r}\right) & 11 \\
 \mu &= \tan \alpha & 12
 \end{aligned}$$

### Measurement of compression properties of cocoa bean

The force required to break cocoa seed sample with respect to the different beans orientations was carried out using the Universal Testing Machine (Model No: 0500-10080) in accordance with the procedure described by Clement (2018). Fifteen (15) cocoa bean seeds representing five (5) beans for each of the axial dimension side's namely major, minor and intermediate diameters of the cocoa sample were used for the test. Each bean sample in turn was placed laterally on the stable platform between testometer and compressed with a motion probe at a constant speed of 1.5 mm/min until the bean sample fractured. The applied force at bioyield point and the corresponding

deflections for each bean sample were read directly from the force-deflection curve. The compressive strength of the sample was expressed in terms of the force required to crack the sample to initial rupture and its specific deformation energy were recorded. The rupture force was taken as displayed on the digital screen when the bean sample under compression makes a clicking sound.

## **Results and Discussion**

### **Physical properties of the cocoa beans**

The physical properties of the cocoa sample were assessed at average moisture content of  $7.49 \pm 1.5$  %wb. The moisture content value was within the 6 – 8 %wb required for maintaining the quality of cocoa beans during storage (Afoakwa *et al.*, 2012). The summary of the maximum, minimum, mean and standard deviation (STD) for sample size of 50 seeds of the measured physical properties of the cocoa sample are presented in Table 1. The mean values of L, W and T were  $19.68 \pm 2.56$ ,  $10.91 \pm 1.46$  and  $7.34 \pm 1.51$  mm, respectively. The result is in agreement with corresponding mean values of 25.02, 14.28 and 7.96 mm obtained for TD8 cocoa variety report by Ha *et al.* (2016). The result is also in agreement with the corresponding ranged of values of 20.0 - 26.0, 10.0 - 14.0 and 6.0 - 10.0 mm, respectively obtained for criollo cocoa variety reported by Bart-Plange *et al.* (2002). Axial dimensions and size are physical properties essential in the screening as well as in the grading and evaluation of the quality of grain products and are also significant in the setting of the huller component clearance in hulling mechanism (Kuala *et al.*, 2019). The results of the  $G_{md}$  and  $A_{md}$  range of 3.01 – 3.36 mm and 14.64 – 8.30 mm, respectively obtained were lower to the corresponding range of 13.04 – 13.34 and 14.2 – 14.57 mm reported for amelonado cocoa variety by Anyidoho (2015). The  $S_{md}$  value was  $20.92 \pm 2.44$  mm with maximum value of 25.37 mm and minimum value of 15.49 mm. While the  $E_{qd}$  value was  $11.95 \pm 1.33$  mm with maximum and minimum values of 14.82 and 8.99 mm, respectively. The table also showed value of the cocoa bean surface area range from  $41.05 \pm 5.05$  mm<sup>2</sup> with maximum value of 50.72 mm<sup>2</sup> and minimum value of 29.57 mm<sup>2</sup>.

The angle of repose and coefficient of friction of cocoa bean on mild steel surface ranged from 23.68 - 38.6° and 0.439 - 0.798 with mean values of  $29.1 \pm 6.28$ ° and  $0.564 \pm 0.15$ , respectively. Bart-plange *et al.* (2012) found

coefficient of friction and angle of repose for mild steel increase from 0.48–0.60 and 23.7–33.8°, respectively for cocoa

**Table 1: Descriptive statistics of *Forastero* cocoa sample dimensions**

| Properties                         | Max.  | Min   | Mean   | ST. dev |
|------------------------------------|-------|-------|--------|---------|
| L, (mm)                            | 24.91 | 13.45 | 19.68  | 2.56    |
| W, (mm)                            | 14.46 | 6.99  | 10.91  | 1.46    |
| T, (mm)                            | 10.66 | 4.095 | 7.34   | 1.51    |
| $G_{md}$ , (mm)                    | 3.613 | 3.01  | 3.36   | 0.13    |
| $A_{md}$ , (mm)                    | 14.64 | 8.3   | 11.51  | 1.41    |
| $S_{md}$ , (mm)                    | 25.37 | 15.49 | 20.92  | 2.44    |
| $E_{qd}$ , (mm)                    | 14.82 | 8.99  | 11.95  | 1.33    |
| $\emptyset$ , (%)                  | 23.82 | 41.31 | 59.12  | 5.15    |
| $A_R$ , (%)                        | 72.32 | 40.24 | 55.44  | 5.09    |
| $S_A$ , (mm <sup>2</sup> )         | 50.72 | 29.57 | 41.05  | 5.05    |
| V, (mm <sup>3</sup> )              | 1502  | 799   | 985.75 | 302.89  |
| $M_{100}$ , (g)                    | 263.8 | 243.2 | 255.3  | 90.66   |
| Angle of repose                    | 38.6  | 23.68 | 29.1   | 6.28    |
| Co of friction, (rad)              | 0.798 | 0.439 | 0.564  | 0.15    |
| Bulk density, (g/cm <sup>3</sup> ) | 623   | 518   | 566    | 0.04    |

L: Major diameter, W: Intermediate diameter, T: Minor diameter,  $G_{md}$ : Geometric mean diameter,  $A_{md}$ : Arithmetic mean diameter,  $S_{md}$ : Square mean diameter,  $E_{qd}$ : Equivalent diameter, Sph: Sphericity, Ar: Aspect ratio, SA: Surface area, Bm: beans mass

The bulk density ranged from 518 to 623 g/cm<sup>3</sup> with mean value of 566±0.042 g/cm<sup>3</sup>, particle density ranged from 854 to 989 g/cm<sup>3</sup> with mean value of 932±0.057 g/cm<sup>3</sup>. Bart-Plange and Edward (2002) reported mean bulk density and particle density to be 559.6 g/cm<sup>3</sup> and 946.17 g/cm<sup>3</sup>, respectively. Volume ranged from 799 to 1502 cm<sup>3</sup> with mean value of 985.75± 302.09 cm<sup>3</sup> and values of the mass of one hundred beans ranged from 263.8 to 243.2 g with mean value of 255.3 ± 90.66 g, respectively.

### **Compression Properties of Cocoa Beans**

The compression test properties of the cocoa beans sample along their three axial dimensions; major, intermediate and minor diameters consisting of the minimum, maximum, mean and standard deviation and coefficient of variation, Lower Control Limit (LCL) and Upper Control Limit (UCL) are presented in Tables 2, 3 and 4, respectively. The measured compression test result comprised of the force at peak point, force at breaking point and deformation at peak, deformation at breaking point and energy at peak and energy at breaking point for the cocoa beans. The force at peak point on the major, intermediate and minor bean diameters of the cocoa sample ranged from  $49.78 \pm 20.70$ ,  $72.03 \pm 17.07$  and  $47.78 \pm 16.47$  N with minimum and maximum values of 30.42 and 73.70 N; 45.53 and 90.10 N and 33.440 and 66.59 N, respectively. Similarly, the corresponding force at breaking point ranged from  $40.26 \pm 23.47$ ,  $70.53 \pm 17.60$  and  $46.60 \pm 17.69$  N with minimum values of 22.24, 45.53 and 29.75 N and maximum values of 72.79, 90.40 and 66.59 N, respectively. The deformation at peak point on the major, intermediate

**Table 02: Compression test result of dried cocoa beans on the major diameter axis**

| Properties       | Unit | Min   | Max   | Mean  | ST. dev | C of V | LCL   | UCL   |
|------------------|------|-------|-------|-------|---------|--------|-------|-------|
| <b>F @ peak</b>  | N    | 30.42 | 73.70 | 49.78 | 20.70   | 41.58  | 24.08 | 75.48 |
| <b>F @ break</b> | N    | 22.24 | 72.79 | 40.26 | 23.47   | 50.72  | 17.13 | 75.40 |
| <b>D @ peak</b>  | Mm   | 0.86  | 1.56  | 1.18  | 0.30    | 25.41  | 0.81  | 1.56  |
| <b>D @ break</b> | Mm   | 0.92  | 1.61  | 1.38  | 0.27    | 19.98  | 1.03  | 1.71  |
| <b>E @ peak</b>  | Nm   | 0.02  | 0.07  | 0.04  | 0.02    | 62.32  | 0.01  | 0.06  |
| <b>E @ break</b> | Nm   | 0.02  | 0.07  | 0.04  | 0.02    | 48.26  | 0.02  | 0.06  |

F @ peak–force at peak, F @ break–force at break, D @ peak–deformation at peak, D @ break–deformation at break, E @ peak–energy at peak, E @ break–energy at break, Min–minimum, Max–maximum, ST. dev – standard deviation, C of V co-efficient of variation, LCL–lower control limit and UCL–upper control limit

**Table 3: Compression test result of dried cocoa beans on the minor diameter axis**

| Properties | Unit | Min   | Max   | Mean  | ST. dev | C of V | LCL   | UCL   |
|------------|------|-------|-------|-------|---------|--------|-------|-------|
| F@ peak    | N    | 33.44 | 66.59 | 47.78 | 16.47   | 34.49  | 27.31 | 68.22 |
| F @ break  | N    | 29.75 | 66.59 | 46.60 | 17.69   | 37.96  | 24.63 | 68.56 |
| D @ peak   | mm   | 0.65  | 1.67  | 1.08  | 0.39    | 36.32  | 0.59  | 1.57  |
| D @ break  | mm   | 0.71  | 1.67  | 1.09  | 0.38    | 34.56  | 0.62  | 1.56  |
| E @ peak   | Nm   | 0.01  | 0.04  | 0.02  | 0.01    | 47.38  | 0.01  | 0.04  |
| E @ break  | Nm   | 0.01  | 0.04  | 0.03  | 0.01    | 44.90  | 0.01  | 0.04  |

**Table 04: Compression test result of dried cocoa beans on the intermediate diameter**

| Properties | Unit | Min   | Max   | Mean   | ST. dev | C of V | LCL   | UCL   |
|------------|------|-------|-------|--------|---------|--------|-------|-------|
| F @ peak   | N    | 45.53 | 90.10 | 72.036 | 17.07   | 23.71  | 56.83 | 93.23 |
| F @ break  | N    | 45.53 | 90.40 | 70.53  | 17.60   | 24.96  | 48.64 | 92.39 |
| D @ peak   | mm   | 0.714 | 1.53  | 1.080  | 0.31    | 28.82  | 0.69  | 1.47  |
| D @ break  | mm   | 0.715 | 1.53  | 1.126  | 0.30    | 26.50  | 0.76  | 1.50  |
| E @ peak   | Nm   | 0.03  | 0.05  | 0.041  | 0.01    | 22.40  | 0.03  | 0.05  |
| E @ break  | Nm   | 0.03  | 0.05  | 0.044  | 0.01    | 20.67  | 0.03  | 0.06  |

And minor bean diameters of the beans ranged from  $1.18 \pm 0.30$ ,  $1.08 \pm 0.31$  and  $1.08 \pm 0.39$  mm, respectively and the corresponding values of the deformation at breaking point were  $1.38 \pm 0.27$ ,  $1.13 \pm 0.30$ . The energy at peak point on the major, intermediate and minor bean diameters ranged from  $0.04 \pm 0.02$ ,  $0.04 \pm 0.01$  and  $1.09 \pm 0.38$  Nm, respectively. While the energy at break point on the major, intermediate and minor bean diameters ranged from  $0.04 \pm 0.02$ ,  $0.04 \pm 0.01$  and  $0.03 \pm 0.01$  Nm, respectively.

Generally, the values of the forces presented in Tables 2, 3 and 4 indicated that the force required both at the peak and breaking points for breaking the cocoa beans along the major diameters were lower to the force required along the intermediate diameters. This may be attributed to the difference in areas of contact between the beans and the two compression plates of the device; the area between the top and bottom plates was larger in the horizontal loading position than in the vertical loading position of the beans. The result is in

agreement with Anyidoho *et al.* (2015) who reported that the required force for bean rupture on amelonado cocoa variety decreased from 110.895 to 39.421 and from 65.354 to 21.365 N at horizontal and vertical orientations, respectively, while the rupture force for hybrid cocoa variety decreased from 289.59 – 105.14 and from 81.721 – 28.415 N at horizontal and vertical orientations, respectively and that the rupture force at horizontal orientation was higher than that of vertical orientation for the two varieties studied.

### **Conclusion**

The physical properties of the forastero cocoa variety of Nigerian origin were assessed at the moisture content of  $7.49 \pm 1.5$  %wb. The properties assessed include axial dimensions; major, intermediate and minor diameters; geometric mean, arithmetic mean and square mean diameters and equivalent diameter. Other properties assessed were sphericity, aspect ratio surface area, volume, weight of cocoa sample, bulk density, angle of repose and coefficient of friction. The force required at the peak and breaking points for breaking the cocoa beans along the major diameters were lower to the force required along the intermediate diameters.

### **Recommendation**

Nigeria as one of the leading producers of cocoa cannot continue to export larger percentages of her cocoa production in the raw form. Measures should therefore be taken towards adequate investment in the research and development of cocoa processing technologies so as to encourage local processing of cocoa into its finished products. Furthermore, cocoa farmers should be assisted financially and empowered with adequate provisions of farm inputs that will allow them to meet international standards.

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