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Research Article

Bitter Kola (*Garcinia Kola*): Exploring Its Uncharted Territory in Polymer Composites-A Pathway to Enhanced Mechanical Attributes and Sustainable Innovation

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Abstract: This study unveils the hitherto unexplored mechanical attributes and chemical composition of bitter kola (*Garcinia kola*), shedding light on its promising role as a constituent in polymeric fillers. Three random bitter kola fruits were selected for the experiment. Employing advanced techniques, including Scanning Electron Microscopy (SEM) and mechanical testing, we comprehensively investigated the physico-chemical properties of bitter kola seeds. Our findings revealed a density of 1.2944 g/cm^3, a moisture content of 22.3%, a water absorption rate of 4.48%, and a compressive strength of 0.179 MPa for bitter kola. These quantitative results characterize bitter kola and underscore its potential as a valuable material for diverse applications. Moreover, this research bridges the gap between traditional medicine and mechanical engineering, offering a unique perspective on bitter kola's untapped potential. The study opens doors for the development of innovative materials and products with vastly improved mechanical attributes, catering to a wide array of industries. From pharmaceuticals to sustainable packaging, bitter kola's promise extends into multiple sectors, promising groundbreaking advancements.

***Keywords*:** bitter kola, physico-chemical properties, polymer composites, mechanical attributes

1. Introduction

Natural fibre for composite material production is known for its biodegradability, which makes its lifespan limited [1]. Thus, there is a need to study these materials beyond the normal scope before their lifespan. Bitter Kola (*Garcinia kola*) belongs to the Clusiaceae family and is a monocotyledonous plant. It typically reaches an average height of about 33 m, featuring a robust trunk with thick slash and greyish-brown bark. The tree displays buttressed characteristics and produces greenish-white flowers, along with orange-colour fruits containing brownish seeds within the pulp [2]. Its natural habitat spans Benin, Cameroon, Democratic Republic of Congo, Ivory Coast, Gabon, Ghana, Liberia, Senegal, Sierra Leone, and Nigeria, predominantly found in subtropical or tropical lowland forests [3].

Each fruit typically contains an average of four seeds. Besides, various parts of the plant, beyond the seeds, hold significance for humans. Commonly known as Akuilu or Agbuilu (Igbo-O), Orogbo (Yoruba), Namigingoro (Hausa), and Edu (Bini), among other names in Nigeria, Bitter Kola (*Garcinia kola*) is recognized for its medicinal properties. This recognition

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is attributed to comprehensive information on its ethnopharmacology, pharmacology, toxicology, and phytochemistry properties, which highlight its bioactivities from natural sources and its potential in managing various diseases [4].

To optimize the design of machines for the handling, transportation, cleaning, sorting, separation, drying, aeration, storing, and processing of biomaterials, fundamental physical and mechanical information is crucial. Engineers, as well as food science processors and breeders, require information on geometrical characteristics such as size, shape, sphericity, volume, surface area, weight density, and porosity [5]. Such data aids in the design and analysis of machinery behaviour for different post-harvest operations.

Physical properties, like size and shape, play a pivotal role in grading grains, seeds, and fruits [6]. The handling losses during operations such as threshing, separation, cleaning, and grading are influenced by the size and shape of agricultural materials. Density is commonly utilized to separate impurities from agricultural products, estimate floor space during transportation, and determine storage requirements in food industries [7].

Parameters like surface area, volume, and porosity of biomaterials are essential for estimations related to spray coverage, removal of residues, respiration rate, light reflectance, colour determination, evaluation of diffusion coefficients in shrinking systems, heating and cooling processes, and the rate of reaction airflow [8]. Additionally, the coefficient of static and dynamic friction on various surfaces is crucial for designing conveying, transporting, and storing machinery [6]-[7].

Okundaye and Oviawe [9] investigated the physical and mechanical characteristics of bitter kola nuts, including measurements such as length, width, thickness, diameters, sphericity, porosity, angle of repose, and static coefficient of friction. The average dimensions of bitter kola nuts ranged from 20.5 to 35.0 mm in length, 15.6 to 21.0 mm in width, and 14.0 to 17.0 mm in thickness. Additionally, they determined sphericity, aspect ratio, surface area, volume, bulk density, and true density, which were found to be 73%, 66%, 1,182 mm^2, 750 kg/m^3, and 1,274 kg/m^3, respectively. The static friction coefficients on various surfaces (glass, plywood, galvanized steel, and rubber) were measured at 0.465, 0.532, 0.466, and 0.582, respectively. However, it is important to note that this study primarily focused on the physical and mechanical properties of bitter kola nuts. It did not delve into their chemical composition or potential applications in material science, limiting the scope of its findings to handling and processing bitter kola nuts.

The chemical composition of bitter kola has been a subject of interest in previous studies. Okwu and Ekeke [10] conducted a chemical analysis of bitter kola seeds and reported the presence of bioactive compounds such as saponins, alkaloids, and flavonoids, which have been linked to their traditional medicinal uses. This research provides valuable insights into the potential chemical constituents that may play a role in the mechanical properties of bitter kola.

Investigations into the mechanical properties of bitter kola are limited in the existing literature. However, studies on other seeds and plant materials offer relevant insights. For example, Abba et al. [2] conducted mechanical testing on African nutmeg (Monodora myristica) seeds, highlighting the importance of compressive strength in evaluating the suitability of seeds as potential fillers or reinforcements in polymer composites.

Scanning Electron Microscope (SEM) analysis has been used in the past to investigate the microstructural properties of various seeds and plant materials. In a study by Ogunsona et al. [11], SEM was utilized to examine the microstructure of an African locust bean (Parkia biglobosa) seed, revealing insights into its potential as a natural filler in polymer composites. The application of SEM in characterizing bitter kola's microstructure aligns with the broader trends in materials science research.

Bitter kola has a rich history of traditional medicinal uses in West Africa. A study by Gruenwald [7], discusses the ethnopharmacological significance of bitter kola, highlighting its use in treating various ailments, including malaria and digestive disorders. While this literature focuses on the medicinal aspects, it underscores the importance of exploring bitter kola's multifaceted properties.

The current research explores the potential of bitter kola as a filler material in polymer composites. The concept of using natural fillers in polymer composites has gained attention due to its potential to enhance mechanical properties while reducing environmental impact. Studies on other natural fillers, such as kenaf [12] and coconut leaf stalk [13] and others, have demonstrated their effectiveness in reinforcing polymers. The current study on bitter kola seeks to contribute to this growing body of research by investigating its compatibility with polymer matrices exploring the water absorption rate, optical structural view, compressive strength, scanning electron microscopy view, density, and moisture content of bitter kola, aiming to unlock bitter kola's untapped potential in the development of novel materials and products catering to diverse industries.

2. Material and methods

2.1 *Material and apparatus used*

The key substance for this research is Bitter Kola. The bitter kola used were harvested in Umuchima Ihiagwa in Owerri West L.G.A of Imo State. The harvested nuts were then selected to remove bad and amateur seeds. The equipment used in carrying out this research includes Laboratory High Precision Analytical Balance (Mettler Toledo XS204 Analytical Balance), Electrothermal Oven (Thermo Scientific^{TM} Heratherm^{TM}), Micrometre Screw gauge (Mitutoyo 293-340-30 Digimatic Micrometer), laboratory beaker (Pyrex Griffin Low Form), Graduated Measuring Cylinder (Class A Volumetric GMC), Inverted Microscope (Nikon Ti2 IM), Eco Press Compression Machine (Carver Auto Series Plus Model 2696 Hydraulic Laboratory Press) and Scanning Electron Microscope (JEOL JSM-7600F).

2.2 *Test procedures*

2.2.1 *Density test*

The density test was conducted on three specimens A, B, and C of bitter kola nuts, determined by ASTM D792-08 [14], by measuring the masses in a Laboratory High Precision Analytical Balance (Mettler Toledo XS204). Afterward, a volume test was conducted by placing the three specimens in a graduated measuring cylinder containing water with the displacement taken as the volume (Archimedes' principle), the average values of the mass and volume were used to determine the density, using equation (1).

$$Density = \frac{Mass\ of\ substance}{Volume\ displacement\ of\ substance} \tag{1}$$

2.2.2 *Moisture content test*

During this experiment, the weight of the three different specimens of bitter kola was measured in the Analytical Balance and recorded, determined by ASTM D4442-18 [15]. The specimen was subjected to an electrothermal oven to allow for oven-drying (at 105 °C until constant weight was obtained), hence being weighed again to determine the difference in weight, brought out to cool, and measured [6]. The moisture content was calculated using equation (2).

$$Moisture\ Content = \frac{b-a}{b} \times 100\% \tag{2}$$

Where b = *weight before drying* and a = *weight after drying*.

2.2.3 *Water absorption test*

Following ASTM D570-98 [16], a water absorption test was carried out by measuring and recording the weights of the three specimens of bitter kola before placing them in a beaker of distilled water. After measuring the weight of the specimens, they were placed in different beakers of water and kept at room temperature for 24 hours [17]. Next, the specimen was removed from the beaker, cleaned off surface moisture, and weighed on the analytical balance. Finally, the results were calculated using equation (3).

$$Water\ Absorption\ Rate\,(By\ Mass) = \frac{b-a}{b} \times 100\% \tag{3}$$

Where: a = *weight after absorption* and b = *weight before absorption*.

2.2.4 *Optical structure test*

The selected fresh bitter kola seeds were peeled and broken with cleaned hands to avoid disrupting the structural optical views. The seeds were placed on a slide and water drops were added for clarity [18]. Then the microscope was turned on, and the equipment lighting was adjusted, using low magnification for initial focus (coarse and fine focus knobs). Afterward, the seed was brought into sharp focus by increasing the magnification as needed and the internal structures were observed. The various views were observed and recorded.

2.2.5 *Compressive test*

During this experiment, the bitter kola was cut and shaped cylindrically to allow for compression to take place. Next, it was placed in the Eco Press Compression Machine (Carver Auto Series Plus Model 2696 Hydraulic Laboratory Press) and compressed by placing the machine indenture on the specimen the result was observed and recorded from the value display unit [19].

2.2.6 *Scanning electron microscopy test*

For this experiment, the sample of the bitter kola was shaped into an appropriate size of about 15 cm and was mounted rigidly with carbon tape on a specimen stub, it was then put in a gold-sputtering system for gold to be sputtered for 30 seconds at 70 mTorr pressure and then removed [18], [20]. The SEM chamber of the JEOL JSM-7600F SEM Machine was then vented so it could reach nominal pressure and then the stub was fixed in the sample stage inside the chamber and the chamber was then closed. The SEM software was then opened to capture the image. Adjustments to the focal length and magnification were made and different pictures were taken at different magnifications for image clarity and better analysis of the image. After the image capture process, the software measuring tool was used to obtain precise measures (length, area, etc.) of the image, and these were then saved.

3. Results and discussion

This section introduces the comprehensive results of the experimental investigation into the physico-chemical properties of bitter kola (*Garcinia kola*). These findings shed light on the intrinsic attributes of bitter kola, offering valuable insights into its potential applications in diverse industries and bridging the gap between traditional medicine and mechanical engineering. Figure 1 shows the experimental results from the moisture content of the bitter kola seeds.

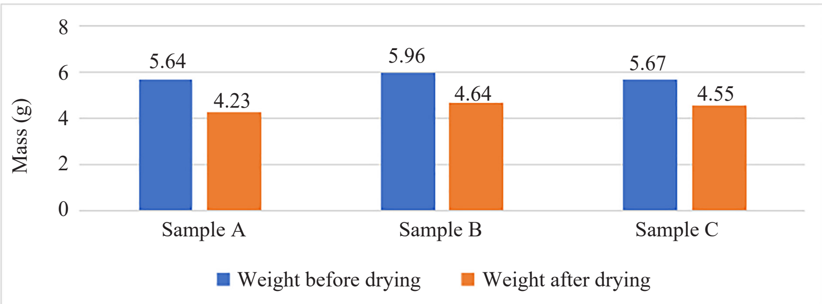

Figure 1. The moisture content of bitter kola

The presence of moisture in bitter kola (*Garcinia kola*) is one of its main characteristics as a seed, dictating its area of application and method of usage [8]-[9]. The result in Figure 1 indicates that the presence of moisture in bitter kola varies according to its weight (g) before and after drying, thereby specimen A indicated 5.64 g and 4.23 g, while specimen B indicated 5.96 g and 4.64 g, and finally specimen C indicated 5.67 g and 4.55 g respectively. Afterward, equation 2 was applied to the values in Figure 1, where the specimens indicated 1.4119 g, 1.3186 g, and 1.1188 g for specimens A, B, and C, respectively, having 22.3% approximate moisture content.

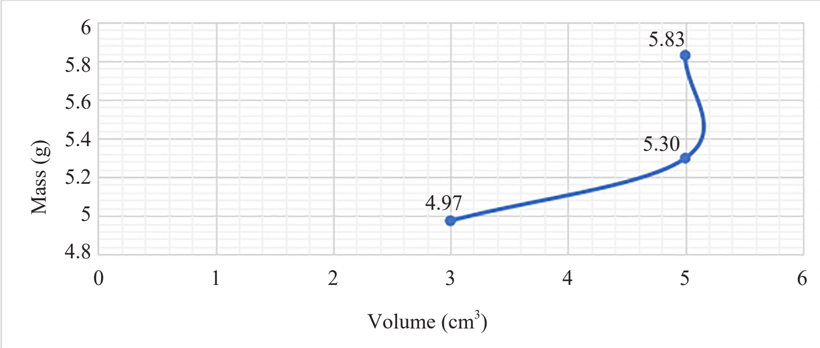

Figure 2. The density values of the bitter kola

Figure 2 presents the graph of mass against the volume values of the specimens after the experiment. The density values (g/cm^3) of the three samples of the selected nuts were then calculated applying equation 1, in which sample A depicts 1.6579 g/cm^3, sample B shows 1.0595 g/cm^3, while sample C indicates 1.1658 g/cm^3. The variation in the mass, volume, and density may be due to mechanical, thermal, and chemical properties instability of natural composite material [21], in which bitter kola is one of the natural composite materials. The result indicates an average density of bitter kola of about 1.2944 g/cm^3, which falls within a typical range for many natural materials and is well-suited for various engineering applications.

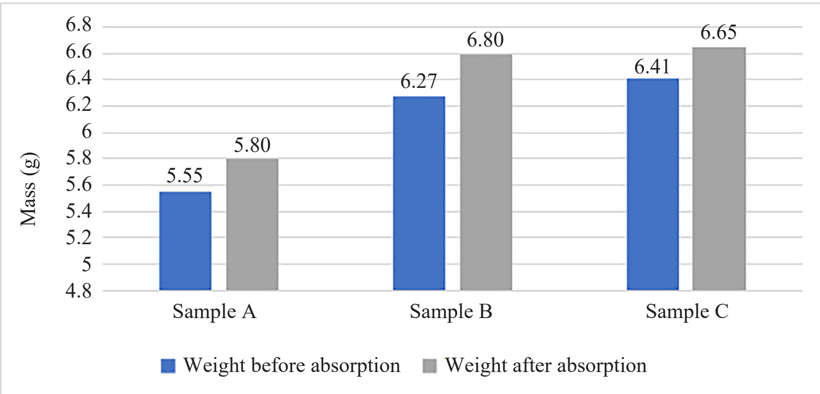

Figure 3. The water absorption of the various bitter kola

As shown in Figure 3, the specimens indicated different weights before and after absorption in water (5.55 g and 5.80 g for specimen A, 6.27 g and 6.80 g for specimen B, and 6.41 g and 6.65 g for specimen C), afterward, equation 3 was applied on the values, which shows the water absorption of 4.5858%, 5.1451%, and 3.6867% for specimens A, B, and C, respectively, having 4.4725% mean value, which agrees with the variation of natural composite material properties by Ekpechi et al. [17]. The ability of a material to retain a percentage of water is quite required for mechanical, structural, and other solid applications [15].

From the results in Figures 4-5, bitter kola is seen to be composed of different elements in their various percentage weight. The SEM result indicated that carbon being the major composition of bitter kola takes up 35.45% of its total weight followed by oxygen which accounts for 25.30% of its weight and other elements like silicon occupying 22.20%, calcium 12.33%, potassium 2.17%, and the least element magnesium taking up just 1.25% of its total weight. The probable uses from the result were that the carbon contained in the bitter kola can be extracted and used for activated carbon, supercapacitors, and carbon-fibre reinforced composites, and as an alternative to fossil fuels in the production of chemicals [22]-[23]. The oxygen extracted can be used in oxygen gas tanks for oxyacetylene welding, for the smelting of metal in ore, and for the manufacturing of steel [24]. The silicon and calcium contained can be accumulated in large quantities for the manufacturing of silicon wafers for semiconductors and the manufacturing of types of cement, etc., respectively [25]-[26].

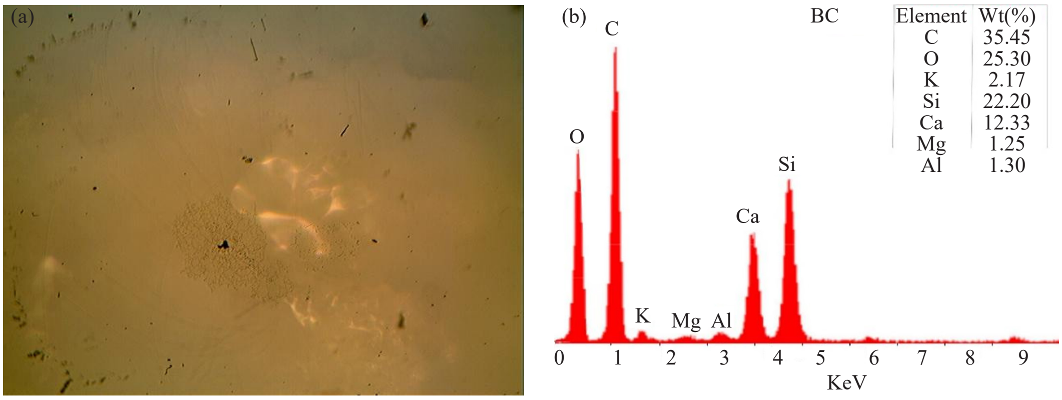

Figure 4. The optical structure (a) and chemical composition of bitter kola (b)

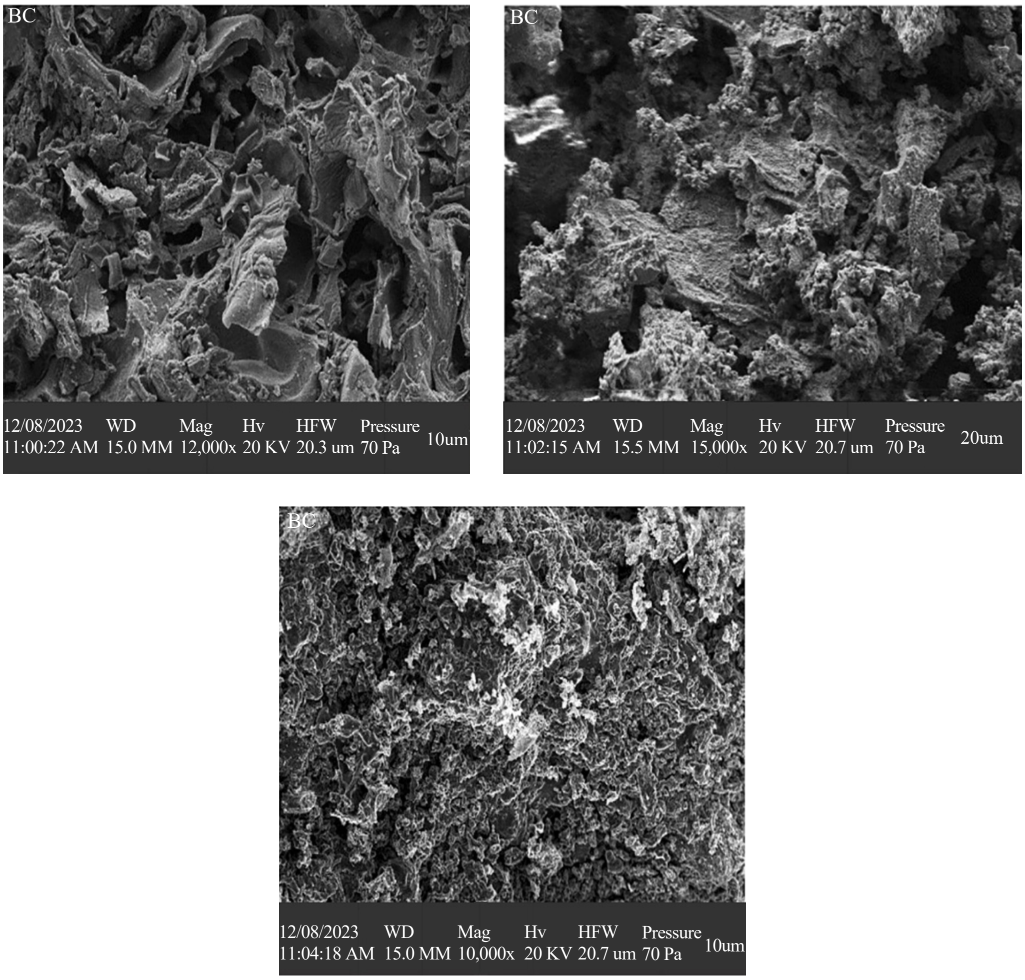

Figure 5. The SEM test result with views of different magnifications of the specimens

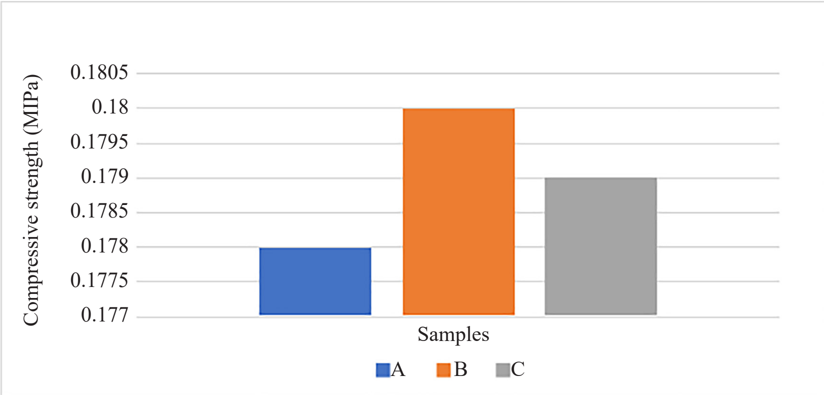

Figure 6. The compressive strength of the bitter kola

To determine the compressive properties of Bitter Kola, a compression test was conducted using Eco Press Compression Machines to determine the various compressive strengths. As presented in Figure 6, the resulting values fluctuated may be due to the instability property of natural fibre material [19] or machine conditions affecting the experimental results, having an average compressive strength of 0.18 Mpa. Although the compressive strength acquired from this test is quite low, if higher strength is needed, alternative materials with superior mechanical properties may need to be explored, however, the unique chemical composition or bioactive compounds present in bitter kola nuts as presented in the SEM result (Figures 4-5) if further explored, may open opportunities for applications beyond traditional structural uses.

4. Conclusions

This research highlights the versatile potential of Bitter Kola, not only in the medical and pharmaceutical fields (as seen in previous research) but also in automotive and industrial applications, particularly for low-stress parts and interior components. While its compressive strength may not meet automotive part requirements, its low water absorption rate makes it a valuable material for various production purposes. Bitter kola's unique properties position it as a promising natural fibre reinforcement for composites in low-stress areas. From optical and SEM experiments conducted, some essential elements were found inside the fruit, if further explored or researched, could be used as composite material for reinforcement, specifically, a recent supercapacitor battery used in electric-powered vehicles and other applications is made up of activated carbon; and from the result, it is seen that bitter kola has up to 35% of carbon, which, if extracted, could be used in activated carbon production for the supercapacitor.

5. Recommendations

Bitter kola offers a sustainable and versatile resource with various applications. It can serve as an eco-friendly alternative to conventional body fillers for automobiles, addressing sustainability and health concerns. The carbon composition within bitter kola can be harnessed for applications such as lightweight composites, energy storage, and water purification. Harnessed oxygen has potential applications in improving industrial processes such as steel production, metal smelting, and welding. Furthermore, calcium and silicon found in bitter kola can be accumulated for cement production and semiconductor manufacturing. These guidelines, when implemented in industrial operations, encourage innovation and sustainability in a variety of sectors, establishing bitter kola as a key raw material.

Conflict of interest

The authors declare no competing financial interest.

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