

INTERCROPPING POTENTIAL OF OIL PALM (*E. GUINEENSIS* JACQ.) AND LIBERICA COFFEE (*C. LIBERICA* L.): A CASE STUDY IN SMALLHOLDER PLANTATION

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Abstract. Oil palm (*Elaeis guineensis* Jacq.) has become the main plantation commodity in Indonesia. Climate change phenomena and competitiveness fluctuation of palm oil commodities have led to increased need for optimized land productivity while maintaining sustainability. This research aimed to study the potential of oil palm intercropping with liberica coffee (*Coffea liberica* L.) in several smallholder oil palm plantations in Riau Province, Sumatera Island, Indonesia. Measurements in the middle of the non-harvesting path of oil palm showed the age of oil palm is directly proportional to the difference between air and soil temperature and relative humidity under canopy. Oil palm roots were dominantly distributed vertically in solum 0 - 30 cm and always dominant compared to coffee at all horizontal distances observed. While the dominant root coffee distribution was in solum 31 - 60 cm. Analysis results show the tap roots extend no further than 30-45 cm below the soil surface. It was known that oil palm roots are dominantly distributed at a distance of 2-3 m from the trunk while the coffee roots are dominantly distributed at a distance of 1-2 m from the trunk. Analysis of oil palm yields in the intercropping system showed no significant decrease compared to monocropping systems with relatively the same age and production input. Coffee production per tree has decreased by 25-30% compared to the average production in monocropping systems.

Keywords: intercropping; oil palm; liberica; coffee

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) has become the most rapidly expanding equatorial crops in the world during the past few decades. In 2007, oil palm is cultivated in one-tenth of the world's permanent cropland (Koh & Wilcove, 2008). Since 2006, Indonesia has become the country with the most extensive oil palm plantation and the highest production of palm oil in the world. Oil palm is the most recently introduced plant to Indonesia compared to other commodities such as coffee (1696), sugar cane (1595), tea (1684), and cocoa (1560). Palm oil was introduced to Indonesia by the Dutch East Indies government in 1848. However, today oil palm is becoming the main plantation commodity in Indonesia.

Based on the status and size of the concession, 41% of the total area of Indonesian oil palm plantation is smallholder plantation, while private and estate owned plantation respectively 54% and 5%. In 2018, the area cultivated by smallholders was estimated to reach 5.8 million hectare of the total oil palm plantation in Indonesia (Anonim, 2019).

Smallholder plantations have the lowest productivity compared to estate and private plantation. In 2015, their productivity reached 18.94 and 20.15 ton ha⁻¹ year⁻¹ respectively, while smallholder

plantation only reached 16.44 ton ha⁻¹ year⁻¹. Crude palm oil (CPO) productivity from smallholder plantations had only 2.5 ton ha⁻¹ year⁻¹, far from the average productivity of private and state plantation which reached 4-6 ton ha⁻¹ year⁻¹. The data showed that the average production yield of public and private large estates was 25% greater than smallholders yield (Anonim, 2019).

Increased competitiveness of other vegetable oil-producing crops against palm oil due to falling CPO prices, encourages the need for efforts to diversify sources of income for farmers (Goh, 2000). So far, palm oil is almost always cultivated in monocropping system. The high level of business profits and the pattern of developing oil palm plantations are the main factors causing farmers to use a monocropping system in oil palm cultivation.

Plantation managers (farmers) are currently faced with challenges to optimize the potential of existing land in order to obtain land productivity as high as possible while maintaining environmental sustainability. In addition, CPO commodity price fluctuations are a threat to the sustainability of smallholders' oil palm business.

In West Africa (the origin of oil palm) is a part of agroforestry which is cultivated in a polyculture or intercropping manner both with food crops and other permanent tree crops (Khasanah *et al.*, 2016). Climate change phenomena and competitiveness fluctuation of palm oil commodities have led to increase an interest of intercropping cultivation system. The purposes of intercropping are to diversify income and to optimize the use of available resources from the same land area.

At present, the practices of intercropping in oil palm plantation are commonly with annual crops and carried out when oil palm has not produced yet (0 - 3 years after planting/YAP). Their canopy had not yet met, so that sunlight penetration could reach the surface of the frond of annual crops (Harun *et al.*, 2018; Trisna *et al.*, 2018). Meanwhile, intercropping practice in produced plants (> 4 YAP) is very rare, even it is almost never done by estate, private and smallholder plantation. The intercropping system with annual crops has several deficiencies that is not massively adopted. Intensive management is needed in terms of inputs (fertilizers, pesticides, and herbicides) and labor to ensure its success.

Efforts are needed to explore intercropping possibilities between oil palm and other plants, especially annual crops. This research aimed to study the potential of oil palm intercropping with liberica coffee (*Coffea liberica* L.) in several smallholder oil palm plantations. The benefit of this research is considered important in order to improve the sustainability of the oil palm cultivation system in terms of economy and environment.

2. Methods

2.1. General information of Research Location

This research was carried out in smallholder oil palm plantation in Kepenuhan Raya Village, Rokan Hulu Regency, Riau Province in the island of Sumatera. It was conducted in July 2018 – September 2019. The research location has a flat topographic area of 0 - 50 meter above sea level and shallow peat soil type. The climatic characteristics are very suitable for oil palm growth. Overall based on topography, physical, and chemical properties of the soil, as well as climatic conditions, the category of research's site is a highly suitable for oil palm growth (class S1).

Three (3) conditions of oil palm block were used in this research, namely oil palm 5 YAP (PP 2), 8 YAP (PP 5), and 12 YAP (PP 9), in which PP (production phase) term means plant commence to produce commercial fresh fruit bunch. Oil palm plants were planted with a uniform spacing, which is a triangle form, 9 x 9 x 9 m (142 Stands Per Hectare).

In other hand, Liberica coffee plants are ranged between 4-5 YAP. They were planted in non-harvesting path with spacing in 4 m rows and spacing between 7.8 m rows (320 plants per hectare). Oil palm and coffee plants maintenance consist of fertilizing, pruning, managing pests and disease, and without irrigation system.

2.2. Research Methods

A case study method with a quantitative descriptive approach was used in this research. Descriptive quantitative research methods are research methods which are used to examine natural conditions of objects. Data was obtained by interview of smallholders and direct observation.

2.3. Data analysis

Primary data observed were (1) microclimate (consisting of sunlight intensity, air temperature under the canopy, soil temperature, radiation energy, and relative humidity. Measurements are taken 3 times a day, from 08.00 - 09.00 am, 12.00 - 13.00 pm, and 16.00 - 17.00 pm); (2) distribution of oil palm and coffee roots. Measurements of the vertical distribution were carried out on 3 different solums (0 - 30 cm, 31 - 60 cm, and 61 - 90 cm), while measurement of the horizontal distribution was carried out at 4 different distances from stems (100, 200, 300, and 400 cm); (3) oil palm and coffee production.

Root dry mass analysis for oil palm and coffee were conducted according to the method develop by [Vicente et al. \(2017\)](#). After removal from each solum, soil and root samples were placed on a 2 mm mesh sieve. With the aid of water jets, roots were separated from the soil. Subsequently, roots were dried in an oven at 80 °C for 24 hours to achieve constant mass. Dry mass was determined in an analytical scale. The distribution of oil palm and coffee roots in several solum were shown in [Figure 1](#).

Based on preliminary identification, it was known that there were 60 farmers who practice oil

palm-coffee intercropping, consisting of 15 farmers in 5 YAP, 25 farmers in 8 YAP, and 20 farmers in 12 YAP. Data obtained were processed into a database for later analysis with descriptive analysis methods using IBM SPSS Statistics 24.

3. Results and Discussion

3.1 Microclimate under oil palm stands

Climatic conditions on a narrow land area, a few meters from the ground surface, or under the plant canopy is called microclimate. Often the conditions of the microclimate are very different from the general climatic conditions around it. According to [Kingra and Kaur \(2017\)](#) this allows several plants to grow side by side and interact positively as long as their growing environment is in appropriate microclimate.

Based on observation, it is known that there were differences in the amount of oil palm fronds that were left at different plant ages. At 5 YAP, there were an average of 56 fronds, while at ages 8 and 12 YAP the number of fronds were 52 and 40 fronds respectively. This number of fronds are optimum according to [Perez et al. \(2017\)](#) and [Luskin and Potts \(2011\)](#). Their difference was influenced and adjusted by harvesting technique and tool.

At the age of 5 YAP, the oil palm height was still quite short. Therefore, Fresh Fruit Bunch (FFB) harvesting could be done using chisel (*dodos*). It allows harvester cut the FFB without cutting the supporting fronds. Increased plant height at 8 and 12 YAP caused chisel could be unsuitable so harvester switched to using sickle (*egrek*). The harvester who used sickle then needed to cut off the supporting fronds first to cut FFB. Number of fronds maintained by smallholder farmers was in accordance with [Turner and Gillbanks \(1974\)](#) and [Perez et al. \(2017\)](#) which stated that to optimize the photosynthesis process and productivity, preferably for young plants (≤ 8 years) the number of fronds is maintained in the range of 48-56 fronds, while in mature plants (> 8 years) maintained in the range of 40-48 fronds.

Measurements of plant height (from stem base to the lowest frond) showed that 5 YAP plants had an average height of 1.75 m, while plants aged 8 and 12 YAP had 3 and 4.5 m height, respectively. The difference in the number of fronds and plant height affected the intensity of light under the stand of oil palms. Frond length was measured from the base of the petiole to the tip of the rachis ([Perez et al., 2017](#)). Frond length in 8 YAP oil palm or more is relatively stable, ranging from 4 - 4.2 m.

Measurements in the middle of the dead row of oil palm plants (non-harvesting path) showed there are significant variability in light radiation intensity under the canopy. Average light radiation intensity under the canopy of 5 YAP plants reached 44.3%, while those in plants aged 8 and 12 YAP experienced 64.6% and 83.3% compared above the plant canopy. The increased

intensity of irradiation under the canopy of older plant was not only due to the reduced number of fronds but also the presence of saturated light.

Although there is a decrease, the intensity of light observed under the stand in the entire age range of the oil palm is still in the range suitable for coffee growth. According to [Ceulemans and Saugier \(1993\)](#) compared to other annual crops, coffee has a low rate of net CO₂ assimilation, typically in the range of 4-11 mmol m⁻² s⁻¹ so that it can take place at saturating light.

Coffee evolved in the forest as an understorey tree, and thus it was considered to be shade-obligatory ([Damatta et al., 2007](#)). The protective effects of shading have been associated with the lower radiation input at the level of the coffee canopy, which may reduce the extent of photooxidative damages, a phenomenon frequently observed in coffee grown at full exposure in marginal zones, and ultimately increases crop life expectancy (da Matta, 2004). Shade may positively affect bean size and composition as well as beverage quality (lesser bitterness and astringency) by delaying and synchronizing berry ripening ([Vaast et al., 2006](#)).

Increased plant height will decrease horizontal barriers from oil palm fronds. Its allowed not only light to reach into soil surface, but also the air movement (wind) that decrease relative air humidity. Air humidity has a significant impact on the vegetative growth and fertilization of the coffee tree. Relative humidity in 8 YAP and 12 YAP compare to 5 YAP decreased 7.8 and 8.4%, respectively. It had a significant effect on the microclimate under oil palm stands ([Table 1](#)).

Table 1. Effect of oil palm's age on microclimate stands

| Microclimate parameters | Oil palm's age (year after planting) | | |
|--|--------------------------------------|---------|---------|
| | 5 | 8 | 12 |
| Air temperature (°C) | 28.24b | 30.01a | 30.96a |
| Soil temperature (°C) | 23.73a | 22.62b | 22.54b |
| Radiation energy (watt m ⁻²) | 198.33b | 247.21a | 256.84a |
| Relative Air Humidity (%) | 74.98a | 69.15b | 68.66b |

Note: numbers followed by the same letter on the same line are not significantly difference at the 5% level

This finding was slightly different from the [Wasito et al. \(2014\)](#) which stated that solar radiation energy decreases with increasing age of oil palm, but in accordance with the opinion of [Ismail et al. \(2009\)](#) which stated that photosynthetically active radiation (PAR) passing through the leaf canopy increased with distance from the palms. PAR reaching the soil surface was higher at the center of the area between the palm rows or between two avenues ([Haniff et al., 2003](#)). According to [Mahmud \(2017\)](#) radiation decreased by 198.62 watt.m⁻² between oil palm aged 10 years compared to 4 years. The observation on temperature and air relative humidity was accordance with [Wasito \(2014\)](#) that there was an increase in temperature of 0.59 °C and a decrease in air relative humidity of 13% between oil palm aged 10 YAP compared to age 4 YAP.

The age of oil palm is directly proportional to the difference between air and soil temperature under oil palm stands. An increase in air temperature from 0.95 to 2.72 °C was happened in plants aged 5-15 years. Soil temperature fluctuations in different oil palm age were relatively low, but the difference between air and soil temperature in plants aged 5-15 years increased between 1.03 to 3.91 °C.

These findings indicate that the relative humidity under palm oil in all observed ages is still appropriate for the growth of liberica coffee since it has similar requirements for growing with robusta coffee. According to [DaMatta \(2004\)](#) robusta is successfully grows under high air humidity approaching saturation, or in less humid sites, provided that the dry season is short.

3.2 Distribution of Oil Palm and Coffee Roots

When two or more crops are subjects to intercropping, the interaction between each component crop will be sharing, competition, or both. Interactions are based on above- and below-ground. It accounts for light, water, and nutrient as growth resources, subject to competition and sharing ([Khasanah et al., 2016](#)). The aim of implementing an intercropping system is to optimize sharing and minimize competition among the constituent crops. If crop not choose correctly, the crops can compete with each other for resources such as water, nutrient, light, and growing area which cause negative yield results ([Nchanji et al., 2015](#)).

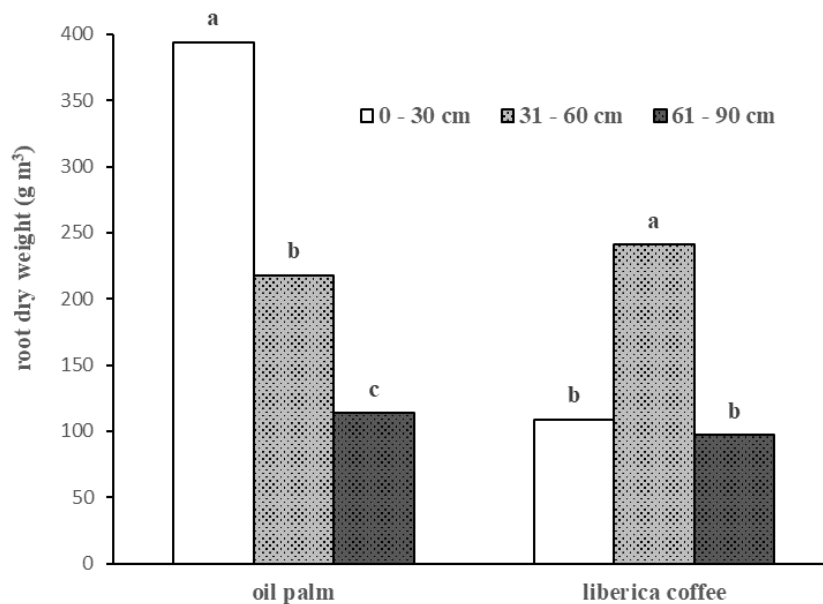


Figure 1. Vertical distribution of oil palm and coffee root in the intercropping system (g DWm^{-3})

One of the basic considerations for implementing an intercropping cultivation system is the vertical and horizontal distribution of roots from each crop as a part of intercropping. Root system distribution is directly linked to the various functions ensured by the roots such as water and nutrition absorption. The characteristics of growth and distribution of roots will affect the distance and cropping pattern of intercropping system.

Oil palm roots were dominantly distributed vertically in solum 0 - 30 cm (54.3%), and decreased to 30.1% and 15.7% in solum 31-60 cm and 61-90 cm, respectively. Solum 0 - 30 cm was dominated by tertiary roots and a few secondary roots. Secondary roots dominated in 31 - 60 cm, and >60 cm solum. This finding is in accordance with Safitri *et al.* (2018) which states that the roots of oil palm in favorable condition when all growing factor are available grow only to a depth of 1 m. However, according to Corley and Tinker (2003) it can reach more than 5 m if the soil as growing medium cannot provide sufficient growth factors, especially water.

The results showed that coffee roots had different distribution characteristics. Its dominant distribution was in solum 31 - 60 cm (53.9%), while the distribution in solum 0 - 30 cm and 61 - 90 cm was relatively same, 24.4 and 21.7% respectively. According to da Silva *et al.* (2016) mature coffee roots concentrated in the upper soil layer, while the presence of roots detectable until 1.45 m depth. In areas close to the periphery of the liberica coffee canopy projection, the number and the depth of roots gradually decreasing (Rena & Guimarães, 2000).

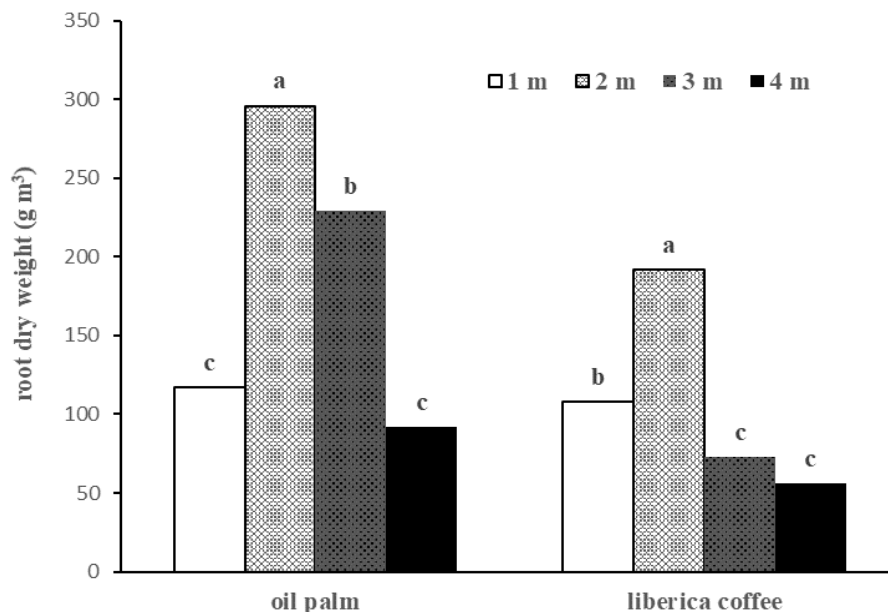


Figure 2. Horizontal distribution of oil palm and coffee roots in the intercropping system (g DW m^{-3})

There are main roots, tap roots, and lateral roots which grow parallel to the ground. Analysis results show the tap roots extend no further than 30-45 cm below the soil surface. These observations are in accordance with the da Silva *et al.* (2016) which states that about 80-90% of the feeder root is in the first 20 cm of soil and is 60-90 cm away from the trunk of the coffee tree. Damatta and Ramalho (2006) states that the biggest root concentration is in the 30 to 60 cm depth.

Liberica coffee trees have a deeper root system, which means they're more robust and able to access water deeper than other varieties. They can therefore be grown in harsher climates, and even in soils that might not be viable for other trees such as heavy clay and peatland. Liberica, being bigger than both arabica and robusta, also has a much more extensive root system. The roots

of liberica go much deeper than any other coffee tree (Anonim, 2019). Observations were also performed on the horizontal distribution of roots. The results were showed in Figure 2.

It was known that 71.5% of oil palm roots are distributed at a distance of 2-3 m from the trunk while the coffee roots are dominantly distributed at a distance of 1-2 m (69.9%). Competition for resources (water and nutrients) in the intercropping system mainly occurs only if the roots of both crops are in the same field. In this case, the largest overlap of roots occurs at a distance of 3 m from oil palm's trunk, where there were 17% of oil palm roots and 11% of coffee roots at the same distance and solum. Oil palm and liberica roots distribution showed a different pattern (Figure 3).

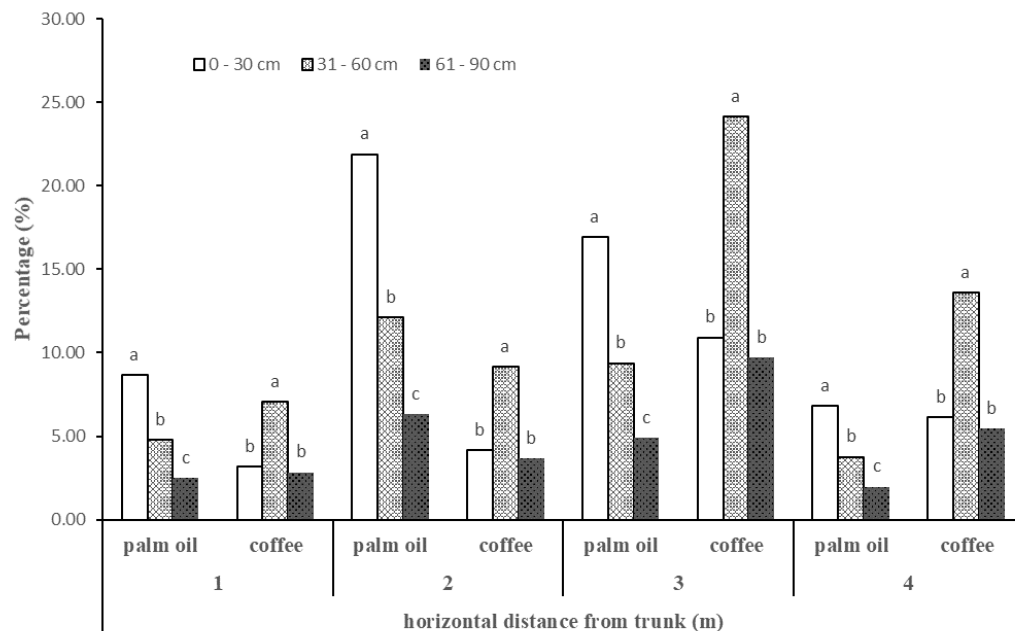


Figure 3. Horizontal distribution of oil palm and coffee roots in different solum (%)

Oil palm had a consistent distribution of roots in the shallow solum (0 - 30 cm), and always dominant compared to coffee at all horizontal distances observed. The largest roots distribution was at a distance of 2 m, followed by a distance of 3 m, 1 m, and the lowest at a distance of 4 m from stem. On the other hand, the distribution of coffee roots mostly dominates the medium solum (30-60 cm), except at a distance of 2 m from the trunk.

The largest coffee roots distribution is at a distance of 3 m, followed by a distance of 4 m, 2 m, and the lowest at a distance of 1 m. Oil palm roots dominated more than coffee except at a distance of 3 m from the trunk in solum 30-90 cm and 4 meters from the trunk at all solum. These results indicated that the potential for competition between oil palm and liberica coffee was relatively small, given the canopy architecture and rooting distribution of each crop.

The adequacy of growth factors was indicated by the productivity of a crop. Analysis of oil palm yields in the intercropping system showed no significant decrease compared to monocropping systems in the location with relatively the same age and production input. The decline only occurred in oil palm aged 12 years, but it is not certain that the cause of the 4.7%

decline in production was due to intercropping practices alone. According to Corley and Tinker (2003) the reproductive development of oil palm from the flowers initiation to the maturation of fresh fruit bunch (FFB) takes between 24-26 months, so it takes longer observation time in order to draw conclusions as to the cause of the decline in production.

Different findings are shown in coffee production. Observations in the first year of research showed productivity per tree in the intercropping system decreased between 25-30% compared to monocropping systems. The average production in Tanjung Jabung Barat regency which is the development center of liberica coffee in Indonesia is 950 g coffee beans tree⁻¹ year⁻¹ or equivalent to 950 kg coffee beans tree⁻¹ year⁻¹ with a population of 900-1000 trees hectare⁻¹ (Waluyo & Nurlia, 2017). The average production at the study site with the monocropping system is 560 - 770 g coffee beans tree⁻¹ year⁻¹.

4. Conclusions

The results of this study indicate that intercropping between oil palm and liberica coffee is possible because it does not cause a decrease in oil palm production as the main crop. Horizontally, oil palm roots are dominant at a distance of 2 m from the trunk, while coffee roots are dominant at a distance of 3 m from the trunk. Assuming the distance between oil palm and coffee is 4.5 m, it is possible to overlap between the roots of the two plants, but because both plants have different vertical root dominance, where oil palm has a dominant root distribution at 0-30 cm solum, while coffee root is dominant at solum 30 - 60 cm, the competition for factors of production and space is minimal. Nevertheless, it is necessary to analyze the feasibility of farming in a longer time period by considering economic factors.

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