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Spectral analysis for phenological studies of leaves and fruits development in coffee plantation in Gunung Puntang: a preliminary result

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Abstract This is important to know plant health that affects fruits production. Especially in a coffee plantation, even though it will be dried before harvesting, the farmers depend on their fruits and only the mature will be taken. The biochemical parameters in leaves and coffee fruits will be defined as the major factors in determining plant health. Both leaf and fruit coffee's reflectance used to determine biochemical content during its development stages. Some of modification vegetation indices that used to evaluate the greenness level, chlorophyll and water content, and colorization named MNDVI, MCARIs, MNDWI and MYI and the associated indices with all parameters name REPD was used to understand the leaves development. The result shows that all leaves biochemical factors are decreased during its development. All factors also shown a moderate to strong relationship each other. The highest correlation is given by the water content based on the estimated values of MYI. It has R^2 -0.96 to the values of REPD. Since the REPD capable to control the values of MNDVI, MCARIs, and MNDWI with R^2 -0.91, -0.66 and -0.71 respectively.

1. Introduction

The basics of plant development that easy to observe is doing a monitoring in leaves and fruits. Both plant organs describes the entire processes of plant itself directly. Especially for leaves, it plays an important function in biological processes, such as for photosynthesis. Without it, plant cannot capture the light from the sun and unable to produce flowers [1]. Most of plant leaves development is started from the seeds, then followed with two leaves buds, to mature leaves and the dried leaves at the end. This changes that occurs in leaves will be followed with in increase the size and leaves color.

In coffee plants, the leaf development also use to detect the disease. Such as coffee leaf rust. This type of disease is caused by the *Hemileia vatatrix* and found at the unshaded coffee plantation in at altitude less than 1000 meters above sea level. It occurs on leaves when the pale yellow spots up to 3 mm in diameter appear on under the leaf surface [2] and possible to make leaf drops [3]. Related to the yield, this plant will produce the little, not fully ripe and turn black of berries (coffee fruits) [2]. Other coffee leaf diseases is also possible to observe such as leaf miner, and cercospora leaf spot. In Gunung Puntang region, the coffee plant is cultivated as shaded plantation under the pine trees or with other crops as an

intercropping agriculture systems. In at altitude between 800 to 1200 meters above sea level, it distributes randomly in many areas around the mountain.

The research of coffee plant based on the remote sensing data have been the interesting approaches. It started from understanding the leaf through the empirical modelling of leaf chlorophyll content [4] and leaf area index[5], the soil quality through soil moisture deficit stress [6], plant detection and mapping [7,8], to the yield [9,10]. Monitoring a single leaves of coffee plant is difficult if using the satellite images basis analysis. it requires another approaches named spectral analysis for vegetation as like as the hyperspectral analysis vegetation [11]. This type of analysis divided into three parts includes leaf biochemistry that consist of leaf pigment, leaf moisture and leaf residues, leaf structure such as leaf area index and fraction absorbed photosynthetically active radiation (FPAR), and plant physiology. Additionaly, other remote sensing indices such as Normalized Difference Vegetation Index (NDVI), Yellowness Index (YI), Normalized Difference Water Index (NDWI), and Red Edge Position Determination (REPD) also was used. This research focussed in spectral analysis for phenological studies of coffee leaves and fruits development. In order to address issue, the equations used in this study is discussed in Table 1.

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Table 1 Spectral based indices used to study leaves and fruits development

No	Indices	References
1	Normalized Difference Vegetation Index (NDVI)	[12]
2	Modified Chlorophyll Absorption Ratio Index (MCARI)	[13]
3	Yellowness Index (YI)	[14]
4	Normalized Difference Water Index (NDWI)	[15]
5	Red Edge Position Determination (REPD)	[16]

2. Data and method
Gunung Puntang is one of the mountain in south Bandung and situated at **2.223 meters above sea level** and located in two region includes Cimaung and Banjaran sub-district. Coffee plants (*Coffea*) in gunung Puntang, mostly grown in a shaded area below the canopy of pine trees (*Pinus mercusii*). **In other location the coffee trees also grown in an intercropping system with cassava** *(Manihot esculenta),* sweet potatoes (*Ipomoea batatas*) and banana *(Musa Spp).* The farmers are cultivating both coffee Arabica than Robusta.
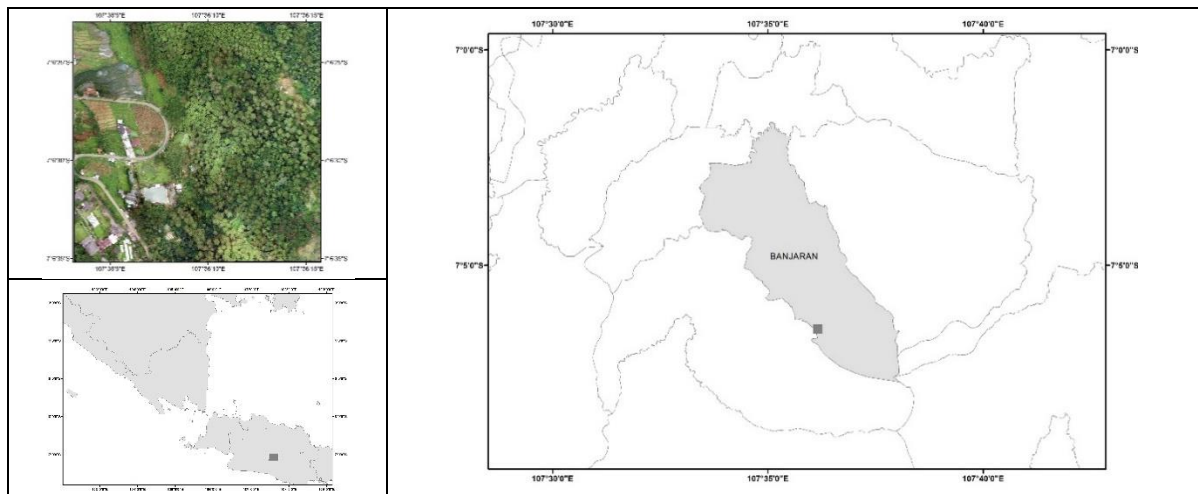
Figure 1 Study location for monitoring the coffee leaves and fruits development in Banjaran sub-district, gunung Puntang region, West Java.

Data used in this study was eight spectral reflectance of coffee leaves from a coffee tree. It was recorded using spectroradiometer systems of stellar-rad in the range of wavelength at 337.03 - 1181.37nm. IT includes 4 leaves combination that allowed to represent the healthy leaves evelopment. Started from a shoot (younger leaf tp the dark green leaf (Figure 3.a) and the dark green leaf, yellow-green leaf, yellow-green leaf with clorosis and dried leaf (Figure 3.b). All spectral signatures shows in Figure 2.
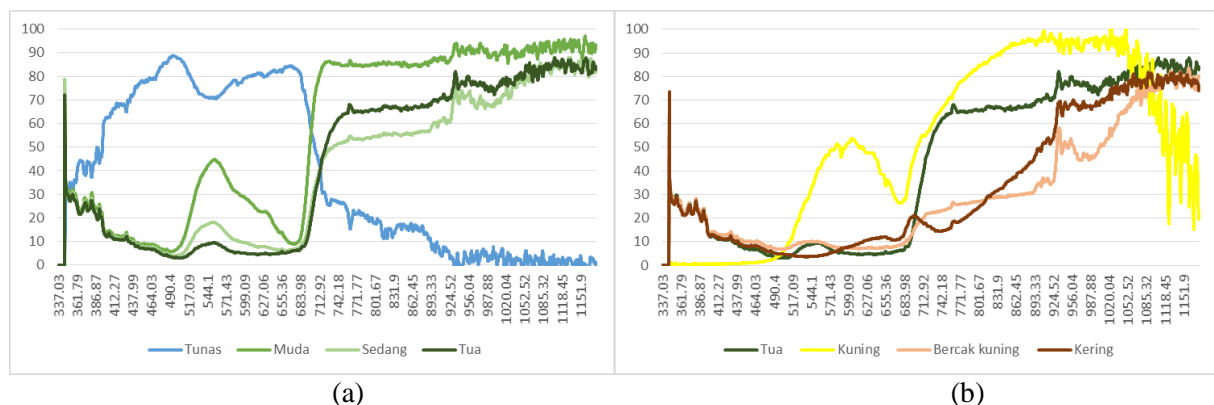

(a)   (b)

Figure 2 Spectral signatures of four different coffee leaves development taken using stellar-rad in 330 -1180nm from a coffee plantation grown in Banjaran sub-district, gunung Puntang region, West Java. A healthy leaves development (a), represent the leaves grown from the shoot to the dark green color when it mature. The unhealthy leaves development (b) the mature leaves changes to dried leaves.

(a)

(b)

Figure 3 Physical appearance of a healthy coffee leaves development (a) and unhealthy coffee leaves development (b) with clorosis and dried leaf from a coffee tree in Banjaran sub-district, gunung Puntang region, West Java. From left to right, shows a each leaves is correspond with the spectral signature in Figure 2

The analysis of leaf development conducted using the modified equation in Table 1 according to the availability of bands in the reflectance values recorded by spectroradiometer systems of stellar-rad. At this system the reflectance values recorded in the range of wavelength at 337.03 - 1181.37nm. It covered

the ultraviolet light at 337.03 – 400 nm, the visible light in 400 – 700 nm, and the infrared light in 700 – 1181.37 nm.

The NDVI is previously proposed by Rouse et al.,[12]. It requires the reflectance of red and near infrared. The result will show a range between -1 to 1. The modified version of NDVI is used and named MNDVI (equation 1). The purpose of using MNDVI is to get the change in greenness level during the leaf development. As it the indicator of changing in chlorophyll content that estimated using a modified of MCARI [13] named MCARIs (equation 2). As describes by Sheffield and Liang both equation has utilized the bands in the visible light region, includes the 550 – 760 nm, and considered as chlorophyll absorption bands. This is the physical reason why the reflectance value in leaf spectral is lower in that range. The chlorophyll cell is absorbed much green and red reflectance [17,18].

$$MNDVI = \frac{Average\ (860.29nm+860.72nm) - Average(660.57nm+660.57nm+660.98nm)}{Average\ (860.29nm+860.72nm) + Average(660.57nm+660.57nm+660.98nm)} \qquad (1)$$

$$MCARIs = (((700.24 + 700.65))/2 - ((670.23 + 670.24))/2) - 0.2 * (((700.24 + 700.65))/2 - ((550.23 + 550.24))/2) * ((((700.24 + 700.65))/2)/(((670.23 + 670.24))/2)) \qquad (2)$$

The water content in leaves was computed using a modified NDWI named MNDWI (equation 3). It based on the Gao [15]. Typically, in the leaves spectral signature there are five band that represents the water absorbance bands or explicitly explained the water content at 970, 1200, 1450, 1930 and 2500nm[19]. In this cases, since the Stellar-Rad do not has the band at 1200, 1450, 1930 and 2500nm, the estimation of MNDWI was examined the band at 970nm. The amount of leaves water content will be vary and follow the change in leaves color. For example, when it green, the water content will be higher than when it turn to yellow and brown. The change in leaves color also known as the leaves chlorosis and is an indicator of stresses in plant. The leaves chlorosis is easily observed directly by eyes. It possible to assess using a modified YI named MYI (equation 4). The water content in a limit amount may explain the plant stress. It was used to detect the plant stress through the change of color leaves [14]. This change indicates the plant diseases but also the stress due to water supply deficiency. In other cases the chlorosis also affected by a virus, lack of an essential mineral or oxygen, injury from alkali, **fertilizer**, **air pollution**, or cold, insect, mite, or nematode feeding, gas main leaks, compaction or change in soil level, and stem or root. Severely chlorotic plants are stunted, and shoots may die back to the roots. Control is aimed specifically at the causal agent of the **disease** [20]. When it happened, all the vegetation parameters discussed above will be declined. In a coffee, the chlorosis is appear due to the deficiency of available iron [21,22].

$$MNDWI = \frac{Average\ (860.29nm+860.72nm) - Average\ (970.35nm+970.8nm)}{Average\ (860.29nm+860.72nm) - Average\ (970.35nm+970.8nm)} \qquad (3)$$

$$MYI = \frac{Average\ (550.23nm+550.61nm)}{Average(650.15nm+650.55nm+650.95nm)} \qquad (4)$$

The red edge (re) is known as the point of maximum slope on the reflectance spectrum of a plant leaf between red and near-infrared wavelengths and strongly correlated with foliar chlorophyll content, also describes the variety of environmental factors affecting leaves such as stress, drought and senescence [23]. REPD used to detect the yield in paddy rice [24], and nitrogen content in wheat [25]. In this study, the REPD was estimated using a modified version named MREPD (equation 5, 6).

$$\rho_{(re)} = \frac{\rho(average\ 670.23+670.64) + \rho(average\ 780.16+780.58)}{2} \qquad (5)$$

$$MREPD = 700 + 40 \left(\frac{\rho\left(\frac{860.29+860.72}{2}\right) - \rho\left(\frac{1179.46+1179.93}{2}\right)}{\rho\left(\frac{860.29+860.72}{2}\right) + \rho\left(\frac{1179.46+1179.93}{2}\right)} \right)$$

(6)

3. Results and discussion

During pheneologycal stages indirectly explain the change of biophysical parameter in coffee leaves. Based on the Figure 4, four of five vegetation indices shows the negative trends. Started from the MNDVI and MCARIs, Both shown a negative trends. This is means that during the maturity stages from tunas, muda, sedang to tua, the coffee leaves might be grown in a not good environment condition. But if assume that the coffe trees used for sampling, It already to produce coffee berries. As like as the change the paddy leaves color, when they are ready to produce grain. If so, the decreasing of NDVI value then followed with the chlorophyll content based on the MCARIs is reasonable. Because the energy produced through the photosynthesis processes, is used to produce coffee berries. Especially in coffee trees in fifth years since planting. At this age, They are ready to harvest monthly.

Both MNDWI and MYI describes the water content relation in coffee leaves. Along the phenology stages, both indices shown a declining in estimated water content on leaves. In other hand, the water content from tunas will be decrease until the tua. The impression result has found that in a coffee leave that infected by clorosis, it also has the lowest water content if compared with the water content in muda leaves. Then of course in a dried leaves, it unable to maintain the water content anymore.
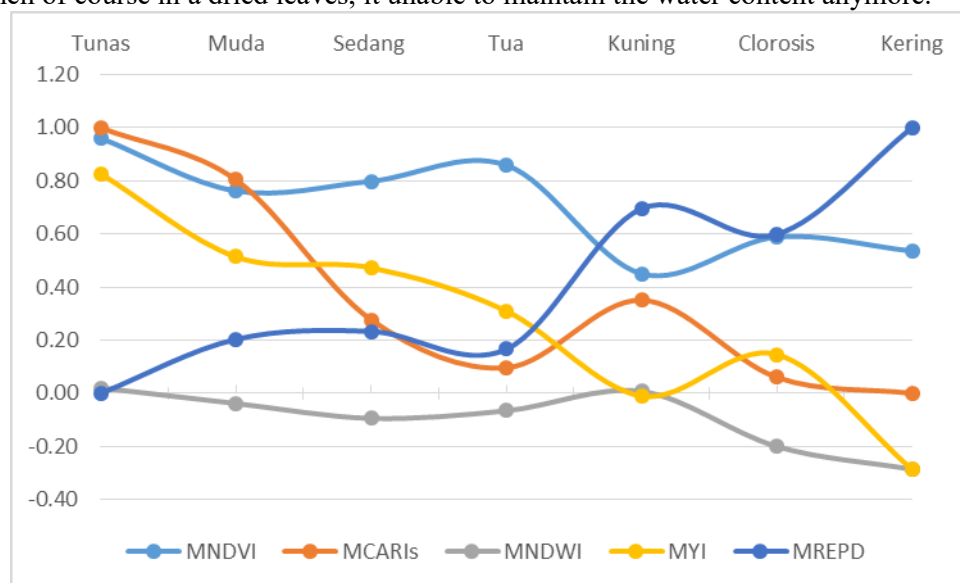

Figure 4 The trends on the change of estimated value of coffee leaves vegetation indices.

Table 2 Spectral based indices used to study leaves and fruits development

	Tunas	Muda	Sedang	Tua	Kuning	Clorosis	Kering
MNDVI	0.96	0.76	0.80	0.86	0.45	0.59	0.54
MCARIs*	38.27	31.46	13.13	6.85	15.71	5.59	3.49
MNDWI	0.02	-0.04	-0.09	-0.07	0.01	-0.20	-0.29
MYI	0.83	0.51	0.47	0.31	-0.01	0.15	-0.29
MREPD*	686.97	688.54	688.77	688.25	692.32	691.58	694.66

*The estimated values was rescaled into 0 to 1. This is necessary to do, in accom-modating the other values that also have the similar range.

In the modified of red edge, it has an increasing in all stages. This condition is not reasonable since the red edge is allow to describes the variety of environmental condition that affecting stress, drought and senescence in plant [23], not only in coffee. It was expected that at least in the clorosis stages, it must be lower than other stages. This condition is similar with at the dried (kering) stages. The MREPD went to the top values. The details of estimated values discuss above shown in Table 2.

Although the estimated values of MREPD given an anomaly if compare with other values of vegetation indices. Over all, the estimated values have good performance in explain the relationship each other. For instance, in general all the vegetation indices used to detect the quality of coffee leaves development have a moderate to strong relationship both negative and positive. If confidence with this explanation through the correlation within the parameters, the anomaly of MREPD is acceptable. It might be the new opportunities to enhance the capability of red edge reflectance in explaining the quality of plant growth. Since in this case the MREPD has a strong negative correlation with MYI, MNDWI and MNDVI Figure 5.

The changes in MNDVI values influences the MCARIs 55%. It has a moderate positive relationship. The chlorophyll content will increase when the value of MNDVI is increase. As like as the water content from MNDWI, it only affected the MNDVI 45%. It can be explained that the water content in coffee leaf do not play a very important role to control the change of MNDVI. Which is the leaves color turns to be dark green. It seems, it does not matter if the coffee trees or in a plantation experiencing a long drought season. It will grow healthy.
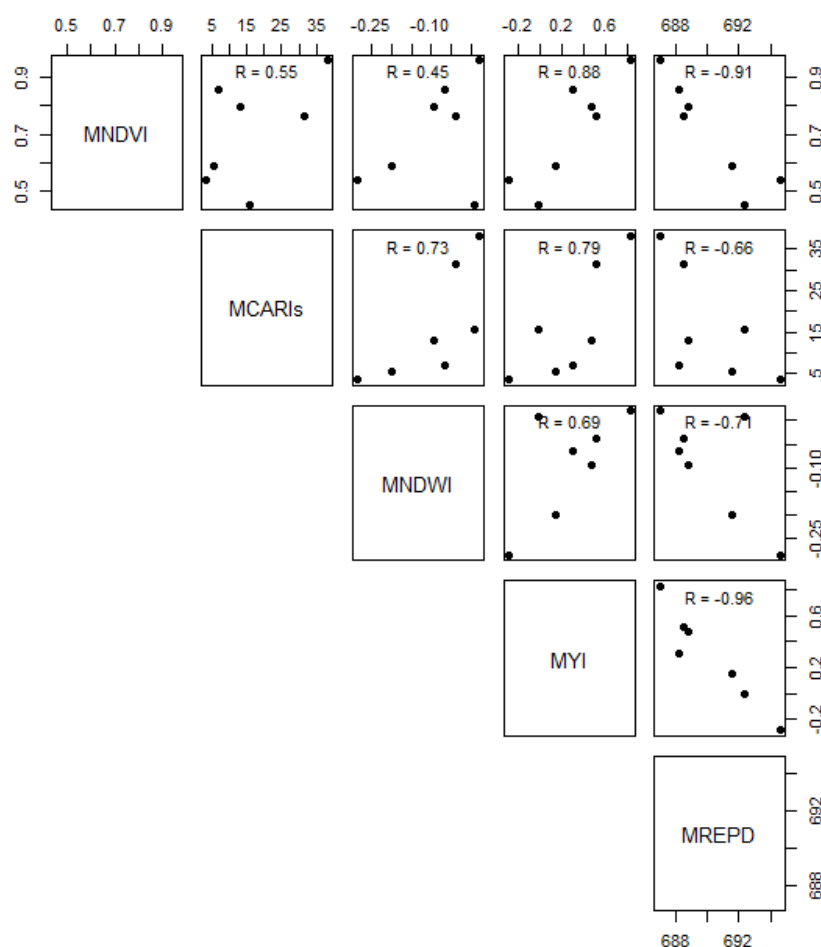

Figure 5 The relationship and correlation of coffee leaves development based on the modified vegetation indices.

Besides that, the most factors that given the highest effect to leaves development is related to the water content and yellow index. Both factors are critical in maintaining the chlorophyll content. The strong correlation provides by MYI and MNDWI at 79% and 73% makes it reasonable. Let's to imagine, at the time leaves losing their capability to absorb and to keep the water due to a high rate of evapotranspiration, the chlorophyll will be drained. It is easily to observe, the green color of leaves will turn into the yellow or brown. As like as the MNDWI, the MYI also said the same. The MYI does not only say the strees caused by a limit of water content but also it will open the opportunities to study the possibility to detect the plant symptom affected by *Hemileia vatatrix.*

4. Conclusion

The study of leaves development through spectral analyses is allowed to open the new opportunities in evaluating the sustainable coffee cultivation. In a major or in a minor scales, it offers the leading approaches. At this point, the understanding to what is the most affecting factors that influencing the coffee yield is water availability. It causes the red edge, chlorophyll and capability of leaves to absorb the water. So this is might be the answer, why most of coffee plantation is located in a shaded location?. It aims to maintain the water availability in ground, in the leaves and surround. For further works, the same studied necessary to consider is using the larger area or in trees scale. After the behaviour of coffee trees through it leaves is clearly defined.

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