accounting for 72.3% of the households. The type of intercropping avocado has only recently developed, accounting for more than 8% of the households. Multiple intercropping model had above 11.7% of the households.

- Type of intercropping durian with a spacing of 12 × 12 m and 12 × 15 m for coffee yield of over 3 tons/ha and durian productivity of over 60 kg per tree, economic efficiency higher than pure coffee planting from 75.89 to 96.85%.

- Type of intercropping pepper with spacing of 3 × 6 m, 6 × 6 m for coffee yield of 3 tons/ha and pepper yield of 2.7 kg per plant, economic efficiency higher than pure planting from 100.25 to 120.45%.

- Type of intercropping avocado with all spacing had coffee yield over 3 tons/ha and the productivity of avocado over 30 kg per tree, economic efficiency increased from 39.58 to 83.24%.

- Type of intercropping cashew with all spacing had low coffee yield and economic efficiency was not significantly increased comparing to pure coffee planting.

Recommendations

- On the basis of coffee as the main crop, to increase income per area unit and ensure sustainable coffee cultivation, recommending reasonable intercropping, ensuring the harmonious development of crops, the average coffee yield is over 3 tons per ha and the economic efficiency is higher than that of pure coffee planting.

- Recommending durian and avocado intercroping with the spacing of 12 × 12 m and 12 × 15 m; pepper intercroping with the spacing of 3 × 6 m and 6 × 6 m. The recommended density was the same as in the intercropping process. It is not recommended to develop cashew intercroping.

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FLOWER BIOLOGY OF BLACK PEPPER (PIPER NIGRUM) IN VIETNAM

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Abstract

A study on flower biology of black pepper (*Piper nigrum*) was carried out to provide important understanding in flower biology which is vital to breeding and hybridization studies in Vietnam. Three varieties namely Vinh Linh, Phu Quoc and SRLK have been used for this study. The results showed that it takes about 242 days to 270 days from spike appearance to fruit ripening. The longest period is fruit development and fruit maturity. Anther dehiscence of Vinh Linh and Phu Quoc occurs at around 7:00 pm to 8:00 pm. However, SRLK is earlier at 4:00 pm to 5:00 pm. Sigma receptivity happens 1.8 days to 2.8 days after anther dehiscence. Stigma remains receptive from 4 days to 6 days and up to 10 days.

Keywords: *Piper nigrum*, flower biology, anther dehiscence, stigma receptivity

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INTRODUCTION

Black pepper (*Piper nigrum* L., *Piperaceae*), the King of Spices, is one of the most important spices in over the world. Black pepper is used as culinary spice as well as medicine and cosmetics industries.

Black pepper originated in the Western Ghats of Kerala and the history of this spice is closely linked to the history of India (Parry, 1969; Rosengarten 1973). In early nineteen century, black pepper was introduced to Vietnam, and then became popular after 1975. Currently, the crop is mainly cultivated in Central Highlands and South-eastern region with total area was about 152,000 hectares and total production was 235,889 tons which have made Vietnam become the biggest pepper producer in the world.

Breeding study is still very limited so far, and there is no varieties have been released. Farmers only use local varieties such as Vinh Linh and Loc Ninh which are high yielding varieties but very susceptible to *Phytopthora capsici* and nematodes. Limited work in breeding as well as hybridization may results of lacking of fundamental information.

Hybridization is considered a good breeding methodology to create new variety that is able to resist to *Phytophthora capsici* and/or nematodes. Successful hybridization is resulted from understanding of flower biology. This paper aims to provide information in different stages of spike development as well as anther dehiscence and stigma receptivity.

MATERIALS AND METHODS

Materials

Vinh Linh, Phu Quoc and SRLK varieties have been used for this study. Semi-hardwood cuttings of these varieties were collected from mother garden at Pepper Research and Development Centre.

Soil moisture meter: checking soil moisture in pot.

Head magnifier: monitoring anthers, stigmas.

Microscope: identifying pollens.

Methods

Preparation of plants

Semi-hardwood fruiting branches are harvested from disease - free garden. Then, they are planted in pots with 40 cm of diameter and 40 cm of height. Fifteen pots per variety are prepared (forty five pots in total). The pots are filled with potting mixtures which are contain cow dung, coir pit, top soil and river sand with the ratio of 1 : 1 : 1 : 1. The pots are placed in green house with shade conditions. After one month of planting, semi-hardwood branches produce shoots and rooted. Water and fertilizers are applied to keep the plants healthy and good growth. After four to five months of planting, the plant is able to produce flowers and ready for experiment.

Investigate different development stages of spikes

Only Vinh Linh variety was used for this experiment. At the beginning of experiment, water stress is applied to facilitate flower formation. This means that the plants were left in green house without watering. Soil moisture in the pots was recorded daily by soil moisture meter to make sure soil moisture does not reach to wilting point. In addition, daily observations all treatments must be done to ensure all plants are healthy.

After 31 days of water stress, 3 liters of clean water per pot will be applied every 7 days. After 21 days of re-supply water, pepper spikes will be appeared.

Forty five spikes were randomly selected to investigate number of days in different stages of spike development: Stage 1: Re-supply water; Stage 2: Spike appearance; Stage 3: Spike development; Stage 4: Pollination and fertilization; Stage 5: Fruit setting; Stage 6: Fruit development; Stage 7: Fruit maturity; Stage 8: Fruit ripening.

Anther dehiscence

Vinh Linh, Phu Quoc and SRLK varieties were used for this study. Vinh Linh and Phu Quoc are local varieties which high yield and good quality while SRLK is imported variety which is good development. Around fifty anthers per variety at the pre-dehisced stage were selected. Then, observations were done every one hour to identify anther dehiscence. Magnifier was used to observe powder (pollens). Finally, released pollens were confirmed by microscope observations.

Stigma receptivity

Three above varieties also used for this study. The receptive periods were differentiated by Chen *et al.* (2018) (Figure 1).

Time and place of the study

The study was conducted in 2018, at Pepper Research and Development Centre (PRDC). The location details are 13°57'32" N 108°0'57"E, 790 m of elevation, Pleiku city, Gia Lai, Vietnam.

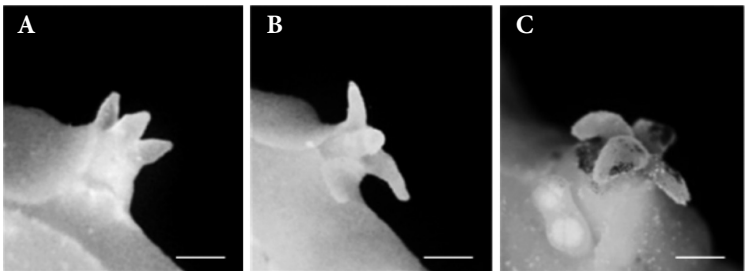

Figure 1. Stages of stigma

Source: Chen *et al. (2018).*

Note: Stage 1 (A): First appearance of stigma (days); Stage 2 (B): Elongation and spreading of stigma (days); Stage 3 (C): Complete emergence and wide spreading of stigma (days).

RESULTS AND DISCUSSION

Spike characteristics

The inflorescence in black pepper is a glabrous, filiform, pendulous spike borne opposite to the leaves on plagiotropic branches (Parthasarathy *et al.*, 2007).

Similarly to other piper nigrum, Vinh Linh, Phu Quoc and SRLK are pendulous spike. SRLK has longest spike which is about 18.5 cm, following by Vinh Linh around 10.4 cm. Phu Quoc has shortest spike which is about 8.4 cm.

Flowers

In Vietnam (Central Highlands and Southeast), flowering season generally starts at pre-monsoon (June - July) when soil gets moist. High air humidity is considered the best conditions for pollination and fertilization.

Flowers are borne in the axils of ovate, fleshy bracts in long spikes, which are pendant, singular in nature, and appear opposite to the leaves on the plagiotropic branches (Parthasarathy *et al.*, 2007).

Black pepper flowers are mainly bisexual; one flower contains one ovary and two stamens which are borne from each side of ovary (Figure 4, 5). In addition, black pepper also has female flowers but proportion is very limited.

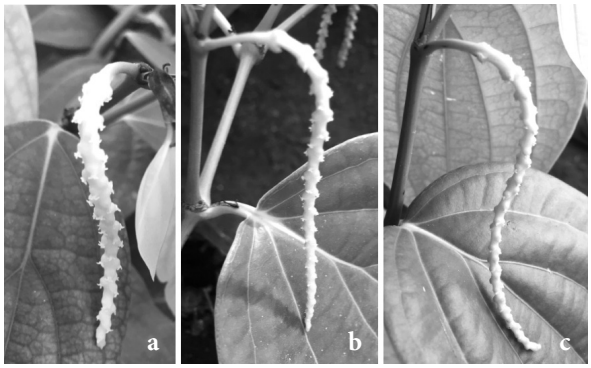

Figure 2. Spikes

Note: a: Vinh Linh; b: Phu Quoc; c: SRLK.

High percentage of bisexual flower will result in high yield. For example, high yielding varieties in India such as Panniyur 3 (99.90% of bisexual flower), Panniyur 1 (99.20%), and Subhakara (99.00%).

Similarly, Vinh Linh has highest percentage of bisexual flowers with 97.30%, following by Phu Quoc and SRLK around 95.20% and 93.45%, respectively.

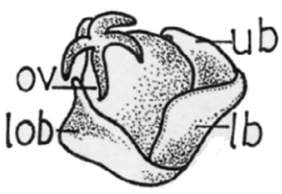

Figure 3. Female flower

Figure 4. Bisexual flower

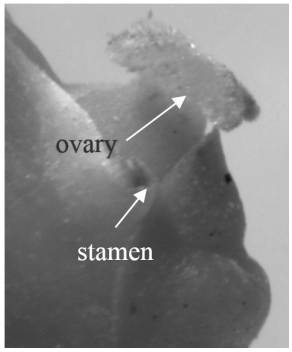

Figure 5. A Vinh Linh bisexual flower

Source: Parthasarathy *et al. (2007).*

Note: St: stamen; ov: ovary; lob: lowest bract; ub: upper bract; lb: lower bract.

The process from spike appearance to fruit ripening of Vinh Linh takes about 242 days to 270 days, including 8 stages (Figure 6). At the beginning of the process, spike is fully appeared after 28 - 30 days of water supply. Then, it takes about 18 days to 20 days for full development of spike, following by 12 days to 13 days of pollination and fertilization. Fruit setting only takes 6 - 9 days; in contrast fruit development lasts from 120 days to 130 days, followed by a period of 34 - 38 days of maturity. Finally, fruits need 25 days to 30 days to ripen.

The above results are similar to the field conditions and other study. In field conditions in Vietnam, flowering season generally starts from June and July. Then, fruit development and maturity is from August to December. The fruits are ripened and ready to harvest in March. In India, it takes about 180 days to 240 days from flowering to maturity. Late maturity may be due to of cool weather (Ravindran, 2000).

KAU (1978) also concluded that it takes about three to four weeks for full spike appearance. Pollination and fertilization period is about 8 - 24 days, depending varieties and weather conditions (KAU (1978) cited by Ravindran, 2003).

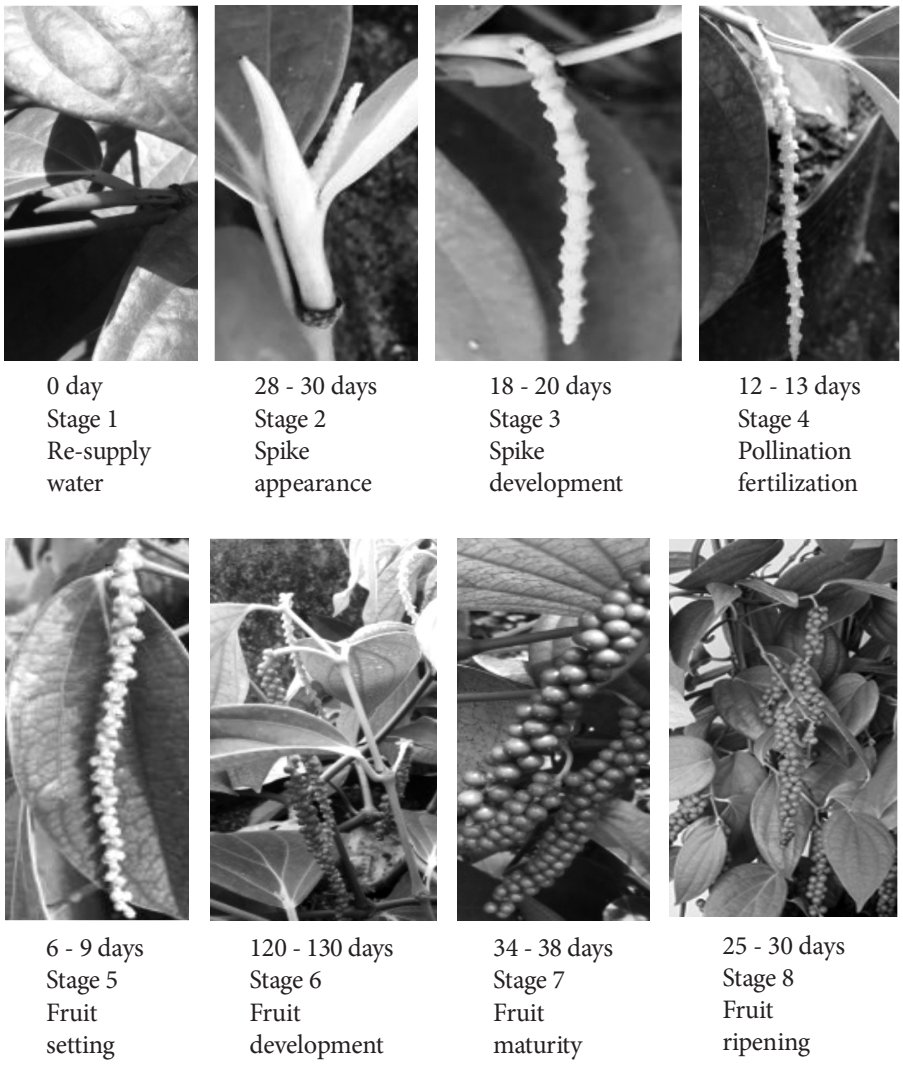

Figure 6. Different stages of spike and fruit development in green house

Anther dehiscence

Black pepper is mainly self-pollinated. Pollens can be transported from one flower to others. In one bisexual flower, stigma will appear first and the time interval depends on the cultivars. Generally, the stigma emergence can be noticed in 10 - 20 days, though there are cultivars where the stigma emergence takes place in around five days after full spike emergence. It takes about 5 - 15 days for completion of stigma emergence. The period of receptivity of stigma varies

from 3 - 9 days, and the receptive period of stigma in the first opened basal flowers is longer and the period gradually decrease in flowers opening later in the developmental stage (KAU, 1978).

The results showed that anther dehiscence in Vinh Linh and Phu Quoc varieties starts at the same time at 7:00 pm to 8 pm. However, SRLK is earlier at 4:00 pm to 5:00 pm (nursery conditions in May and Junes in Central Highlands). Chen *et al.* (2018) concluded that the median time of anther dehiscence was between 11:00 pm to 12:00 pm for ten cultivars namely Semongok Aman, Kuching, Semongok Emas, Semongok Perak, Semongok 1, Nyerigai, India, Lampung Daun Lebar, Sarikei and Yong Petai.

The author further supported that time of anther dehiscence is significantly affected by weather conditions. For example, anther dehiscence for Semongok Aman takes longer in March and April compared to May, June and July. These differences may be due to level of relative humidity and rainfalls where March and April has more rainfall and higher relative humidity compared to May, June and July.

Chen *et al.* (2018) also investigated pollen viability of the above ten varieties. It is concluded that pollens are more viable between five and ten hours after anther dehiscence.

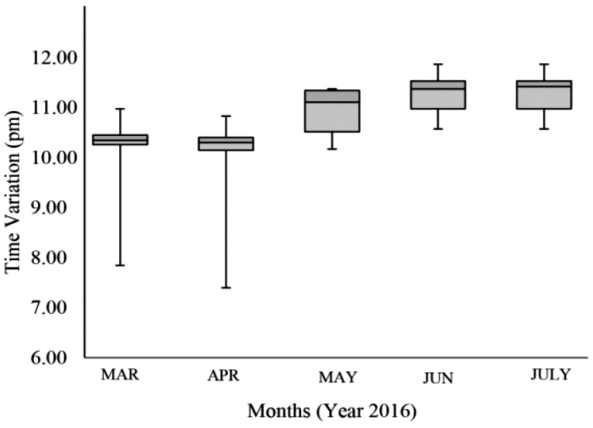

Figure 7. Time of anther dehiscence in cultivar Semongok Aman between March and July 2016
Source: Chen *et al. (2018).*

Stigma receptivity

The results showed that stigma receptivity occur after anther dehiscence. This time intervals is significant different between three varieties with 2.7 days (Vinh Linh), 1.8 days (Phu Quoc) and 2.8 days (SRLK) after anther dehiscence. In other words, anther becomes dehisced and release pollens before sigma get mature and receive pollens.

Observations of sigma development shows that it takes about 4 days 6 days from stage 1 (first appearance of stigma) to stage 3 (complete emergence and wide spreading of stigma). Vinh Linh takes longest time of stigma receptivity with 6 days, following SRLK with 5 days and Phu Quoc is only 4 days.

This outcome is also similar to other one. Chen *et al.* (2018) also concluded that it take about 7 days to 10 days from stage 1 to stage 3 (varieties: Semongok Aman , Kuching, Semongok Emas, Semongok Perak, Semongok 1, Nyerigai, India, Lampung Daun Lebar, Sarikei and Yong Petai). Details are: Stage 1: first appearance of stigma (one day); Stage 2: elongation and spreading of stigma (1 - 2 days) and Stage 3: complete emergence and wide spreading of stigma (2 - 3 days). The author also recommended that stage 2 and stage 3 had better receptivity than stage 1.

Early study also concluded that the best time for stigma receptivity is five days after emergence (stage 2, 3) (Purseglove, 1968) and sigma may receive pollens up to ten days. Without pollination, stigma surfaces may remain receptive for a long period (Wetzstein and Sparks, 1989), spike without pollination, however, may falling down.

CONCLUSIONS AND RECOMMENDATIONS

Vinh Linh variety needs about 242 days to 270 days from spike appearance to fruit ripening. The longest stages are fruit development and fruit maturity.

Anther dehiscence occurs differently between three varieties; Vinh Linh and Phu Quoc become dehisced around 7:00 pm to 8:00 pm. By contrast, SRLK is earlier at 4:00 pm to 5:00 pm. Stigma receptivity happens after 1.8 to 2.8 days of anther dehiscence. Then, sigma receptivity remains from 4 days to 10 days. The best time for stigma receiving pollens is to 6 days after first stigma appearance.

It is proposed that pollen collection of Vinh Linh and Phu Quoc need to be done around 10:00 pm to 12:00 pm. SRLK, however, should be done around 8:00 pm to 10:00 pm. Artificial pollination should be done 5 days to 6 days after first stigma appearance.

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DEVELOPMENT OF POTATO STAPLE FOOD IN ZHEJIANG PROVINCE OF CHINA FROM THE PERSPECTIVE OF WHOLE VALUE CHAIN

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Renxiang Cai[2], Zaogui Wu[3], Bing Li[1]

Abstract

Potato is the fourth most important food crop in the world. The potato staple food strategy launched in 2015 has brought new opportunities for the development of potato industry in China. Zhejiang province has its unique development strengths and experiences in potato industry though potatoes are neither staple food nor staple crop in Zhejiang province. In this study, the foundation of the potato staple food development in Zhejiang province was elucidated from the perspective of the whole value chain involving potato production, process and consumption. Specifically, through the measures of varieties breeding for special use, localization of seed potato, regionalization of planting areas, diverse processing and popularization of staple food products, the implementation of potato staple food was gradually accelerated and the potato industry was further upgraded. In addition, a consumption-oriented collaborative extension model for the development of potato industry chain was established. The results in this study will provide an important reference for the sustainable development of potato industry in certain areas in China or in Asia where there are similar natural resources and dietary habits with Zhejiang province.

INTRODUCTION

Potato is the fourth food crop in the world after wheat, rice and corn (Ezekiel *et al.,* 2013; Zhang *et al.,* 2017). Since potato is highly adaptable to climate conditions with short growth period, balanced nutrients and long value chain, it has been widely used in staple food consumption, process and utilization (Beals, 2019; Mu *et al.,* 2017; Zhang *et al.,* 2017). China is the world's largest potato producer and consumer (Wang and Zhang, 2004; Scott and Suarez, 2012; Zhang *et al.,* 2017). Around 70% of potato is taken for fresh consumption (Zhang *et al.,* 2017). In 2015, the government released the strategy of potato as staple food, the proposal of potato staple food strategy offers an unprecedented opportunity and points the way for accelerating the industrialization of potatoes, and followed by a series of problems that need to be solved, such as the adjustment of variety structure, the integration of agricultural machinery and agronomy, the processing technology and equipment of staple food products, and the change of consumption habits (Cai, 2016; Cai *et al.,* 2016; Zhang *et al.,* 2017).

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