INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 08 Issue 11 November 2025

DOI: 10.47191/ijmra/v8-i11-01, Impact Factor: 8.266

Page No. 5910-5918

Effect of Peptide Concentration on the Flowering and Fruiting Phenology of Arabica Coffee (*Coffea arabica* L.)

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ABSTRACT: This study is a descriptive experimental research aimed at observing and describing the phenological phases of flowering and fruiting in Arabica coffee (*Coffea arabica* L.) plants in response to the application of different peptide concentrations. The research was conducted using a Randomized Block Design (RBD) with a single factor treatment, namely peptide concentration (P), consisting of three levels: P_0 = 0 ml peptide/L water (control), P_2 = 2 ml peptide/L water, and P_4 = 4 ml peptide/L water. Each treatment was replicated nine times, resulting in a total of 27 Arabica coffee plants as samples. The observed variables included three main phenological components: (1) new shoot growth, observed based on the time of emergence (days after treatment) and morphological changes until the shoots reached the flowering-ready stage; (2) flowering, observed from the appearance of the first flower until full bloom, with visual documentation at each developmental stage; and (3) fruiting, observed from the formation of the first fruit (fruit set) until the fruit turned red (physiological maturity), with periodic visual documentation of fruit development. All observations were conducted visually and photographically at intervals corresponding to the plant developmental stages. The results showed that peptide application had a significant effect on all observed phenological phases. Treatment with a concentration of 4 ml/L water (P_4) produced the best results, including faster new shoot growth, more uniform flowering, and more optimal fruiting compared to the other treatments. This indicates that peptide acts as a natural biostimulant, enhancing plant physiological activity and accelerating the differentiation of generative tissues. Therefore, the application of peptide at a concentration of 4 ml/L is recommended as a cultivation strategy to improve growth efficiency, productivity, and uniformity of Arabica coffee plants. Further studies are suggested to determine the most effective timing of application and to investigate the physiological mechanisms by which peptide supports the development of generative organs in coffee plants.

KEYWORDS: Arabica Coffee, Concentration, Flowering, Fruiting, Peptide, Phenology.

INTRODUCTION

Indonesia is one of the largest coffee-producing countries in the world and plays an important role in the trade of plantation commodities. Among the various types of coffee cultivated, Arabica coffee (*Coffea arabica* L.) is considered the most prominent due to its distinctive flavor, strong aroma, and high economic value (Priantari et al., 2022). According to data from the Central Bureau of Statistics (2021), Indonesia ranks as the fourth largest coffee producer globally, after Brazil, Vietnam, and Colombia. Bali Province is one of the centers for Arabica coffee production, with an area of 12,293 ha and a production of 4,278 tons (National Plantation Statistics, 2022). However, the productivity of Arabica coffee in Bali is still relatively low compared to its optimal yield potential of 3 tons/ha (Puslitbangbun, 2021).

The gap between potential and actual production is caused by several agronomic factors, including cultivation practices that do not fully adhere to Good Agricultural Practices (GAP), unbalanced fertilization, and excessive use of inorganic fertilizers. According to Handayani et al. (2023), continuous use of chemical fertilizers can reduce soil fertility, disrupt soil microbial activity, and ultimately decrease crop productivity. Therefore, innovations in environmentally friendly fertilization techniques are needed to maintain soil health while enhancing the growth and yield of Arabica coffee.

One alternative that is being developed is the use of Keratin Hydrolysate Peptide, an organic product derived from the decomposition of poultry feather and fish scale waste, which is rich in nitrogen, sulfur, and essential amino acids. According to CH Biotech (2023), peptides function as bio-protectants, bio-stimulants, and bio-fertilizers capable of improving plant physiological processes. Peptides can enhance plant defense systems against biotic and abiotic stresses, strengthen enzymatic activity, and improve cellular metabolism by increasing protein synthesis and plant tissue collagen. Research by Zhang et al. (2023) reported that peptide application on coffee plants in China increased flowering by up to 20% and improved fruit quality.

These findings indicate that peptide application has the potential to influence the phenological phases of Arabica coffee. Plant phenology is the study of the natural developmental stages of plants, such as bud emergence, flowering, fruiting, and fruit maturation, which are influenced by genetic and environmental factors (Gao & Zhang, 2021). Information on flowering and fruiting phenology is essential for determining cultivation strategies, fertilization timing, and harvest yield estimation (Canisius et al., 2018).

Understanding the effect of peptide concentration on the flowering and fruiting phenology of Arabica coffee is crucial, as these phases determine crop productivity and bean quality. Proper peptide application is expected to optimize plant physiological processes, accelerate flowering, increase fruit set, and maintain a sustainable balance between vegetative and generative growth. Therefore, this study was conducted to investigate the effects of different peptide concentrations on the flowering and fruiting phenology of Arabica coffee (*Coffea arabica* L.) to improve yield and bean quality sustainably.

RESEARCH METHOD

Research Design

This study was a descriptive experimental research aimed at observing and describing the flowering and fruiting phenology of Arabica coffee (*Coffea arabica* L.) plants in response to the application of different peptide concentrations. The research employed a Randomized Block Design (RBD) with a single factor treatment, namely peptide concentration (P), which consisted of three levels:

P_0 = 0 ml peptide/L water (control)

P_2 = 2 ml peptide/L water

P_4 = 4 ml peptide/L water

Each treatment was replicated nine times, resulting in a total of 27 Arabica coffee plants as samples. Treatments were randomly assigned to each block according to the field design.

Research Location and Time

The study was conducted in Belantih Village, Kintamani Subdistrict, Bangli Regency, Bali Province, at an altitude of approximately 1,200 meters above sea level. Observations were performed directly in the field, and documentation was analyzed at the Laboratory of Agronomy and Horticulture, Faculty of Agriculture, Udayana University. The research was carried out from November 2024 to June 2025, covering all phenological phases of the plants from new shoot emergence to fruit maturation.

Research Equipment and Materials

The equipment used in this study included: sprayers, pruning scissors, rulers, labeling tape, digital cameras, stationery, and computers for visual data analysis.

The materials used were Arabica coffee plants (*Coffea arabica* L.), peptide solution (CH Biotech Co., Ltd., Taiwan), and clean water as a solvent and control.

Research Implementation

The research was carried out through the following stages:

1. **Selection of Sample Trees**
   Arabica coffee plants aged 6–8 years, which were already in full production, were selected as samples. Trees were chosen from the same plot with relatively uniform soil conditions, microclimate, height, and canopy size to ensure a homogeneous growing environment.
2. **Plant Maintenance**
   All sample trees were maintained according to the Standard Operating Procedure (SOP) for Arabica coffee cultivation, including weeding, pruning, fertilization, and pest and disease management. Maintenance was conducted uniformly to avoid affecting the phenological observations.
3. **Peptide Treatment Application**
   Peptide treatments were applied four times as follows:
   a. 15 days before the flowering phase (pre-anthesis)
   b. During the fruit-set phase (when flowers start to form young fruits)
   c. 1.5 months after the second application
   d. When fruits begin to change color from green to red (early maturation phase)

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Peptide solutions at P_2 and P_4 concentrations were applied as foliar sprays over the entire canopy for the first three applications, while the fourth application was performed as soil drenching around the base of the plant. The control treatment (P_0) received only water without peptide.

Observed Variables

The study focused on three main phenological components:

1. **New Shoot Growth Phenology**
   Observed based on the time from peptide application (days after treatment, DAT) until new shoots emerged, and morphological changes were recorded from emergence to the flowering-ready stage.
2. **Flowering Phenology**
   Observed by recording the time from the appearance of the first flower to full bloom, with visual documentation at each developmental stage.
3. **Fruiting Phenology**
   Observed from the formation of the first fruit (fruit-set) until the fruit turned red (physiological maturity), with periodic documentation of physical changes to describe the fruit developmental stages visually.

All observations were performed visually and photographically at intervals corresponding to plant developmental stages. Visual documentation served as the primary data for analysis.

Data Analysis

The collected data were analyzed qualitatively using descriptive methods based on visual observations and photographic documentation from the field. Analysis involved describing the morphological changes of Arabica coffee plants at each phenological stage, including new shoot emergence, flower development, and fruit formation and maturation. Observation results were presented in descriptive narratives and chronological photo series to illustrate the dynamic changes occurring in response to each peptide concentration treatment.

RESULTS

New Shoot Growth Phenology

Observations on new shoot growth were conducted to examine the effect of different peptide concentrations on the rate of shoot emergence and morphological changes until the shoots were ready to form flower primordia. Visual observation results are presented in Table 1.

Table 1. Documentation of New Shoot Growth Phenology of Arabica Coffee Plants

Treatment	Image		
	Point 1 Day 14	Point 2 Day 14	Point 3 Day 28
P0			
	New shoots appeared to grow normally, and young leaves began to emerge.	The young leaves had developed larger with a glossy greenish-brown color, accompanied by the emergence of new leaf shoots of similar color.	The new shoots had grown to approximately four nodes with a length of ±16.5 cm.

P2			
	Shoots appeared longer, young leaves began to unfold, and exhibited bright green color, indicating more active growth.	Young leaves had grown larger with a glossy greenish-brown color, and new leaf shoots began to emerge with a similar coloration.	The new shoots had grown to approximately three nodes with a length of ±18.1 cm, and flower primordia began to appear at the first node.
P4			
	New shoots emerged with young leaves exhibiting a greenish-brown color.	The young leaves had grown larger with a glossy greenish-brown color, and new leaves began to appear with a light green color.	The new shoots had grown to approximately three nodes with a length of ±18.6 cm, and flower primordia began to appear at the first node.

Flowering Phenology

Flowering was observed based on the timing of the first flower appearance, bud phase, and full bloom phase. Visual changes for each treatment are presented in Table 2.

Table 2. Documentation of Flowering Phenology of Arabica Coffee Plants

Treatment	Image			
	Point 4 Day 30	Point 5 Day 45	Point 6 Day 28	Point 7 Day 7
P0				
	Flower primordia are visible as small, light	The flower primordia are clearly distinguishable,	A portion of the flowers begin to open.	Flowers are fully open.

	green bumps in the leaf axils, showing minimal growth and uneven distribution.	yellow-green in color, elongating and densely arranged in the leaf axils.		
P2				
	Many flower primordia are visible, and flower buds are starting to emerge.	Flowers start to bloom.	Flowering reaches its maximum.	All flowers begin to wilt, and young fruits start forming.
P4				
	Flower buds are numerous and evenly distributed.	Flowers begin to bloom uniformly across all branches.	Flowering is synchronized and flowers are fully open.	Flowers start to drop, and most are transitioning into young fruits.

Fruit Development Phenology

Fruit development phenology was observed from the formation of the first fruit (fruit-set) until the fruit reached physiological maturity. The visual documentation of each stage for Arabica coffee plants is presented in Table 3.

Table 3. Documentation of Fruit Development Phenology in Arabica Coffee Plants

Treatment	Image				
	Point 1 Day 14	Point 2 Day 14	Point 3 Day 28	Point 4 Day 45	Point 5 Day 14
P0					
	Flowers have fallen, and young fruits are forming.	Fruits are small, oval, pale green with a dull surface.	The green color of the fruit is not uniform.	Fruits begin to turn yellow.	Fruits start changing color to red.

P2					
	The young fruit is clearly visible, light green in color, and small with a round shape.	The fruit enlarges, becomes round, with a smooth surface, and evenly bright green.	The fruit is uniform and dark green.	The fruit begins to turn red.	The fruit reaches physiological maturity.
P4					
	The fruitlet enlarges with a glossy dark green color, indicating active development of young fruit.	The young fruit is perfectly round, smooth, and shiny, with a deep green color.	The fruit reaches its optimal size and remains green.	The fruit color begins to turn yellowish.	The fruit color starts turning red.

DISCUSSION

Visual documentation in this study indicated that peptide application positively influenced the acceleration and synchronization of phenological phases in Arabica coffee plants. In particular, the **P_4 treatment (4 ml L^{-1})** showed the best response compared to the control (P_0) and lower concentration (P_2). Peptide application accelerated new shoot emergence, increased flower number and uniformity, and enhanced fruit set success.

New Shoot Growth

The P_4 treatment (4 ml L^{-1}) showed faster-growing new shoots, with an average length of ±1.4 cm and fully expanded young leaves exhibiting a greenish-brown color. This suggests that peptides function effectively as natural biostimulants by promoting physiological activity in meristematic tissues. Peptides absorbed by plants can accelerate cell division and elongation through activation of carbon and nitrogen metabolism, acting similarly to natural growth hormones (Colla et al., 2014). Studies on tomato and spinach showed that protein hydrolysates (PHs) rich in amino acids significantly increase chlorophyll index, stem length, and plant biomass.

In addition to serving as an organic nutrient source, peptides regulate biochemical signaling pathways controlling cell growth. Amino acids such as glycine, proline, and lysine act as precursors for enzyme and structural protein synthesis that support cell division and wall elongation (Henderson et al., 2025). Sulfur in the peptide structure aids in thiol compound and redox enzyme synthesis, maintaining oxidative stability in young tissues and strengthening cellular defense against environmental stress. This explains the higher vigor and faster shoot regeneration observed in peptide-treated plants compared to controls.

Recent studies also confirmed that peptides can trigger the expression of vegetative growth-related genes such as **EXPANSIN**, **CYCLIN-DEPENDENT KINASE**, and **GA20-OXIDASE**, which are involved in cell wall loosening, cell division, and gibberellin biosynthesis (Sun et al., 2024). Therefore, the 4 ml L^{-1} concentration can be considered optimal for maximizing physiological effects without causing metabolic saturation. This effect is crucial in supporting early growth phases of Arabica coffee, where successful new shoot formation determines the number of productive nodes that will later produce flowers and fruits.

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Flowering Phenology

Flowering is a critical phase in Arabica coffee phenology, as it determines potential yield. Observations showed that the P_4 treatment accelerated flower primordia appearance, increased bud number, and produced more uniform flowering than other treatments. Buds were yellowish-green with slight purpling at the tips, indicating active generative organ formation. Peptides play a key role in modulating endogenous hormone balance, including auxin, gibberellin, and cytokinin, which are known to influence flowering initiation (Colla et al., 2014). Peptides also act as chemical signals that trigger the expression of flowering genes such as **FLOWERING LOCUS T (FT)** and **APETALA 1 (AP1)**, accelerating the transition from vegetative to generative phases (Perkins et al., 2025).

Physiologically, peptides enhance photosynthetic efficiency and assimilate translocation to generative meristems. Amino acids such as arginine and asparagine support structural protein synthesis in flower primordia, resulting in faster bud development and larger bud size (Rouphael et al., 2017). This mechanism is also associated with increased antioxidant activity, protecting flower tissues from oxidative stress, extending bud longevity, and enhancing flower viability. Research by Sun et al. (2024) on horticultural crops showed that peptide application increased flower number by up to 25% and improved flowering synchronization, supporting the observations in Arabica coffee.

The increase in flower number and uniformity in P_4 treatment has important agronomic implications. Uniform flowering enables synchronized fruiting, enhancing pollination efficiency. Malécange et al. (2023) reported that peptide-based biostimulants can improve flowering uniformity and reduce premature flower drop in fruit crops. Therefore, peptides at 4 ml L^{-1} have potential to optimize Arabica coffee flowering, increase potential fruit number, and shorten annual production cycles.

Fruiting Phenology

The P_4 treatment also showed the most pronounced effect on fruiting. Nearly all flowers successfully set young fruits (fruit-set) with larger size and dark green color, indicating high photosynthetic activity. Peptides are believed to strengthen ovary tissue and improve flower viability, reducing young fruit abortion. Xiao et al. (2025) reported that peptide application increases flower viability and fruit-set percentage by enhancing source–sink enzyme activity, such as sucrose phosphate synthase and invertase, ensuring sufficient energy and metabolites for fruit growth.

Peptides also maintain fruit tissue water balance by increasing proline, glycine, and glutamic acid, which act as natural osmoprotectants (Pasković et al., 2024). This function is important under environmental conditions with fluctuating humidity, such as in the highlands of Kintamani. These amino acids enhance membrane stability in young fruits and reduce physiological stress caused by microclimate changes. Peptide application also increases antioxidant enzyme activity, such as catalase and peroxidase, reducing free radical accumulation during fruiting (Malik et al., 2020).

Overall, visual documentation indicated that fruits in P_4 treatment developed more uniformly and matured faster. This demonstrates that peptides not only serve as a nutrient source but also act as growth regulators, enhancing hormonal coordination between auxin, cytokinin, and abscisic acid during fruit formation (Ertani et al., 2014). Therefore, applying peptides at the optimal dose of 4 ml L^{-1} can accelerate and synchronize fruiting, increase fruit set efficiency, and support overall Arabica coffee yield quality.

Practical Implications and Applications

The study indicates that peptide application at 4 ml L^{-1} can serve as an innovative strategy in Arabica coffee cultivation to improve growth efficiency and productivity. This concentration effectively accelerates new shoot growth, synchronizes flowering, and enhances fruit set, potentially shortening generative cycles and producing more uniform yields, which is crucial for commercial coffee production. Physiologically, optimal peptide doses stimulate metabolic pathways related to growth hormones, protein synthesis, and photosynthetic efficiency, supporting balanced vegetative and generative organ development (Colla et al., 2014; Malécange et al., 2023).

Agronomically, applying peptides as natural biostimulants aligns with sustainable agriculture principles by reducing reliance on synthetic chemical fertilizers. Peptides, typically produced via enzymatic hydrolysis of plant or animal protein sources, are biodegradable, environmentally friendly, and leave no harmful residues in soil or plants (Malécange et al., 2023). Peptide application may also enhance plant resilience to environmental stresses, such as drought and temperature fluctuations, by strengthening antioxidant systems and improving water-use efficiency. Thus, peptide use in coffee cultivation offers an adaptive approach to climate change while improving yield quality through better physiological balance (Henderson et al., 2025).

However, increasing the dose above 4 ml L^{-1} does not always yield positive effects and may lead to physiological saturation due to metabolic imbalance or hormonal homeostasis disruption. Therefore, determining the appropriate dose and timing is key to successful peptide application. Further research is recommended to elucidate the molecular mechanisms and target genes activated by peptides, as well as their interaction with environmental conditions such as light intensity, water availability, and soil nutrient status (Perkins et al., 2025). This approach could lead to the development of peptide biostimulant formulations specifically tailored for Arabica coffee, enhancing productivity and sustainability in tropical agriculture.

CONCLUSION

Based on qualitative visual observations and analysis, it can be concluded that peptide application significantly affects the phenological phases of Arabica coffee (*Coffea arabica* L.), particularly in new shoot formation, flowering, and fruiting. Peptides accelerate and synchronize the development of generative organs, thereby supporting improved growth efficiency and yield.

The 4 ml L^{-1} peptide treatment (P_4) produced the best results compared to other treatments. Plants in this treatment showed faster and healthier new shoot growth, more uniform flowering with higher bud numbers, and increased fruit set success. These findings indicate that peptides act as natural biostimulants, enhancing plant physiological activity and promoting optimal generative tissue differentiation.

ADVICE

Peptide application at 4 ml L^{-1} can be recommended as a cultivation strategy to improve Arabica coffee productivity and yield uniformity. However, higher doses should be evaluated carefully to avoid potential physiological saturation. Further studies are suggested to determine the most effective application timing and to understand in greater detail the physiological and molecular mechanisms by which peptides support growth and development in Arabica coffee.

ACKNOWLEDGMENTS

We would like to express our gratitude to the Master's Program in Dryland Agriculture, Faculty of Agriculture, Udayana University, as well as colleagues and supervisors who provided valuable feedback, assistance, facilities, and equipment that enabled this research to be conducted successfully. We also extend our thanks to CH Biotech R&D Co., Ltd., Taiwan, for funding this research and supporting its implementation.

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