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# Molecular characterization of *Sweet potato feathery mottle virus* and sweet potato yield loss due to its infection

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**Abstract.** *Wirya GNAS, Selangga DGW, Listihani L, Temaja IGRM, Sudiarta IP. 2024. Molecular characterization of* Sweet potato feathery mottle virus *and sweet potato yield loss due to its infection. Biodiversitas 25: 2355-2362.* Sweet potatoes are one of the main sources of carbohydrates for Balinese. "Nasi selo," one of Bali's specialties, uses sweet potato as one of its main ingredients. For the past few years, cultivated sweet potatoes in Bali, Indonesia, manifested symptoms of diseases, particularly purple ring spots, occurring on its young and old leaves. The causative agent of the purple ring symptom is still unknown. Therefore, this study aims to analyze the molecular characteristics of SPFMV Bali isolate and the yield loss estimation it causes. Research methods that were used in this study are survey, sampling, virus identification with RT-PCR using universal *Potyvirus* as its primer, and field observation to assess the yield loss estimation. Field observation was conducted in five districts in Bali province: Badung, Gianyar, Bangli, Karangasem, and Klungkung. The result indicates that SPFMV infection has been found in these 5 districts, with the highest incidence and severity occurring in Bangli at 86% and 53%. The nucleotide homology of the SPFMV Bali isolates gene has the closest genetic relationship with isolates found in South Korea (MH388494, MH388494) and East Timor (MF572056), at >99%. Based on the latest phylogroup classification, SPFMV is categorized into phylogroups A and B. Phylogroup A consists of SPFMV with O-I strain, O-II strain, and EA strain; phylogroup B only consists of SPFMV with RC strain. Isolate SPFMV found in Bali, has an O strain that belongs to the same group as the O-I strain, also seen in South Korea, East Timor, and China. Actual yield loss that was found by comparing sweet potatoes suffering from purple rings symptom with the one without purple rings symptom reveals a yield loss of 50.9%. Harvested sweet potatoes with purple ring symptoms showed quality deterioration in malformation, discoloration, hollowing, and changes in color and shape. Yield loss of up to 29.53% in fields with a disease severity of 53% has caused a loss of IDR 2,105,166.

**Keywords:** Bali, *Potyvirus*, purple rings symptoms, SPFMV, strain O

## INTRODUCTION

Sweet potato planting areas in Bali province from 2016, 2017, 2018, and 2019 continued to decline by 2.73 ha, 1.97 ha, 1.56 ha, and 1.45 ha (Bali Province Agriculture and Food Security Service 2020). Meanwhile, the production of sweet potatoes in Bali fluctuated from 2016, 2017, 2018, and 2019 by 42,952 tons, 35,225 tons, 21,880 tons, and 22,130 tons. The reduction of sweet potato production in Bali in 2017 and 2018 was in line with the decrease in planting areas. Aside from the decrease in planting area, production decline can also stem from diseases and pest attacks, resulting in crop losses.

The diseases that can infect sweet potatoes include bacterial wilt, scab, leaf spot, fusarium wilt, tuber rot, root-knot by nematodes and viruses, among others (Gao et al. 2021; Listihani and Selangga 2021; Paul et al. 2021; Listihani et al. 2022b, 2023). Several viruses which have been reported as infectious agents of sweet potatoes are *Sweet potato feathery mottle virus* (SPFMV), *Sweet potato chlorotic stunt virus* (SPCSV), *Sweet potato virus disease* (SPVD), *Sweet potato mild mottle virus* (SPMMV), *Sweet potato vein mosaic virus* (SPVMV), *Sweet potato latent virus* (SPLV), dan *Sweet potato yellow dwarf virus* (SPYDV) (Zhang et al. 2020; Kiemo et al. 2021; Mbewe et al. 2021). *Sweet potato virus G* (SPVG; *Potyvirus*) is reported to be observed only in regions of Africa, China, and the United States (Jo et al. 2020; Tibiri et al. 2020; Zhao et al. 2020).

SPVG, which has been reported to infect sweet potatoes in Tana Toraja, and SPFMV, which was found on sweet potatoes in Bogor, are several virus species that were reported in Indonesia (Anjarsari et al. 2013; Hondo et al. 2018). Sweet potatoes in Malang, East Java, showed symptoms of interveinal yellowing caused by double infection of *Sweet potato virus C* (SPVC) and *Pepper yellow leaf curl virus* (PYLCV). SPVC, *Sweet potato leaf curl virus* (SPLCV), and SPFMV were reported to infect sweet potatoes in Bali (Listihani and Selangga 2021; Listihani et al. 2022b; Griyaningsih et al. 2023; Putri et al. 2023).

Among the reported viruses in Bali, SPFMV is one of the viruses that has not been molecularly characterized. *Sweet potato feathery mottle virus* (SPFMV; species *Sweet potato feathery mottle virus*, genus *Potyvirus*) is a member of Potyviridae, which is the largest and most important plant virus family (Wokorach et al. 2020). In sweet potatoes, SPFMV is the most significant *Potyvirus* (*Ipomoea batatas* L.) and can be found worldwide (Flamarique et al. 2020; Zhang et al. 2020). The SPFMV can be grouped into three

strains-O, EA, and RC-according to older classification (Kreuze et al. 2000). Classifying plant viruses based on their geographical location and biological properties, which can be found in the naming of SPFMV strains (i.e., O, EA, and RC) was deemed as misleading (Jones et al. 2016). Recently, SPFMV group examinations proposed a new classification and classified the isolates into phylogroups A and B (Maina et al. 2018). Strain O and strain EA isolates are grouped in phylogroup A, and phylogroup B comprises strain RC isolates. Strain EA isolates were first detected in East Africa and Madagascar and seemingly localized. These isolates formed the major SPFMV virus group (Kreuze et al. 2000). Studies later found strain EA occurrence in Peru and Dili and strain O occurrence in East Timor (Maina et al. 2018; Wokorach et al. 2020). Strain O and RC were more widely distributed geographically but had a limited occurrence in the East African regions (Kawanna and Aseel 2019; Mazyad et al. 2020; Wokorach et al. 2020; Ogero et al. 2023).

In addition, there is no information about sweet potato yield loss due to SPFMV infection in Bali, Indonesia. Therefore, this study aims to analyze the molecular characteristics of SPFMV Bali isolate and estimate the yield loss it causes. This information is valuable in determining appropriate SPFMV control strategies.

## MATERIALS AND METHODS

### Survey and sampling

The survey and sampling were conducted in five districts in Bali Province: Badung, Gianyar, Bangli, Karangasem, and Klungkung. Fifty samples of sweet potatoes with purple ring spots were taken from each district for 250 samples.

### Detection and identification of viruses causing purple ringspot disease

The virus detection method used was RT-PCR which consists of several stages: total RNA extraction, cDNA synthesis, DNA amplification, and visualization of amplification result. Total RNA was extracted from leaf tissues using the CTAB method following the procedure of Listihani et al. (2022b) with minor modification; the lysis stage at 65°C was reduced from 1 hour to 30 minutes, and the reverse Transcription Reaction (RT) following the protocol used by Anjarsari et al. (2013). The cDNA from this reverse transcription was used as a DNA mold in the PCR amplification reaction. PCR reaction with a total volume of 25 µL comprise of 8.5 µL nuclease-free water, 12.5 nuclease-free water 2X PCR mix (Thermo Scientific), 10 mM forward primer and reverse primer 1 µL each, and 2 µL cDNA. PCR was performed to amplify CI gene using *Potyvirus* universal primer pairs (CIFor_5'-GGIVVIGTIGGIWSIGGIAARTCIAC-3'/CIRev_5'-ACICCRTTYTCDATDATRTTIGTIGC-3') through 1 cycle of pre-denaturation stage at 94°C for 3 minutes, followed by 40 cycles of denaturation stage at 94°C for 1 minute, primer attachment stage at 40°C for 30 seconds, and DNA synthesis at 68°C for 1 minute. Final extension stages were added to the last cycle at 68°C for 5 minutes (Ha et al. 2008).

Nucleic acid staining dye FluoroVue™ (Smobio, Taiwan) was added to the agarose gel used for electrophoresis. The electrophoresis was performed for 30 minutes at 100 volts. A UV transilluminator visualized the DNA.

FirstBase Analytical Service (Malaysia) conducted nucleotide sequencing of amplified DNA fragments. Nucleotide sequences were examined for similarity with those found in GenBank using the Basic Local Alignment Search Tool (BLAST) program on the National Center for Biotechnology Information (www.ncbi.nlm.nih.gov). Nucleotide homology levels were analyzed with BioEdit software, while the phylogenetic tree was analyzed with Molecular Evolutionary Genetic Analysis (MEGA v6.0) software using the neighbor-joining method with 1000 times bootstrap.

### Observation of agronomic variable and disease severity

Individual plant observations were conducted every 2 weeks for 5 observations. The observed variable is the plant height and disease severity according to the scale listed in Table 1. After the disease severity percentage was acquired, AUDPC (Area Under Disease Progress Curve) was calculated. The formula for disease severity and AUDPC is as follows:

Disease severity. Disease severity is calculated using the formula:

$$KP = \frac{\sum_i (n_i v_i)}{NxZ} \text{x} 100\%$$

Where:

KP : Disease severity
n : The number of sweet potatoes observed would show a certain score
v : The sweet potatoes' score
N : Highest score possible
Z : Total amount of sweet potatoes

**Table 1.** Scoring of stunt viruses disease severity

| Score | Variation in symptom's |
|---|---|
| 0 | Asymptomatic |
| 1 | Plants showing mild ringspot symptoms |
| 2 | Plants showing moderate ringspot symptoms |
| 3 | Plants showing severe ringspot symptoms without leaf retraction or deformity |
| 4 | Plants showing severe ringspot symptoms with leaf retraction or deformity |
| 5 | Plants showing very severe ringspot symptoms with severe leaf retraction or deformity, stunting, or death |

Area Under Disease Progress Curve (AUDPC). It was determined based on disease severity that was observed using the formula:

$$AUDPC = \sum_{i:1}^{n} \frac{Xi + 1 + X1}{2} X(t_{i+1-ti})$$

Where:
AUDPC : Area Under Disease Progress Curve
Xi : Disease severity when observed at i weeks
ti : I-th observation time
n : Observation at the terminal stage of the disease

Observation with different disease intensities. The parameters observed were the plant height and the disease severity. After acquiring the disease severity levels, AUDPC (Area Under Disease Progress Curve) was calculated. Plant observations were conducted every 2 weeks for 5 observations. At the end of the observation, the yield of each field and its selling prices were calculated and its yield loss estimation was calculated afterward.

**Estimated yield loss calculation**

Individual plant observation. At the end of the observation, the amount of crops harvested from symptomatic and asymptomatic plants was calculated. The observed variables are the amount of sweet potatoes produced, the weight of each sweet potato per plant, and the total weight of sweet potatoes per plant and their quality. The percentage of estimated yield loss was then calculated.

The yield loss percentage could be obtained by using the formula (FAO 2001):

$$\text{Yield loss} = \frac{\text{Optimum result} - \text{Actual result}}{\text{Optimum result}} x\ 100\%$$

Where:
Optimum result: Result obtained without pathogen damage
Actual result: Result obtained during pathogen infestation and control measures were already implemented

Observation with different disease severities. At the end of the observation, the yield of each field and its selling prices were calculated. The next step was the calculation of its yield loss percentage.

**Data analysis procedure**

A chi-square test was conducted to compare the number of sweet potatoes' tubers, the weight of each tuber, and the total weight of the observed field per plant. Regression correlation analysis evaluated the relation between yield loss at various disease severities.

## RESULTS AND DISCUSSION

Sweet potatoes cultivated in Badung, Gianyar, and Bangli Districts manifest severe purple ring symptoms, while Karangasem and Klungkung Districts only display mild purple ring symptoms (Table 2; Figure 1). Sweet potato tubers from plants with purple ring symptoms were smaller than healthy plants, with an average weight per tuber of 94 g and 217 g (Table 4). Suspectedly, the cause of this weight disparity is the disruption in plant nutrient absorption caused by pathogens. This disruption appears in photosynthesis inhibition, resulting in incomplete cell formation. Clinical manifestation of the virus infection causes physiological disturbance in plants, inhibiting photosynthesis (Listihani et al. 2019, 2020, 2022a; Selangga et al. 2022). Carbon fixation cannot occur optimally, causing mosaic or chlorosis symptoms. The inhibition of the photosynthesis process changes chloroplast structure and reduces the photosynthesis pigment or rubisco (Wang et al. 2019; Hu et al. 2020; Sherin et al. 2022; Chauhan et al. 2023).

The survey, conducted in five sweet potato cultivation districts in Bali Province, revealed that the incidence and severity of the purple ring disease ranged from 47-86% and 28-53% (Table 1). The highest incidence and disease severity was found in Bangli at 86% and 53%. Previous research data on cultivated sweet potatoes from 2019 to 2023 showed chlorotic spot symptoms caused by *Potyvirus*, most commonly found in Bangli Districts (Listihani and Selangga 2021). Most vectors are the aphids, which are always found in the area, and farmers rarely do weed eradication around sweet potato crops. Consequently, sweet potato becomes an alternative host and source of inoculum in the field.

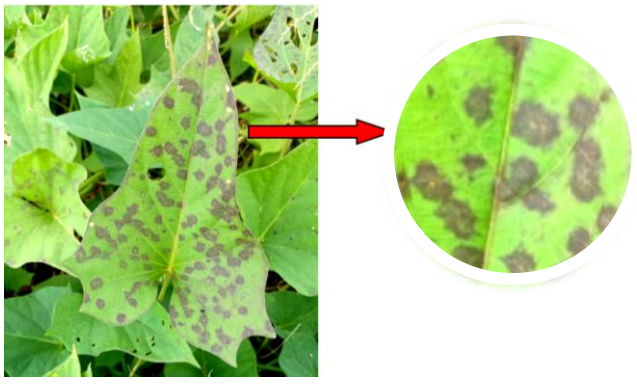

**Figure 1.** The purple rings symptoms on sweet potatoes in Bali Province, Indonesia

**Table 2.** The disease incidence and severity of ring symptoms on sweet potato in Bali Province, Indonesia based on RT-PCR

| Location | Variety | Type of symptoms disease | Diseases incidence (%) | Diseases severity (%) |
|---|---|---|---|---|
| Badung | Selo Sidan | Purple rings and malformation | 69 | 38 |
| Gianyar | Selo Sidan | Purple rings and malformation | 75 | 49 |
| Karangasem | Selo Sidan | Purple rings | 47 | 35 |
| Klungkung | Selo Sidan | Purple rings | 54 | 28 |
| Bangli | Selo Sidan | Purple rings and malformation | 86 | 53 |

**Table 3.** Nucleotide (nt) CI sequence identity between SPFMV Province, Indonesia isolates and isolates from other countries with sequences deposited in GenBank

| Isolates | Strain | Homology nt (%) SPFMV_IDN_ | | | | | Accession number |
|---|---|---|---|---|---|---|---|
| | | Badung | Gianyar | Bangli | Klungkung | Karangasem | |
| Badung | O | | 100 | 100 | 99.9 | 99.8 | - |
| Gianyar | O | 100 | | 100 | 99.9 | 99.8 | - |
| Bangli | O | 100 | 100 | | 99.9 | 99.8 | - |
| Klungkung | O | 99.9 | 99.9 | 99.9 | | 100 | - |
| Karangasem | O | 99.8 | 99.8 | 99.8 | 100 | | - |
| South Korea | O | 99.7 | 99.7 | 99.7 | 99.6 | 99.6 | MH388494 |
| South Korea | O | 99.5 | 99.5 | 99.5 | 99.5 | 99.4 | MH388493 |
| East Timor | O | 99.1 | 99.1 | 99.1 | 99.0 | 99.0 | MF572056 |
| China | O | 98.5 | 98.5 | 98.5 | 98.4 | 98.3 | KY296450 |
| China | O | 98.5 | 98.5 | 98.5 | 98.5 | 98.4 | MK778791 |
| China | O | 98.3 | 98.3 | 98.3 | 98.3 | 98.2 | MK778788 |
| China | O | 97.9 | 97.9 | 97.9 | 97.9 | 97.8 | MK778785 |
| Kenya | O | 97.5 | 97.5 | 97.5 | 97.5 | 97.4 | MH763680 |
| Japan | O | 97.3 | 97.3 | 97.3 | 97.2 | 97.3 | AB509454 |
| Japan | O | 97.3 | 97.3 | 97.3 | 97.2 | 97.3 | AB439206 |
| Argentina | O | 97.3 | 97.3 | 97.3 | 97.3 | 97.2 | KF386013 |
| East Timor | EA | 96.3 | 96.3 | 96.3 | 96.3 | 96.3 | MF572055 |
| Peru | EA | 96.1 | 96.1 | 96.2 | 96.1 | 96.3 | FJ155666 |
| China | RC | 88.7 | 88.7 | 88.7 | 88.6 | 88.5 | MK778795 |
| China | RC | 88.7 | 88.7 | 88.7 | 88.7 | 88.7 | MK778794 |
| Japan | RC | 88.7 | 88.7 | 88.7 | 88.7 | 88.7 | D86371 |
| South Korea | RC | 88.5 | 88.5 | 88.5 | 88.4 | 88.5 | KP115608 |
| Australia | RC | 88.5 | 88.5 | 88.5 | 88.5 | 88.5 | MF572047 |
| Argentina | RC | 87.8 | 87.8 | 87.8 | 87.7 | 87.7 | KF386014 |
| China | RC | 87.6 | 87.6 | 87.6 | 87.5 | 87.4 | KY296451 |
| Uganda* | SPVC* | 77.6 | 77.6 | 77.6 | 77.5 | 77.4 | OR233834 |

Note: nt (nucleotide); *SPVC (Sweet Potato Virus C) was used as outgroups

**Table 4.** The yields of sweet potato harvest on healthy and purple rings symptom plants

| Plants | Agronomic variables | | | Harvest (g) |
|---|---|---|---|---|
| | Number of tuber per plant (tuber) | Weight per tuber (g) | Tuber weight per plant (g) | |
| Symptomless | 6.2 a | 217 a | 902 a | 57239.2 a |
| Purple rings symptoms | 5.1 a | 94 b | 536 b | 28069.6 b |
| Yield losses (%) | 17.7 | 56.7 | 40.6 | 50.9 |

Note: Numbers in one column followed by different letters indicate the difference with the chi-square test

**Table 5.** The quality of sweet potatoes yields on yellow symptomatic plants and healthy plants

| Tuber quality | Symptomless | | Purple rings | |
|---|---|---|---|---|
| | Number (fruits) | Percentage (%) | Number (fruits) | Percentage (%) |
| Healthy | 319 | 87.2 | 283 | 80.2 |
| Tuber malformation | 16 | 4.4 | 17 | 4.8 |
| Discoloration and tuber holes | 19 | 5.2 | 18 | 5.1 |
| Discoloration and malformation | 12 | 3.2 | 35 | 9.9 |

**Table 6.** Yield loss in each location

| Location | AUDPC DS* | Yields (kg/1,000 $m^2$) | Yield loss (%) | Yield loss (IDR) |
|---|---|---|---|---|
| Badung | 1064 | 1794.63 | 18.14 | 1,026,833.00 |
| Gianyar | 1372 | 1667.57 | 24.68 | 1,662,166.00 |
| Karangasem | 980 | 1927.43 | 13.27 | 362,833.00 |
| Klungkung | 784 | 1942.47 | 10.64 | 287,666.00 |
| Bangli | 1484 | 1578.97 | 29.53 | 2,105,166.00 |

Note: AUDPC DS*: Score of area under disease progress curve, disease severity

DNA with the size of 700 bp derived from sweet potato leaf samples with purple rings symptoms from sample sites were successfully amplified using *Potyvirus* universal primer (the figure is not featured). These detection results confirmed that SPFMV-infected sweet potato plants showed purple ring symptoms. It has been confirmed that the DNA sequence of Cylindrical Inclusion (CI) genes in SPFMV have the highest homology towards SPFMV strain O. Generally, SPFMV strain O causes systemic purple rings symptom, which disrupts the photosynthesis of Selo

Sidan sweet potato plants. The nucleotide homology of strain O SPFMV from Bali (specifically Badung, Gianyar, Bangli, Klungkung, and Karangasem districts) has the closest genetic relationship with an isolate that was found in South Korea (MH388493, MH388494) and East Timor (MF572056), with similarity ranged from 99.0-99.7% (Table 3). The nucleotide homology of strain O SPFMV from Bali also has a similarity with the SPFMV EA strain isolate found in East Timor and Peru, with a similarity ranging from 96.1-96.3%. The nucleotide homology between the SPFMV RC strain found in Bali and other countries (except South Korea, East Timor, and Peru) ranges between 87.4-98.5%.

Based on phylogenetic analysis, SPFMV is classified into phylogroups A and B (Figure 2). Phylogroup A consists of SPFMV with O-I strain, O-II strain, and EA strain; phylogroup B only consists of SPFMV with RC strain. SPFMV with O strain can be found in Bali-Indonesia, South Korea, East Timor, China, Kenya, Japan, and Argentina. SPFMV with EA strain can be found in East Timor and Peru. SPFMV with RC strain can be found in China, Japan, South Korea, Australia, and Argentina. SPFMV from Bali-Indonesia belongs to the group O-I with South Korea, East Timor, and China. This indicates the genetic similarity between Bali isolate SPFMV with isolates from South Korea, East Timor, and China.

Calculation of yields from healthy sweet potatoes and sweet potatoes with purple rings symptoms shows a significant difference in individual tuber weight and tuber weight per plant between healthy and infected plants, but the amount of tubers per plant is relatively similar (Table 4). This indicates that purple rings disease promotes a decline in individual tuber weight and tuber weight per plant but does not affect the amount of tuber produced. Sweet potato yield is affected by the quality and quantity of the produced tuber, and the increase in the quantity of the tuber produced resulted in a higher yield. The imbalance between the weight of asymptomatic sweet potatoes and sweet potatoes with purple ring symptoms significantly reduces crop yield.

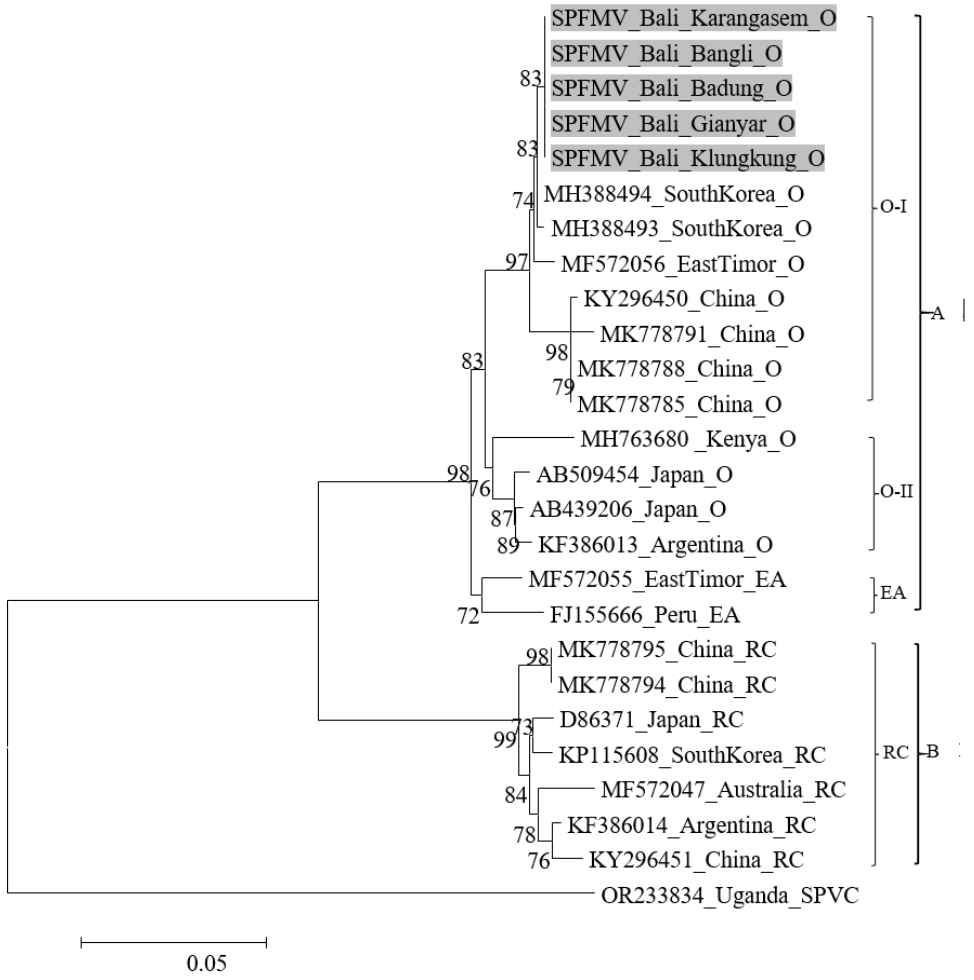


**Figure 2.** Phylogenetic tree based on the CI gene from SPFMV Bali isolates. Sweet Potato Virus C (SPVC) was used as an outgroup. Isolates marked with gray highlights are Bali isolates. Bootstrap values greater than 70% based on 1000 replicates are shown on tree branches. The scale bar below the tree indicates 0.05 nucleotide substitutions per site

Combined SPFMV and SPCSV infection reduced the number of roots formed as well as root diameter, resulting in a greater length-to-diameter ratio compared to the healthy control (Adikini et al. 2016; Mulabisana et al. 2019). Several studies revealed that a single SPFMV infection resulted in yield losses of 14-52%; combined SPFMV +SPCSV infection resulted in yield losses of 60-95%, depending on its cultivar (Adikini et al. 2016, 2019; Wokorach et al. 2019; Wanjala et al. 2020; Mbewe et al. 2021; Ogero et al. 2023). Meanwhile, total yield loss due to SPFMV-infected material obtained from on-site testing ranged from 14% to 26,1% (Adikini et al. 2016). Actual yield loss by comparing sweet potato yields showing purple rings symptoms with asymptomatic sweet potatoes is 50,9% (Table 4). This study's results align with research from other countries that SPFMV causes yield losses of >50% in sweet potatoes. In various countries, there have been reports of SPFMV infection causing losses of up to 90% in Uganda, Tanzania, East Africa, and Western Burkina Faso (Adikini et al. 2016; Adam et al. 2018; Ssamula et al. 2019; Tibiri et al. 2019; Wanjala et al. 2020; Wokorach et al. 2020; Ogero et al. 2023); those yield loss due to purple rings disease is quite significant.

Yield loss can have both direct and indirect impacts (Selangga and Listihani 2022). A direct impact may be economic loss, detrimental to farmers and buyers. This will indirectly cause lower motivation and intent to plant sweet potatoes again. Harvested sweet potatoes with purple ring symptoms showed quality deterioration in malformation, discoloration, hollowing, and changes of color and shape (Table 5). Quality deterioration in the form of discoloration and malformation in groups of purple ring symptoms has a percentage of 9.9%, while in the symptomless groups is only 3.2%.

The impact of various disease intensities on yield loss showed that the incidence percentage of purple rings disease significantly influences the productivity of sweet potato plants; the higher disease severity has lower tuber production. Table 6 shows a disease severity of 53%, with the highest yield reductions totaling 29.53. The yield with the highest disease severity is visible on land with AUDPC 1484, producing a yield of 1578.97 Kg/1000 $m^2$. It is correlated with the fact that symptomatic plants have smaller tubers than tubers of healthy plants. Moreover, the size and quality of harvested crops affect the selling price of sweet potatoes; the harvested sweet potatoes with big size and good quality without deformities have high selling prices. The average market selling price for sweet potatoes is IDR 6.000 per kilogram, with IDR 3.000 as the average farmer selling price. Purple ring disease affects the selling prices of the infected sweet potatoes, lowering the selling price and reducing the farmers' income. The highest economic losses occurred on the field with AUDPC 1484, which caused yield losses of IDR 2.105.166 (Table 6).

Sweet potato (*Ipomoea batatas*) is ranked seventh in global food production and the third most important tuber crop after potato and cassava (Central Bureau of Statistics 2016). Sweet potatoes are a vegetative propagation of vines, roots, or tubers. Therefore, SPFMV disease can significantly affect sweet potato harvest quantity, typically more than 50% (Tibiri et al. 2019; Wanjala et al. 2020; Wokorach et al. 2020; Ogero et al. 2023). The result of this study suggests that the virus is a significant constraint to sweet potato production, similar to the studies conducted in South Africa, the United States, Ghana, and Western Burkina Faso (Adikini et al. 2016; Adam et al. 2018; Mulabisana et al. 2019; Tibiri et al. 2019). This study shows that SPFMV and virus infection are an alarming threat to sweet potato plant production in Bali and significantly affect its yield.

The characteristic symptom of SPFMV infection is the manifestation of purple ring spots on its young and old leaves, similar to the symptom reported by Wanjala et al. (2020). Symptom expression occurs differently according to the infecting viruses and varieties. The SPFMV infection symptoms in this research differ from those reported by Hondo et al. (2018), which have infected red sweet potato varieties in Bogor, West Java, Indonesia, and also manifested in yellow ring symptoms.

SPFMV is the most widespread virus variant identified in this and previous studies, with higher occurrence frequencies than other viruses. SPFMV has spread in Badung, Gianyar, Bangli, Karangasem, and Klungkung Districts; *Sweet potato leaf curl virus* (SPLCV) was found in Badung and Gianyar Districts, while *Sweet potato virus C* (SPVC) was only found in Bangli Districts (Listihani and Selangga 2021; Listihani et al. 2022b).

This finding is consistent with the research conducted in central, western, and eastern Uganda, which has shown a broad distribution of SPFMV in farmer's fields (Adikini et al. 2016); SPFMV is still the most widespread virus in various parts of East Africa (Wokorach et al. 2020). Several reports also revealed that SPFMV occurs in almost every country where sweet potato is grown (Wokorach et al. 2019). The expansion of SPFMV infection worldwide is due to its ability to induce mild symptoms in sweet potato plants, making it difficult for farmers to detect SPFMV infection during vine propagation and encouraging its spread by sharing infected plants among local farmers.

In Bali Province, Indonesia, farmers often utilize vines from their fields and propagate them for yearly production. Therefore, if a viral infection is present in a production period, it will inevitably be transmitted by the propagation material to the next newly planted field, causing yield losses. More often than not, these fields are already infected by other viruses, exacerbating the impact on crop yields.

An effective way to control SPFMV in vegetatively propagated sweet potatoes is by providing farmers with planting material confirmed as virus-free. The PCR, serology, and grafting on virus-indicating sweet potato plants tested high-yielding crops for virus availability. Afterward, meristem tips were taken from the negatively reacting plants. Then, the meristems are grown separately from other sweet potato plants, kept under insect-resistant conditions, and distributed to farmers in the next reproduction cycles.

In conclusion, SPFMV has spread among the cultivated sweet potatoes in 5 districts in Bali Province: Badung, Gianyar, Bangli, Karangasem, and Klungkung, with purple rings symptom on their leaves. Selo sidan, a sweet potato variant, is quite vulnerable to SPFMV infection. Bali isolates SPFMV belong to strain O and have the closest genetic

relationship with isolates found in South Korea and East Timor. SPFMV causes 50.9% yield loss of sweet potato harvest.

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