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BIOTECHNOLOGY AND INDUSTRIAL MICROBIOLOGY - RESEARCH PAPER

Solid-state fermentation of Saba banana peel for pigment production by *Monascus purpureus*

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Abstract

Eco-friendly natural pigment demand has ever-increasing popularity due to health and environmental concerns. In this context, the aim of this study was to evaluate the feasibility use of Saba banana peel as low-cost fermentable substrate for the production of pigments, xylanase and cellulase enzymes by *Monascus purpureus*. Among the strains tested, *M. purpureus* TISTR 3385 produced pigments better and had higher enzyme activities. Under the optimal pigment-producing conditions at the initial moisture content of 40% and initial pH of 6.0, the pigments comprising yellow, orange, and red produced by the fungi were achieved in the range of 0.40–0.93 UA/g/day. The maximum xylanase and cellulase activities of 8.92 ± 0.46 U/g and 4.72 ± 0.04 U/g were also obtained, respectively. More importantly, solid-state fermentation of non-sterile peel could be achieved without sacrificing the production of the pigments and both enzymes. These indicated the potential use of the peel as fermentable feedstock for pigment production by the fungi and an environmental-friendly approach for sustainable waste management and industrial pigment and enzyme application.

Keywords Banana peel · Pigment · *Monascus purpureus* · Solid-state fermentation

Introduction

In recent decades, the global market demand for eco-friendly natural pigments has gradually increased due to health concerns over artificial pigments [1]. Natural pigments are derived from plants and microbes; however, microbial pigments have numerous advantages over plant pigments due to their fast growth, as well as season-independent and substrate-dependent cost effectiveness [2]. In Asian countries, industrial production of natural-based pigment is dominated by the *Monascus* genus, [3] and their pigments have been broadly applied in the food industry worldwide [4]. *Monascus* pigments are secondary metabolites involving red (monascorubramine and rubropunctamine), orange (monascorubin and rubropunctatin), and yellow (ankaflavin and monascin) substances. Red and yellow pigments have been extensively used as food coloring agents in the form of koji and Anka [3]. Nevertheless, the high production cost of microbial pigments compared to artificial ones is a major obstacle preventing the industrial implementation of pigment production through fermentation. Numerous investigations have also been performed to reduce costs and increase the production of pigments [5]. Recently, many agro-industrial by-products and residues have shown their potential in the pigment production by the *Monascus* genus, such as sugar bagasse hydrolysate [6], orange processing waste [3], rice straw hydrolysate [4], corn bran [7], and potato pomace [8]. Furthermore, the production of pigments produced by the *Monascus* species is greatly influenced by the condition factors, such as carbon and nitrogen source, pH, temperature, moisture, aeration, and agitation. Additionally, optimization is a crucial process in order to maximize productivity [9]. Moreover, some *Monascus* sp. can produce enzymes simultaneously with the pigments, such as amylase, xylanase cellulase, and β-glucosidase [10]. Nonetheless, there have been few scientific reports available for the production of xylanase and cellulase by the *Monascus* species.

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Saba banana (*Musa "saba"* (*Musa acuminata* × *Musa balbisiana*)) is one of the most popular varieties among the various banana cultivars in countries in Southeast Asia, such as Thailand, Malaysia, Indonesia, Vietnam, and the Philippines, as it is considered to have good potential for commercial production and trade in the domestic market [11]. In general, the ripe fruit can be consumed raw and also processed into various food products, such as ketchup, sauces, and chips [12]. Due to banana processing, industrial development, and increased production of fruit products, large amounts of banana peel, accounting for 40% of the total weight of the fresh fruit, are discarded as waste or used as animal feed [13]. However, these are uneconomic and not environmentally friendly approaches [14]. Since huge amounts of carbohydrates, including celluloses, hemicelluloses, starch, pectin, etc. are presented in the peel, it could be applied as a renewable feedstock for the production of pigments and enzymes [15].

This study aimed to evaluate the potential use of Saba banana peel for low-cost production of pigments of xylanase and cellulase enzymes. Two *Monascus* genera, *Monascus purpureus* TISTR 3385 and *Monascus purpureus* TISTR 3615, were cultivated on the waste and screened for their abilities to produce pigments as well as present the activities of the xylanase and cellulase enzymes. Several fermentation parameters, including moisture and pH, were optimized to increase the production of the pigments and both enzymes by the selected strain. Finally, the performance using non-sterile Saba banana peel was investigated for cost-effective pigment and enzyme production.

Materials and methods

Microorganisms and seed preparation

Two fungi, *M. purpureus* TISTR 3385 and *M. purpureus* TISTR 3615, obtained from the Thailand Institute of Scientific and Technology Research, Bangkok, Thailand (TISTR), were cultivated in 250 mL-Erlenmeyer flasks containing 50 mL of Potato Dextrose Broth (PDB) at room temperature (30 ± 2 °C) on a rotary shaker at 180 rpm for 5 days. After that, they were transferred to a Potato Dextrose Agar (PDA) slant and further incubated for 7 days. Then 5 mL of sterilized distilled water containing 0.01% (v/v) Tween 80 was added to each tube, and the surface was scraped with an inoculation loop. Afterwards, the spore was counted using a Neubauer hemacytometer and adjusted to the initial spore number of 10^6 spores/mL.

Raw material and its composition

Saba banana (*Musa acuminata* × *balbisiana*) peels (SBP) were collected from a local plant under the network of the Yala Saba banana enterprise community. The characteristics of SBP were as follows: diameter 3–4 cm, wet weight 50–53 g, and fruit age < 2 months. The peels were washed and cut (approximately 0.5 cm) and further dried at 60 ± 2 °C for 24 h. After that, the peels were ground using a conventional kitchen blender and then separated using sieves (2–4 mm). The composition of SBP after drying was as follows: lignin 25.80 ± 0.13%, hemicellulose 19.24 ± 0.03%, cellulose 18.36 ± 0.22%, total nitrogen (TKN) 0.92 ± 0.01%, carbon to nitrogen ratio (C/N ratio) 44.26 ± 0.02, and pH 5.37 ± 0.48.

Culture condition

The cultures were carried out in a 250 mL wide-mouth cylindrical bottle containing 50 g of SBP dry mill. The waste medium was sterilized by autoclaving before use at a temperature of 121 °C for 20 m. The cultures were initiated with 10% of spore suspension (approximately 10^6 spores/mL). Subsequently, the moisture was adjusted by adding sterilized distilled water, and mixed well. The cultures were incubated at room temperature (30 ± 2 °C) for 10 days. The effect of the initial moisture was evaluated by varying at 40% (v/w), 50% (v/w), and 60% (v/w), respectively by adding sterilized distilled water at a pH of 6.0. The effect of the initial pH was evaluated by varying the sterilized distilled water at a pH of 5.0, 6.0, and 7.0, respectively. The effect of the sterile and non-sterile BSP was carried out under the optimal initial moisture and initial pH.

Analytical methods

The fungal spores were counted using a Neubauer hemacytometer to control the number of initial spores as described by the classical procedure [16]. To extract the pigment, the fermented SBP (1 g) was added with 5 mL of 70% (v/v) ethanol solution and mixed at room temperature (30 ± 2 °C) on a rotary shaker at 180 rpm for 1 h. The extracted pigment supernatant was recovered by centrifugation (Z36HK HERMLE, Germany) at 15,259 × g for 20 m. Subsequently, the pigment was estimated by measuring the absorbance of the supernatant with a UV/VIS spectrophotometer (UV7 METTLER TOLEDO, USA) at different wavelengths of 400, 475, and 500 nm for yellow, orange, and red, respectively [3]. The cellulase activity was determined by a filter paper assay as described by Yu et al. [17]. The xylanase activity was measured according to the procedure of Katsimpouras et al. [18] with modification. The amount of the reducing sugars was measured by the DNS method as described by Miller [19]. The experiments were carried out in triplicate. One-way ANOVA (analysis of variance) and

Duncan's multiple range tests ($P < 0.05$) were applied to evaluate the statistical significance of the results (SPSS version 22.0 software, obtained from the Bioprocess Engineering Laboratory Faculty of Agro-Industry, Prince of Songkla University).

Results and discussion

Cultivation of Monascus purpureus

Pigments, involving polyketide derivatives and secondary metabolites, produced by *Monascus* sp. were strongly strain-dependent but independent of their sexual status (teleomorphous or anamorphous) even under the same physical and chemical growth conditions [20–22]. Since banana peels are lignocellulosic materials mainly containing lignin, hemicellulose, and cellulose, the waste could be effectively degraded into simple sugar forms by secreting lignocellulose-degrading enzymes produced by the fungi [23, 24]. In this study, *M. purpureus* TISTR 3385 and *M. purpureus* TISTR 3615 were cultivated on an SBP dry mill with 40% initial moisture and pH of 6.0 and screened for the abilities to produce pigments and represent the activities of the xylanase and cellulase enzymes. Three types of pigment and activities of xylanase and cellulase of two *M. purpureus* cultivated on the SBP dry mill were compared (Fig. 1 and Table 1). Similarly, their pigment production continued for 7 days and declined at 10 days (Fig. 1). The decrease in pigments was due to their decomposition or transformation into other metabolites during the decline phase [25]. Yellow pigment was the most predominant produced, followed by the orange and red pigments, respectively (Fig. 1). The dominance of the yellow pigment was due to the reduction of the orange pigment to the yellow pigment ankaflavin from monascorubrin by the ammonia reaction between the orange pigment and amino acid [26, 27]. In the case of *M. ruber* CGMCC 10910, a high carbon source or high glucose stress but low oxidoreduction potential increased the production of the yellow pigment [28, 29]. Regarding the lignocellulose-degrading enzymes, the presence of both the xylanase and cellulase activities was different. *M. purpureus* TISTR 3385 provided high activities of xylanase and cellulase, and continued to be stable for 7 days, while both activities produced by *M. purpureus* TISTR 3615 were presented at a low level and slowly continued to the end of the fermentation (Fig. 1). Among the two strains tested, *M. purpureus* TISTR 3385 produced pigments and presented the activities of both enzymes better. The highest pigment production obtained at 7 days was 6.51 ± 1.63 UA/g, 4.27 ± 1.60 UA/g, and 3.37 ± 1.10 UA/g for yellow, orange, and red, respectively, which corresponded to their high productivity in the range of 0.48–0.93 UA/g/d (Fig. 1 and Table 1). Likewise,

Table 1 Pigment productivity in various conditions

Conditions	P_Y (UA/g/d)	P_O (UA/g/d)	P_R (UA/g/d)
Strains			
TISTR 3385	0.931 ± 0.233^a	0.467 ± 0.229^a	0.421 ± 0.157^a
TISTR 3615	0.841 ± 0.074^b	0.276 ± 0.033^b	0.226 ± 0.028^b
Moisture			
40%	0.929 ± 0.068^a	0.472 ± 0.022^a	0.354 ± 0.014^a
50%	0.604 ± 0.005^b	0.280 ± 0.013^b	0.224 ± 0.039^b
60%	0.545 ± 0.011^b	0.229 ± 0.004^b	0.206 ± 0.053^b
pH			
5.0	0.692 ± 0.001^b	0.324 ± 0.017^b	0.267 ± 0.016^b
6.0	0.929 ± 0.048^a	0.473 ± 0.067^a	0.377 ± 0.013^a
7.0	0.763 ± 0.064^b	0.384 ± 0.020^b	0.218 ± 0.010^b
SBP			
Sterile SBP	0.931 ± 0.025^a	0.471 ± 0.012^a	0.399 ± 0.003^a
Non-sterile SBP	0.859 ± 0.016^a	0.438 ± 0.004^a	0.385 ± 0.001^a

All data are the data at 7 days. The data are presented as the mean of triplication and standard deviation, and different letters in the same column indicate a significant difference ($P < 0.05$).

P_Y, yellow pigment productivity; P_O, orange pigment productivity; P_R, red pigment productivity; *UA/g/d*, unit of absorbance per gram substrate per day.

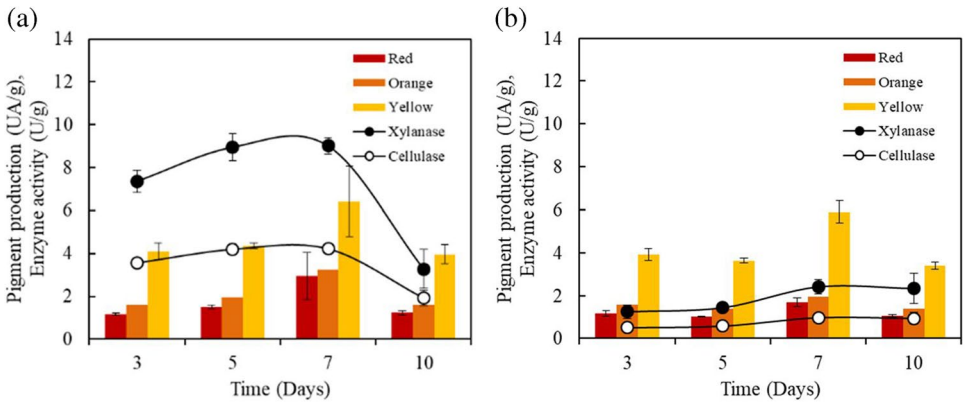

Fig. 1 Pigment production, the xylanase and cellulase activities by the two strains: *M. purpureus* TISTR 3385 (**a**) and *M. purpureus* TISTR 3615 (**b**), cultivated on an SBP dry mill at 40% of initial moisture and initial pH of 6.0. The data are presented as the mean of triplication and standard deviation

the highest xylanase and cellulase activities obtained at 7 days were 9.01 ± 0.39 U/g and 4.22 ± 0.15 U/g, respectively (Fig. 1). This suggested that both enzymes generated by the fungi were included in the breakdown of the banana peel and the subsequent release of simple sugars, such as glucose and xylose, which were immediately assimilated by the fungi for growth and pigment production. Xylanase stimulated the degradation of the cellulose by generating small holes of xylanase that covered the cellulose, and cellulase subsequently promoted the hydrolysis of the cellulose after being accessed through the pores [30]. This indicated that synergism between xylanase and cellulase enhanced the production [31]. However, a decline in both activities generally caused the secretion systems of the enzyme inactivation due to the depletion of cellulase and xylanase, which were fermentable substrate [10]. Accordingly, Jampala et al. [10] reported that the activities of xylanase and cellulase of *Trichoderma reesei* NCIM 1186, cultivated in Prosopis juliflora pods, reached the highest levels in six days and then declined thereafter.

Effect of the initial moisture

The moisture content of the substrate was a significant operating factor affecting the solid-state fermentation process of pigment and enzyme production by fungi because it impacted oxygen transfer, heat exchange, and mass transfer. The unsuitable moisture content of the substrates resulted in a reduction or increment of these impacted factors leading to an improper condition for the growth and formation of the secondary metabolites [32, 33]. Commonly, the optimal initial moisture of fungi to obtain production was in the range of 40–60% [33–35]. In this study, the initial moisture was varied at 40%, 50%, and 60% in order to investigate the impact of this factor on the production of the pigments and activities of xylanase and cellulase of the selected fungi, *M. purpureus* TISTR 3385. Obviously, the production of the pigments and both enzymes was significantly influenced by the initial moisture content (Fig. 2 and Table 1). By setting up the initial moisture of 40%, the pigments were remarkably produced, especially the yellow pigment that was obtained by a high level (6.5 UA/g) (Fig. 2a). In addition, the pigment productivity was obtained with a significant difference among all the conditions tested ($P < 0.05$) (Table 1). Dissimilarly, Velmurugan et al. [36] reported the potential of corn cob powder for pigment production by *M. purpureus* KACC 42,430. The pigment yield of 25.42 UA/g was obtained at the optimal moisture content of 60%. Haque et al. [37] reported utilizing bakery waste as a fermentable substrate for the production of pigments by *M. purpureus* ATCC 16,365. The highest pigment yield and the highest activity of glucoamylase and protease were obtained at the optimal moisture content of 55% and 65%. Zhang et al. [38] reported using millet as feedstock for monacolin K production by *M. ruber*. At the initial moisture of 55%, the production obviously increased, whereas the initial moisture further increased to 60%, and the production began to decline. These indicated that the optimal moisture content depended on the strains of the *Monascus* species and the substrate, which had differences in the water holding capacity affecting the water activity-Aw, and also its change during fermentation [39]. Regarding the xylanase and cellulase activities, at the initial moisture of 40%, the profiles of both enzymes were presented at a high and stable activity during 7 days of fermentation (Fig. 2a). On the contrary, at the initial moisture of 50% and 60%, both enzyme activities rapidly increased and gained the highest level at 7 days (Fig. 2b and c). This was probably because the free water availability within the substrate particles slightly evaporated, thus causing the particles to have porosity, and thereby increasing the oxygen transfer leading to promoting favorable conditions for enzyme activity [34].

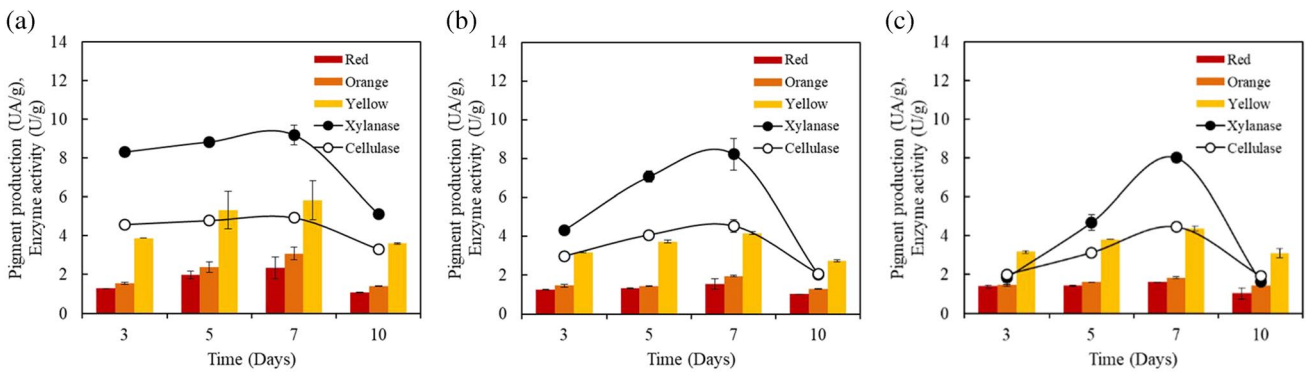

Fig. 2 Effect of the initial moisture at 40% (**a**), 50% (**b**), and 60% (**c**) on the pigment production, the xylanase and cellulase activities by *M. purpureus* TISTR 3385 cultivated on an SBP dry mill at an initial pH of 6.0. The data are presented as the mean of triplication and standard deviation

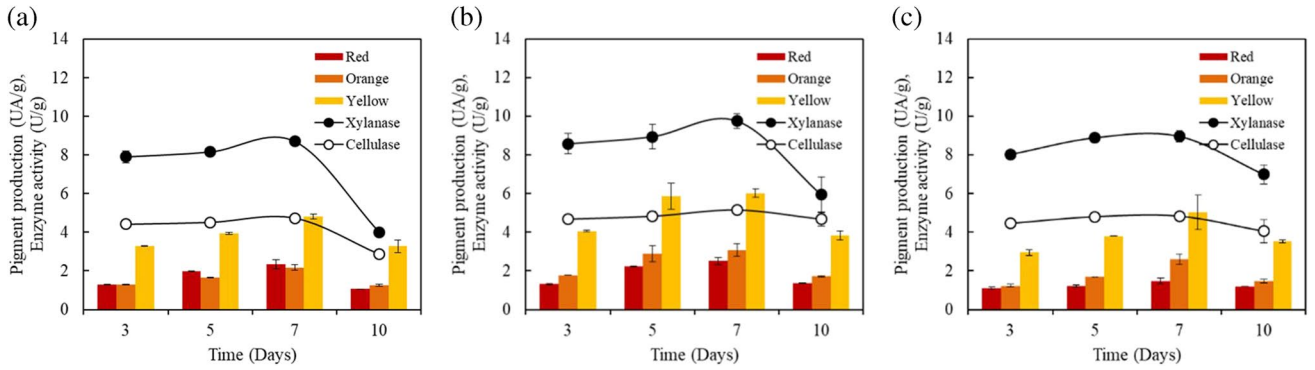

Fig. 3 Effect of the initial pH at 5.0 (**a**), 6.0 (**b**), and 7.0 (**c**) by *M. purpureus* TISTR 3385 cultivated on an SBP dry mill at 40% of the initial moisture. The data are presented as the mean of triplication and standard deviation

Effect of the initial pH

The pH was a vital factor for pigment and enzyme production because it affected the metabolic activity of many enzymes and the transport of numerous nutrient compositions from the substrate into the cell by the fungi [40]. The optimal pH of the substrate by various fungi including *Monascus* species was within the range of 5–7 [41–44]. In the study, the initial pH was varied at 5.0, 6.0, and 7.0 in order to investigate the impact of this factor on the production of the pigments and activities of xylanase and cellulase of the selected fungi, *M. purpureus* TISTR 3385. Obviously, the production and productivity of the pigments were significantly affected by the initial pH of the substrate but not for both enzyme activities (Fig. 3 and Table 1). The initial pH of 5.0 provided the highest pigment production with a significant difference in productivity among the three conditions tested ($P < 0.05$) (Fig. 3a and Table 1). The pigment production was relatively negatively-affected by the initial pH of 4.0 and 7.0 (Fig. 2b and c). Similarly, from a previous study regarding the optimal pH for pigment production, Jun et al. [25] reported that *Monascus* yellow pigments were obtained at a pH of 5.0. Likewise. Embaby et al. [45] reported that the highest significant levels of the pigments were achieved at a pH of 5.0. On the other hand, the profiles of both enzymes were similar in all conditions, which were presented in high and relatively stable activity during 7 days of fermentation and declined at 10 days (Fig. 3). Similarly, in a previous study regarding the optimal pH for pigment production and enzyme activity, Subsaendee et al. [46] reported that the initial neutral pH affected pigment synthesis, but the lower pH was an optimal condition for glucoamylase activity. Zhang et al. [47] also reported that the optimal pH for growth and pigment production was obtained at a pH of 5.0, but high levels of ligninase and xylanase activities were obtained at a pH of 7.0 through 9.0.

Effect of sterile and non-sterile Saba banana peel

Non-sterile fermentation provides many advantages compared to a sterile form, including involving elimination of the sterile step, reduction of the maintenance requirements, simple process for the bioreactor design, and simple process for the operation [48]. In the case of producing a microbial lipid with a plant capacity of 10,000 tons, the cost for sterilization

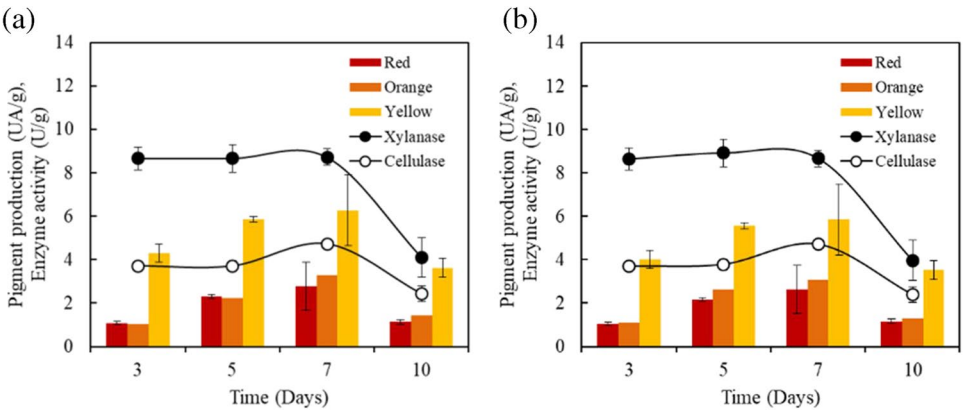

Fig. 4 Effect of sterile SBP (**a**) and non-sterile SBP (**b**) on the pigment production, the xylanase and cellulase activities by *M. purpureus* TISTR 3385 cultivated on an SBP dry mill at 40% of the initial moisture and initial pH of 6.0. The data are presented as the mean of triplication and standard deviation

Table 2 The efficiency of pigment production by *M. purpureus* TISTR 3385 in various conditions

Conditions	Yp/s for YP (UA/g)	Yp/s for OP (UA/g)	Yp/s for RP (UA/g)	P_Y (UA/g/d)	P_O (UA/g/d)	P_R (UA/g/d)	References
Submerged fermentation							
Culture: 250-mL flask Medium: Modified Yeast Malt Extract (YM) Condition: 250 rpm, pH 4.5, 30 °C	-[nd]	-[nd]	~1.7	-[nd]	-[nd]	0.67	[54]Wonganu & Kongruang (2010)
Culture: 5-L Stirred tank bioreactor Medium: Yeast Malt Extract (YM) Condition: maintained pH at 7.0, 30 °C, Aeration at 1.38×10^5 N/m^2, Agitation at 100 rpm	4.52	5.49	5.34	66.28	80.20	77.98	[59]
Solid state fermentation							
Culture: 250 mL wide mouth cylindrical bottle Medium: sterile SBP, Condition: 40% moisture, pH 6.0, 30 °C	6.52 ± 0.35	3.42 ± 0.18	2.78 ± 0.05	0.93 ± 0.03	0.47 ± 0.01	0.40 ± 0.03	This study
Culture: 250 mL wide mouth cylindrical bottle Medium: non-sterile SBP, Condition: 40% moisture, pH 6.0, 30 °C	6.01 ± 0.22	3.09 ± 0.06	2.70 ± 0.08	0.86 ± 0.02	0.44 ± 0.04	0.39 ± 0.01	This study

[nd] is not detect. The data are presented as the mean of triplication and standard deviation.

P_Y, yellow pigment productivity; P_O, orange pigment productivity; P_R, red pigment productivity; $Y_{p/s}$, yield of pigment production per gram substrate; *YP*, yellow pigment; *OP*, orange pigment; *RP*, red pigment; *UA/g*, unit of absorbance per gram substrate; *U/g*, unit per gram substrate; *UA/g/d*, unit of absorbance per gram substrate per day.

accounted for 1.4% and 4% of the total utility cost, and the installed cost fee, respectively [49]. Moustogianni et al. [50] found that the total utility cost was saved by 4.6 times with non-sterile fermentation. Thus, non-sterile fermentation could be a practical approach for the production of pigments and lignocellulosic enzymes by *M. purpureus* TISTR 3385. In this study, fermentation using the sterile and non-sterile SBP dry mill was investigated. Fortunately, the fermentation using the sterile and non-sterile SBP dry mill did not display any significant difference in the production of the pigments and the activities of xylanase and cellulase by *M. purpureus* TISTR 3385 (Fig. 4 and Table 1). The production of the pigment and both enzymes was stable and continued for 7 days with a significant amount and declined at 10 days (Fig. 4). The highest number of pigments obtained by the fermentation of the non-sterile SBP dry mill was achieved in the range of 2.70–6.01 UA/g (Fig. 4b). Commonly, non-sterilized peels harbor various kinds of microbial diversity. Banana peel consisting of bacterial phyla, mainly composed of *Proteobacteria*, *Actinobacteria*, and *Bacilli*, is almost twice more abundant than that of fungal phyla [51]. However, the pigment productivity was obtained with a significant difference among all the conditions tested ($P < 0.05$) (Table 1). Regarding both enzyme activities, the highest xylanase and cellulase activities obtained by the fermentation of the non-sterile SBP dry mill were 8.92 ± 0.46 U/g and 4.72 ± 0.04 U/g, respectively (Fig. 4b). Accordingly, in a previous study regarding non-sterile fermentation, Vasco-Correa et al. [52] reported that non-sterile miscanthus was pretreated by the fungus *Ceriporiopsis subvermispora* for enzymatic hydrolysis. The enzymatic digestibility was significantly achieved 3- to fourfold. Moreover, Yafetto [53] reported that the protein concentration of the sterile and non-sterile cassava pulp fermented by *Aspergillus niger* did not have a significant difference and increased by 22.61% and 21.54%, respectively. Pan et al. [54] also reported that sterile and non-sterile cultivation for the fibrinolytic enzyme by *Bacillus subtilis* was similar in the trends, but the highest activity of fibrinolytic obtained in the non-sterile cultivation (3129 U/mL) was rather higher than that of sterile cultivation (2906 U/mL).

Pigment-producing efficiency of Monascus purpureus TISTR3385

Submerged fermentation offered advantages, such as better monitoring and simplified handling [55], while; solid-state fermentation provided benefits, such as better process control, lower chances of contamination, and simplified downstream processing [56]. Traditionally, pigment produced by the *Monascus* species was performed under solid-state fermentation; however, it was recently performed under submerged fermentation [57]. Table 2 shows the efficiency of the pigment production by *M. purpureus* TISTR3385 through submerged fermentation and solid-state fermentation. Under submerged fermentation, Wonganu and Kongruang [58] revealed the production of the red pigment by *M. purpureus* TISTR 3385 cultivated on a small scale using modified yeast malt extract compared with *M. purpureus* TISTR 3002 and *M. purpureus* TISTR 3180. The red pigment produced by the fungi was obtained at a high production of 1.7 UA/g corresponding to its productivity of 0.67 UA/g/d, which was 1.18-fold and 1.68-fold higher than that produced by *M. purpureus* TISTR 3002 and *M. purpureus* TISTR 3180, respectively (data not shown). In addition, Kongruang [59] revealed that the pigment production by *M. purpureus* TISTR 3385 in a 5-L stirred tank bioreactor was compared with *M. purpureus* TISTR 3002, *M. purpureus* TISTR 3180, and *M. purpureus* TISTR 3090. Among all strains investigated, *M. purpureus* TISTR 3385 provided various pigments comprising yellow, orange, and red at the highest levels. The orange (5.49 UA/g) and red pigments (5.34 UA/g) were predominant, followed by the yellow pigment (4.52 UA/g). The orange pigment yield was 15, 5, and 2 times higher than that of *M. purpureus* TISTR 3002, *M. purpureus* TISTR 3180, and *M. purpureus* TISTR 3090. In this study, the fermentation with sterile and non-sterile SBP was performed by *M. purpureus* TISTR 3385. The trends of the pigment production under both conditions were similar and also obtained at high levels. These indicated the potential of *M. purpureus* TISTR 3385 as pigment-producing fungi due to its ability to produce pigment in various substrates, including synthetic media and waste or residues under submerged fermentation or solid-state fermentation with or without sterile conditions.

Conclusion

This study showed that Saba banana peel could serve as a low-cost fermentable substrate for the production of pigments, xylanase and cellulase enzymes by both kinds of *M. purpureus*: *M. purpureus* TISTR 3385 and *M. purpureus* TISTR 3615. The moisture and pH of the substrate had impacts on the conversion of the waste by the fungi into the products, particularly for the pigments. Yellow pigment was predominant, followed by the orange and red pigments, respectively. In addition, fermentation using non-sterile peel was effective as well as the sterile one, which indicated a practical platform for eco-friendly pigment production.

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Declarations

Ethics approval This article does not contain any experiments with human participants or animals.

Conflict of interest The authors declare no competing interests.

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