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Utilization of Waste Banana Peels and Corn Cobs as Substrates in *Neurospora sitophila* Fermentation for Production of Natural Yellow Dyes

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Abstract

The demands for colored products increased since color adds the attractiveness and value of a product. The commonly used dyes today are synthetic ones which easily produced, inexpensive, but need further handling due to the environment. Therefore, the development of natural dyes from microorganisms is widely carried out. Fungus *Neurospora sitophila* capable to synthesize pigments as its secondary metabolites. This research was conducted to examine the production of yellow pigment from Solid-State Fermentation of *Neurospora sitophila* by utilizing corn cob and banana peel waste as substrates and determine the effect of the water content and the length of the fermentation. Corn cobs and banana peels were first reduced in size to 60 mesh and sterilized before fermentation. The fermentation process was carried out with variations in water content of 40% - 70% by volume, and fermentation time of 5, 7, and 9 days. Carotenoid levels were investigated by spectrophotometric analysis UV-VIS and FTIR with a standard curve of beta carotene. The UV-VIS analysis resulted the best conditions for using corn cobs and banana peel waste were 60% water content and 7 days fermentation by obtaining pigment concentration of 110.49 ppm and 161.37 ppm, respectively, which an increase of pigment concentration compared to the original waste. FTIR analysis resulted that the extracted pigment contained beta carotene compounds. These results indicated that the fungus was capable to carry out the fermentation process for lignocellulosic substrates to produce carotenoid. This microbial pigment produced was potential to be more environmentally alternative to synthetic dyes.

Keywords: corncob, banana peel, natural dyes, solid state fermentation, *Neurospora sitophila*, carotenoid pigments

1. Introduction

Color is an aspect that cannot be separated from human life, such as culture, art, and industry, including fashion, food, and beverages. The use of color is increasing along with the rapid developments in each of these fields. Colors can be classified as synthetic dyes and natural dyes. Synthetic dyes come from chemical reactions or minerals that provide sharp, durable, and inexpensive colors. Textile industry dominating the use of many kinds of synthetic dyes in their dyeing process such as multiple dyeing, fixing, and washing which consume a huge volume of water.

The dyes are difficult to decompose, so they require extra treatment in the waste treatment due to their chemically stable (Ardila-Leal et al., 2021; Forgacs et al., 2004). Bad impacts can occur in the form of land, water and air pollution which endanger humans and other living creatures (Slama et al., 2021). From a health perspective, dyes in products which in direct contact with skin or other human organs pose a health risk if consumed in a long term and in large quantities (Lellis et al., 2019).

The use of natural dyes is one solution to overcome this problem. Natural dyes can be produced from plants, animals and microorganisms which are easily decomposed and are not harmful to humans. Coupled with the sustainability offered by natural dyes, this becomes both interesting and challenging regarding the use and substitution of natural dyes in various industries. The main challenge of natural dyes from plants is the aspect of cultivation. Production of plant-based dyes requires large areas of land, its productivity

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dependences on weather conditions, and even competes with its main function as food (Margono et al., 2022). Carrots, corn, lemons, turmeric crumbs and saffron are examples of sources of yellow color from plants with carotenoid pigments. Suji and pandan leaves are examples of green color with chlorophyll pigment (Kwartiningsih et al., 2021).

Microbial and fungal pigments can be a solution as an alternative natural dye producer because they do not require large areas of land, do not depend on the season, and are easy to cultivate. Microorganisms are capable of producing dyes as a secondary metabolite product which is nutraceutical and anti-oxidant through cultivation and fermentation under certain conditions, and the secreted microbial pigments adhere to the surface or inside of the material (Y. Liu et al., 2021; Narsing Rao et al., 2017).

Bacteria and fungi have various kinds of pigments which are often referred to as microbial pigments or fungal pigments, including carotenoids, *monascin*, melanin, violacein, prodigiosin, pyocyanin, and so on (Aruldass et al., 2018; Margono et al., 2021; Rana et al., 2021). Several fungi and bacteria that have been reported to produce dyes include *Neurospora sp*, *Brakeslea sp*, *Bacillus sp*, *Serratia marcescens, Rodhotulla*, etc (Farawahida et al., 2022; Gmoser et al., 2017; Kavitha et al., 2010; Numan et al., 2018; Panesar et al., 2015; Wang et al., 2021). Studies say that the cost of producing fungal pigments is two times more expensive than conventional dyes (Narsing Rao et al., 2017), but this can be overcome by utilizing waste as a fermentation substrate.

Maize or corn (*Zea mays*) is the number two largest source of carbohydrate in Indonesia, occupying 57.09 qu/ha as average national productivity at 2021 (Badan Pusat Statistik, 2020b). Also, banana (*Musa paradisiaca*) is one of the largest horticultures produced in Indonesia. At 2021, banana production reached 8.74 million tons, increased by 6.82% from 2020 (Badan Pusat Statistik, 2020a). The increase in production and consumption of corn and bananas along with the increase and potentially abundant availability in the organic waste in the form of corn cob and banana peels, especially the type of kepok banana which is most often used as a processed food ingredient. Corn cob was estimated produced approximately 18 kg in every 100 kg of corn ear (Kapoor et al., 2016).

The average chemical composition of corn cob reported was in the range of 33–43% cellulose, 26–36% hemicellulose, and 17–21% lignin (Gandam et al., 2022; Lau et al., 2019; Zou et al., 2021). While banana peel contains ±8.6% cellulose, ±7.9% hemicellulose, ±15.5% pectin, and ±6% lignin (Acevedo et al., 2021). Cellulose and hemicellulose are carbon-rich organic compounds of complex polysaccharides that can be reduced or converted into various products. This is in line with the concept of sustainability in biorefinery utilizing waste biomass into materials with added value, for example dyes. Several studies state that the both wastes still contained trace of carotenoids as maize and banana was rich of that compound (Jodiawan et al., 2021; Lau et al., 2019; Letelay et al., 2020; Pereira & Maraschin, 2015; Savitri et al., 2022).

Carotenoids are natural dyes that give the red, yellow, and orange color spectrum. Some literature states that the fermentation process of natural dyes production from lignocellulosic biomass waste can increase carotenoid levels (Anshori et al., 2022; Kresnowati et al., 2020). This indicates that the abundant corncob and banana peel wastes potential to be processed as fermentation substrates for natural carotenoid dyes. In this study, the microorganism used was *Neurospora sitophila*. *Neurospora sp.* reported to be able to hydrolyze lignocellulosic compound because it has the cellobiose dehydrogenase (CDH) enzyme, which is an extracellular hemo-flavo-enzyme secreted to assist lignocellulolytic enzymes in biomass degradation (Dekker, 1980; Phillips et al., 2011). The use of these fungi is expected to provide a shorter fermentation process without going through the hydrolysis process. *Neurospora sitophila* is generally known as the red oncom-making fungus and sometimes called the orange bread mould since it has pinkish-orange color due to carotenoid pigments.

This study aims to observe the production of carotenoid pigments or natural yellow dyes from the fermentation process of corn cob and banana peel with fungus *Neurospora sitophila* using the solid fermentation method with variations in the water level of the fermentation medium and the length of time of fermentation.

2. Methodology

2.1. Materials

Neurospora sitophila isolate was collected from the Laboratory of the Center for Food and Nutrition Studies, Universitas Gajah Mada. The fungi isolate was maintained in solid potato dextrose agar (PDA) medium and stored at 4°C and was periodically re-inoculated every 2 months. Agricultural lignocellulolytic substrates consisting of kepok banana peel and corncobs were obtained from local farmers in Surakarta, Central Java, Indonesia.

2.2. Preparation of the substrates

The two substrates were reduced in size to 60 – 100 mesh. Banana peel waste was subjected to a delignification process to remove the lignin component with 4% NaOH solution. Heating was carried out for two hours at 90°C, then followed by washing with distilled water until the pH was neutral. Banana peel waste is then dried in an oven at 50°C. Both substrates then be stored in closed container at room temperature.

2.3. Preparation of the microorganism

Neurospora sitophila colony was taken from slanted PDA medium and cultivated in 250 ml culture medium consisted of 24 g/l sterile enrichment potato dextrose broth with the addition of nutrient solution consisted of 2 g/l KH_2PO_4; 5 g/l NH_4NO_3; 1 g/l NaCl; and 1 g/l $MgSO_4$ $7H_2O$. The cultivation process was carried out in the rotary shaker at 27°C and 125 rpm for 7 days. Between the days, the growth pattern of *Neurospora sitophila* was obtained. The fungi were then harvested when entering stationary phase and then acted as a starter in fermentation process.

2.4. Fermentation of *Neurospora Sitophila*

10 grams of each substrate; kepok banana peel and corncobs powder was prepared and sterilized by autoclave for 20 min at 121 °C for the fermentation. The prior nutrient solution was also added to medium to provide the water phase and pH buffer to maintain the acidity at 6.5. Fermentation was carried out in a 250 ml Erlenmeyer flask on a shaker incubator at 125 rpm and kept at 27°C. To study the effect of water level and fermentation length to carotenoid production, the experiments were done by three levels of water content: 50%, 60% and 70% weight for corncobs substrate, and 40%, 50% and 60% weight for banana peel waste substrate; and three levels of fermentation length: 5,7, and 9 days for both substrate variations.

2.5. Natural Dye Extraction Process

After several days of fermentation, fermented substrate or media was taken for entering the extraction process to determine the concentration of carotenoids produced. Solvent extraction was used for this process. Yellow natural dye or carotenoid extraction was carried out by dissolving 4 grams of fermented substrate in 20 ml of ethanol solvent. Extraction was conducted by stirring for 1 hour. The purification process was carried out to separate the extract from residue using a vacuum filter. The carotenoid extract was then centrifuged for 5-10 minutes to remove the to remove remaining impurities. The supernatant was taken and filtered again through a two-micron membrane syringe filter and ready to be analyzed.

2.6. Cell Growth Analysis

Cell growth can be evaluated by the time-dependent changes of the total number of the cell between days 1 to 7 from the culture medium. The hemacytometer analysis was conducted to count number of cells per day. The cell growth data was plotted as a curve to show increase in cell numbers in the matter of time (days).

2.7. Spectrophotometer Analysis

Spectrophotometer analysis was first conducted to obtain standard beta carotene curve. Beta carotene standard was from Sigma Aldrich and was diluted by 0,1 to 10 ppm concentration, then was analyzed by a UV VIS spectrophotometer Thermo Scientific GENESYS 20 with a 475 nm wavelength. Beta carotene standard curve produced was conducted to calculate the levels of carotenoids produced by extrapolation method.

2.8. Functional Group Analysis

Fourier Transform Infrared (FTIR) IR Prestige-21 in the spectral range between 400-4000 cm^{-1} was used to analyze the chemical composition in pigment produced. The analysis was done by comparing the functional groups found between beta carotene standard and pigment produced.

2.9. Statistical Analysis

ANOVA was also used to conduct statistical significance analysis. This analysis was to calculate the significancy of the finding based on research variations; the levels of water content and three levels of fermentation length for both substrate variations.

3. Results and Discussion

3.1. The Growth Profile of *Neurospora sitophila*

Dyes or pigments are one of the products of secondary metabolism, where metabolite products are formed not in line with the cell growth period. Pigments are not synthesized in the exponential phase but are formed at the end of the growth period or at stationary phase (Ashok Kumar et al., 2015), thus harvesting of mold cells for the inoculation process was carried out when entering the early stationary phase. By observing the number of cells with hemacytometer every 24 hours for 7 days, the growth curve obtained is presented in Figure 1. The growth of *Neurospora sitophila* cells entered the stationary phase on day 5 to day 7 with a cell number of 3.5 x 10^6. Based on the references of several journals, this number was adequate to conduct the fermentation (Gmoser et al., 2018; J. Liu et al., 2021; Louhasakul et al., 2023).

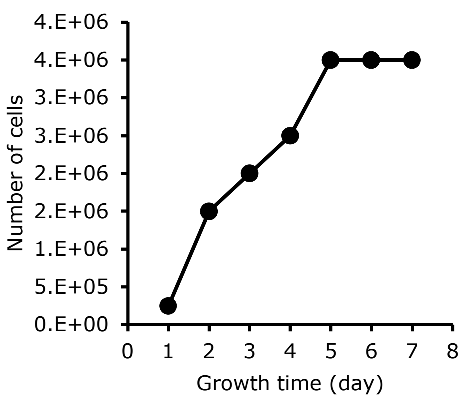

Figure 1. Growth curve of *Neurospora sitophila* in sterile enrichment potato dextrose broth

3.2. Carotenoids fermentation by *Neurospora sitophila* using corn cob and banana peel as substrate

Productivity of natural yellow dye from the fermentation process was analyzed by extracting the fermented media by solvent method and followed by purification. The extract was analyzed using UV VIS spectrophotometry with a wavelength of 470 nm. A calibration curve provided by beta-carotene standard (Sigma Aldrich) in solution around 1 – 10 ppm presented in figure 2. The y-axis shows the absorbance on a UV Vis spectrophotometer while the x-axis shows the standard beta carotene concentration in ppm. Linear equation was obtained from the graph in the form $y = 0.0169x + 0.1328$; with R^2 value 0.9848. Afterwards, this equation was used to extrapolate the carotenoid concentration.

The fermentation process for the synthesis of natural dyes carotenoid was carried out by the fungus *Neurospora sitophila* with lignocellulosic waste substrates: corn cob and banana peels in size 60 – 100 mesh. Particle size is also a key parameter in solid state fermentation that is related to the ability of the voids of the substrate pile to be filled with water and provide a surface for microbes to grow (Chilakamarry et al., 2022). The acidity was maintained at 6.2 as it's the optimum pH in biomass production and also the carotenoid production as secondary metabolite (Kaur et al., 2019; Parra-Rivero et al., 2020). *Neurospora sitophila* was reported had optimum acidity of the growth environment at around 4,5 – 6,5 (Noverina et al., 2008). Since carotenoid was secondary metabolite product of *Neurospora sitophila*, those condition such as controlling the particle size and acidity level would make a great impact of this yellow pigment production.

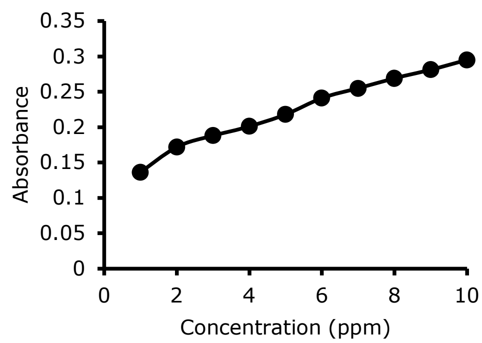

Figure 2. Beta-carotene standard curve

The solid-state fermentation processes were conducted by water content variations of 40% - 60% by weight for corncobs and banana peel. Water content was an important aspect supporting cells to grow and reproduce as biomass in solid phase fermentation (Said et al., 2022), and also has a role in the production of pigment as secondary metabolite by influencing nutrient solubility, oxygen, heat, and mass transfer (Louhasakul et al., 2023). Furthermore, the length of fermentation varied by 5–9 days.

The experimental carotenoid concentration produced by corn cob substrate using UV-VIS spectrophotometer analysis are presented in Table 1, while the carotenoid level by banana peel substrate fermentation is presented in Table 2.

Table 1. UV-VIS spectrophotometer data of the fermentation of *Neurospora sitophila* with corn cob as a substrate

Water Content	Time (Day)	Average of Absorbance (A)	Carotenoid Concentration (ppm)
40%	5	0.17	1.91
	7	0.82	40.86
	9	0.70	33.56
50%	5	0.20	4.07
	7	1.05	54.37
	9	0.78	38.00
60%	5	0.62	29.03
	7	1.76	96.09
	9	1.63	88.49

Based on the data, the best performance at corn cob fermentation was obtained by 7 days fermentation with 60% water content since it has the highest carotenoid concentrations namely 96.09 ppm. While the lowest carotenoid content was obtained by 5 days fermentation with 40% water content namely 1.91 ppm. At banana peel substrate fermentation, the best results were obtained by 60% water content for 7 days producing the highest carotenoid 161.77 ppm. Meanwhile, the lowest carotenoid content was obtained by 70% water content for 9 days with a concentration of 28.24 ppm carotenoid.

Table 2. UV-VIS spectrophotometer data of the fermentation of *Neurospora sitophila* with banana peels powder as a substrate

Water *Content*	Time (Day)	Average of Absorbance (A)	Carotenoid Concentration (ppm)
50%	5	0.90	45.30
	7	2.72	153.00
	9	2.25	125.57
60%	5	1.85	101.90
	7	2.87	161.77
	9	1.57	85.24
70%	5	0.90	45.49
	7	1.70	92.73
	9	0.61	28.24

The highest carotenoid concentration was obtained at 7 days the middle length of fermentation. According to some research, the length of *Neurospora sitophila* fermentation ranging from 3 – 9 days at room temperature (Jhondri et al., 2017; Singgih et al., 2015). The length of fermentation also regarded to the nutrient supplied. The study about productivity of beta carotene by fungi *Yarrowia lipolytica* found that the highest yield was obtained after 7 days of fermentation by the addition of sufficient H_2O_2 which acted as an oxidant agent in the system to cause cells undergo oxidative stress (Jing et al., 2023). These experiments were conducted as batch process which there were no adding nutrient in the middle of fermentation. The lower concentration of carotenoid in the longest time of fermentation was due to nutrient depletion which led to death phase of microorganisms as occurred in day 9.

For molds, massive growth occurs at the final of exponential phase due to the maximum sporulation rate of spores during the static growth period between 5 and 7 days of fermentation as the formation of carotenoid (Seno Aulia et al., 2019). Other study also focused in carotenoid production by observing the profile of carotenoid formation from the appearance of a yellow-orange color on the substrate as an indicator of cell growth. The study about fermentation of palm oil empty fruit bunch by endogenous microorganism also experienced the same way by yellow orange color of substrate gave the highest carotenoid before decreased afterwards by color fading to whitish (Kresnowati et al., 2020).

Based on the experiments, the data showed that water content influenced the carotenoid produced. The highest levels of carotenoids were obtained at 60% water content, the highest water level among the other variations. This because fungus mostly like moist areas. Nevertheless, fungal metabolites work better in moist solid substrates than in submerged fermentation, in other hand, areas rich by water (Gmoser et al., 2019). A high-water level could decrease the porosity of bed substrate which led to lower oxygen diffusion and enhanced aerial mycelial formation. Whereas, a low moisture levels reduced the solubility of the nutrients on substrate surface, and gave lower degree of bed swelling (Maxwell et al., 2019; Pandey, 2003). This optimum level of moisture provided the sufficient void area to the *Neurospora sitophyla* to grow by utilizing the nutrient in the fermentation medium and the oxygen. The continuous shaking by rotary shaker was also helped the medium to release the heat and carbon dioxide of metabolic reaction (Patakova, 2013). Thus, this condition enhanced the fungus to grow and metabolize producing yellow pigment as secondary metabolite.

In this study, fermentation of *Neurospora sitophila* with banana peel and corn cob as substrate produced carotenoid levels equivalent by 161.77 ppm and 96.06 ppm, respectively. As a comparison, the carotenoid content in fresh banana peel waste is 45 mg/1000 g or 45 ppm (Aprilia et al., 2016); 37.12–60.02 mg/1000 g (Letelay et al., 2020); 3.47–36.6 mg/1000 g (Jodiawan et al., 2021), and the carotenoid content in corn cob ranges from 49.35 mg/kg (Lau et al., 2019); and 25.8 µg/g (O'Hare et al., 2015). It was found that there were significantly different levels of carotenoids between both substrates condition, fresh waste and after fermentation occurred. On the other words, the fungus *Neurospora sitophila* was capable to carry out the fermentation process for lignocellulosic substrates producing carotenoid.

The cellobiose dehydrogenase enzyme secreted by *Neurospora sp*. assist lignocellulolytic enzymes in biomass degradation and provide a shorter fermentation process (Phillips et al., 2011). This could be a potential problem solver regarding the abundant of lignocellulolytic biomass in agro-industrial sector in Indonesia. This research could be the preliminary research regarding this potential.

The results of the analysis with UV-Vis spectrophotometer then processed by ANOVA on Minitab to determine the effect of variations treated on the sample. Table 3 and Table 4 shows that the p-value of each variation was smaller than 0.05. It found that variations in water level content and fermentation duration affected the carotenoid fermentation process.

The F-value of each variation and the interaction between the variations of both materials were also found to be significant to the concentration of carotenoid produced.

Table 3. ANOVA result for corn cob substrate

Source	F-value	P-value
Water content (%)	168.64	0.000
Length of fermentation (day)	232.97	0.000
Water content (%) x Length of fermentation (day)	7.40	0.000

Tabel 4. ANOVA result for banana peel substrate

Source	F-value	P-value
Water content (%)	4.55	0.016
Length of fermentation (day)	231.74	0.000
Water content (%) x Length of fermentation (day)	34.59	0.000

3.3. Carotenoid Compounds by FTIR Analysis

From the best fermentation results, the FTIR analysis was conducted to determine the presence of carotenoid compounds. The results of the carotenoid analysis recorded with the IR-Spirit Shimadzu FTIR Spectrometer in the spectral range between 400-4000 cm^{-1} are presented in Figure 3–5.

Beta-carotene naturally presence in trans configuration (Kaur et al., 2019; Saha et al., 2015). The FTIR analysis of standard beta carotene (Figure 2) show transmission peaks at 2900–3050 cm^{-1} represents the C–H groups, bands at around 2800 cm^{-1} indicates the C–H groups. The peaks observed at around 1370–1450 cm^{-1} showed the deformation mode of the C-H group.

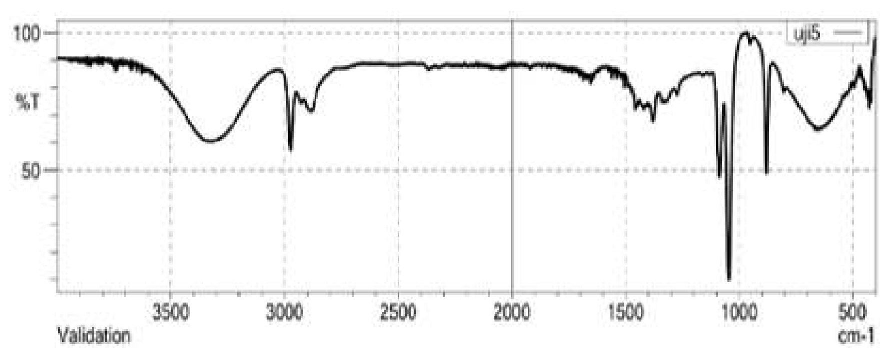

Figure 3. FTIR result (standard beta carotene)

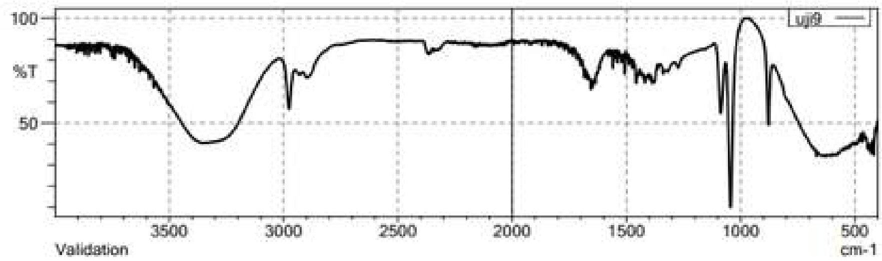

Figure 4. FTIR result (carotenoid produced by corn cob fermentation)

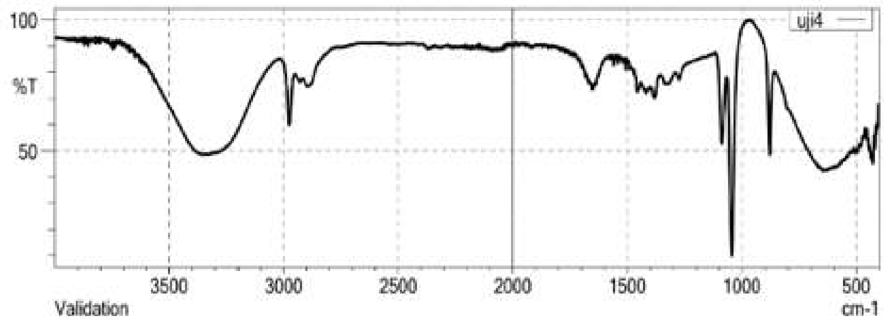

Figure 4. FTIR result (carotenoid produced by banana peel fermentation)

In addition, the peak found at around 1500–2000 cm^{-1} shows the C=C double bond which indicates the stretching vibration of β-carotene (Hagos et al., 2022).

The band also occurred at around 967 cm^{-1} represents the alkene -CH=CH- mode and at around 1020 cm^{-1} represents CO groups (Hassimi et al., 2020; Kaur et al., 2019; Moh et al., 1999; Neha et al., 2017; Pea et al., 2020; Saha et al., 2015).

The existence of those groups in the fermentation product solutions, as the same absorption peaks and bands as the beta carotene standard, indicated that both solutions contained beta carotene compounds (Figure 3 and 4). Another peak was found at around 1650 cm^{-1} which indicated a C=C group which also found at carotenoids (Damayanti et al., 2021; Pea et al., 2020; Saha et al., 2015). It means that *Neurospora sitophila* fermentations by utilizing the corncob and banana peel powder as substrates were successful since it contained the functional group of beta carotene.

4. Conclusion

Neuspora sitophila fungus capable to utilize lignocellulolytic biomass, such as banana peel and corncob powder as substrates for carotenoid fermentation. The best performances of corn cob and banana peel substrate fermentation were obtained 96.09 ppm and 161.77 ppm, respectively. The optimum water content was 60% as this condition provided an optimum void area to fungus growing and metabolizing thus producing yellow pigment as metabolite product. The carotenoid levels of the two lignocellulosic wastes appeared to be increased after the fermentation process by the fungus. The results showed that carotenoid content was significantly influenced by the conducted variations. These findings, both the optimum water level and the length of fermentation, contributes the research of potential lignocellulolytic biomass as high value materials. The natural yellow pigment made from lignocellulolytic waste was a great option regarding sustainable dye in cosmetic, pharmacy, or the other industries. Further studies regarding optimizing the fermentation and extraction process and the potency of other lignocellulolytic biomass as substrate fermentation are highly required.

Author Contributions

Conceptualisation, A.N.R.,; Formal analysis, L.A.R,; Investigation, H.M.R,; Project administration, N.K.N,; Supervision, A.N.R,; Writing – original draft, I.S.,; Writing – review and editing, E.K.

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Data Available Statement

Available on request to the corresponding author.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

References

Acevedo, S.A., Díaz Carrillo, Á.J., Flórez-López, E., & Grande-Tovar, C.D. (2021) Recovery of banana waste-loss from production and processing: a contribution to a circular economy, *Molecules (Basel, Switzerland),* 26(17), 1–30. https://doi.org/10.3390/molecules26175282

Anshori, M., Jafar, R.M., Lestari, D., & Kresnowati, M.T.A.P. (2022) Production of carotenoids from oil palm empty fruit bunches: selection of extraction methods, *Journal of Engineering and Technological Sciences,* 54(3). https://doi.org/10.5614/j.eng.technol.sci.2022.54.3.3

Aprilia, A., Kurniawati, E., Kedokteran, F., Lampung, U., Molekuler, B. B., Kedokteran, F., & Lampung, U. (2016) Pengaruh beta karoten pada kulit pisang kepok dalam mencegah infark miokard akut, *Majority*, 5(4), 2–6.

Ardila-Leal, L.D., Poutou-Piñales, R.A., Pedroza-Rodríguez, A.M., & Quevedo-Hidalgo, B.E. (2021) A brief history of colour, the environmental impact of synthetic dyes and removal by using laccases, *Molecules*, 26(13). https://doi.org/10.3390/molecules26133813

Aruldass, C.A., Dufossé, L., & Ahmad, W.A. (2018) Current perspective of yellowish-orange pigments from microorganisms- a review, *Journal of Cleaner Production,* 180, 168–182. https://doi.org/10.1016/j.jclepro.2018.01.093

Ashok Kumar, K., Gousia, S.K., & Latha, J.N.L. (2015) Evaluation of biological activity of secondary metabolites of Neurospora crassa from machilipatnam sea water, *Research Journal of Microbiology,* 10(8), 377–384. https://scialert.net/abstract/?doi=jm.2015.377.384

Badan Pusat Statistik. (2020a) Horticultural statistics 2021, *BPS-RI/BPS-Statistics Indonesia, BPS Catalogue:* 5204003.

Badan Pusat Statistik. (2020b) The 2021 Analysis of maize and soybean productivity in Indonesia. 2020, *BPS-RI/BPS-Statistics Indonesia, BPS Catalogue:* 5203029.

Chilakamarry, C.R., Mimi Sakinah, A.M., Zularisam, A.W., Sirohi, R., Khilji, I.A., Ahmad, N., & Pandey, A. (2022) Advances in solid-state fermentation for bioconversion of agricultural wastes to value-added products: Opportunities and challenges, *Bioresource Technology,* 343, 126065. https://doi.org/10.1016/j.biortech.2021.126065

Damayanti, J., Azmilia, R., Ainun, Z., & Nurdin, M.I. (2021) Isolation of Lycopene component from Tamarillo (*Solanum betaceum*), *Indonesian Journal of Chemical Research,* 9(2 SE-Research articles). https://doi.org/10.30598//ijcr.2020.9-dam

Dekker, R. F. H. (1980) Induction and characterization of a cellobiose dehydrogenase produced by a species of Monilia, *Journal of General Microbiology,* 120(2), 309–316. https://doi.org/10.1099/00221287-120-2-309

Farawahida, A.H., Palmer, J., & Flint, S. (2022) Monascus spp. and citrinin: Identification, selection of Monascus spp. isolates, occurrence, detection and reduction of citrinin during the fermentation of red fermented rice, *International Journal of Food Microbiology,* 379(July), 109829. https://doi.org/10.1016/j.ijfoodmicro.2022.109829

Forgacs, E., Cserháti, T., & Oros, G. (2004) Removal of synthetic dyes from wastewaters: a review, *Environment International,* 30(7), 953–971. https://doi.org/10.1016/j.envint.2004.02.001

Gandam, P.K., Chinta, M.L., Gandham, A.P., Pabbathi, N.P.P., Konakanchi, S., Bhavanam, A., Atchuta, S.R., Baadhe, R.R., & Bhatia, R.K. (2022) A new insight into the composition and physical characteristics of corncob - substantiating its potential for tailored biorefinery objectives, *Fermentation,* 8(12). https://doi.org/10.3390/fermentation8120704

Gmoser, R., Ferreira, J.A., Lennartsson, P.R., & Taherzadeh, M.J. (2017) Filamentous ascomycetes fungi as a source of natural pigments, *Fungal Biology and Biotechnology,* 4(1), 1–25. https://doi.org/10.1186/s40694-017-0033-2

Gmoser, R., Ferreira, J.A., Lundin, M., Taherzadeh, M.J., & Lennartsson, P.R. (2018) Pigment production by the edible filamentous fungus Neurospora intermedia, *Fermentation,* 4(1). https://doi.org/10.3390/fermentation4010011

Gmoser, R., Sintca, C., Taherzadeh, M.J., & Lennartsson, P.R. (2019) Combining submerged and solid state fermentation to convert waste bread into protein and pigment using the edible filamentous fungus N. intermedia, *Waste Management,* 97, 63–70. https://doi.org/10.1016/j.wasman.2019.07.039

Hagos, M., Redi-Abshiro, M., Chandravanshi, B.S., & Yaya, E.E. (2022) Development of analytical methods for determination of β-Carotene in Pumpkin (Cucurbita maxima) flesh, peel, and seed powder samples, *International Journal of Analytical Chemistry,* 9363692. https://doi.org/10.1155/2022/9363692

Hassimi, A. H., Ezril Hafiz, R., Muhamad, M.H., & Sheikh Abdullah, S.R. (2020) Bioflocculant production using palm oil mill and sago mill effluent as a fermentation feedstock: Characterization and mechanism of flocculation, *Journal of Environmental Management,* 260 (December 2019), 110046. https://doi.org/10.1016/j.jenvman.2019.110046

Jhondri, J., Abun, A., Rusmana, D., & Wiradimadja, R. (2017) Bindering and the stability of beta caroten from Neurospora sitophila, *Scientific Bulletin. Series F. Biotechnologies,* XXI, 143–148.

Jing, Y., Wang, J., Gao, H., Jiang, Y., Jiang, W., Jiang, M., Xin, F., & Zhang, W. (2023) Enhanced β-carotene production in Yarrowia lipolytica through the metabolic and fermentation engineering, *Journal of Industrial Microbiology & Biotechnology,* 50(1). https://doi.org/10.1093/jimb/kuad009

Jodiawan, C.D.N., Vi'atin, N., Prihastyanti, M. N. U., Chandra, R. D., Heriyanto, Siswanti, C.A., Hapsari, L., & Brotosudarmo, T.H.P. (2021) Carotenoid analysis from commercial banana cultivars (Musa spp.) in Malang, East Java, Indonesia, *Indonesian Journal of Chemistry,* 21(3), 690–698. https://doi.org/10.22146/ijc.60865

Kapoor, M., Panwar, D., & Kaira, G.S. (2016) Bioprocesses for enzyme production using agro-industrial wastes: technical challenges and commercialization potential. *Agro-Industrial Wastes as Feedstock for Enzyme Production*, 61–93. https://doi.org/10.1016/B978-0-12-802392-1.00003-4

Kaur, P., Ghoshal, G., & Jain, A. (2019) Bio-utilization of fruits and vegetables waste to produce β-carotene in solid-state fermentation: Characterization and antioxidant activity, *Process Biochemistry,* 76, 155–164. https://doi.org/10.1016/j.procbio.2018.10.007

Kavitha, R., Aiswariya, S., & Ratnavali, C.M.G. (2010) Anticancer activity of red pigment from Serratia marcescens in human cervix carcinoma, *International Journal of PharmTech Research,* 2, 784–787.

Kresnowati, M.T.A.P., Lestari, D., Anshori, M., & Jafar, R.M. (2020) Production of carotenoids from oil palm empty fruit bunches, *IOP Conference Series: Earth and Environmental Science,* 460(1) *International Conference of Biomass and Bioenergy* 19-20 August 2019, Indonesia. https://doi.org/10.5614/j.eng.technol.sci.2022.54.3.3

Kwartiningsih, E., Ramadhani, A.N., Putri, N.G.A., & Damara, V.C.J. (2021) Chlorophyll extraction methods review and chlorophyll stability of katuk leaves (Sauropus androgynous), *Journal of*

Physics: Conference Series, 1858(1), 12015 *The 7th International Conference on Engineering, Technology, and Industrial Application* (ICETIA 2020) 8-9 December 2020, Indonesia. https://doi.org/10.1088/1742-6596/1858/1/012015

Lau, T., Harbourne, N., & Oruña-Concha, M.J. (2019) Valorisation of sweet corn (Zea mays) cob by extraction of valuable compounds, *International Journal of Food Science and Technology,* 54(4), 1240–1246. https://doi.org/10.1111/ijfs.14092

Lellis, B., Fávaro-Polonio, C.Z., Pamphile, J.A., & Polonio, J.C. (2019) Effects of textile dyes on health and the environment and bioremediation potential of living organisms, *Biotechnology Research and Innovation,* 3(2), 275–290. https://doi.org/10.1016/j.biori.2019.09.001

Liu, J., Wu, J., Cai, X., Zhang, S., Liang, Y., & Lin, Q. (2021) Regulation of secondary metabolite biosynthesis in Monascus purpureus via cofactor metabolic engineering strategies, *Food Microbiology,* 95(October 2020), 103689.

Liu, Y., Yu, Z., Zhang, Y., & Wang, H. (2021) Microbial dyeing for inoculation and pigment used in wood processing: Opportunities and challenges, *Dyes and Pigments,* 186(September 2020), 109021. https://doi.org/10.1016/j.fm.2020.103689

Louhasakul, Y., Wado, H., Lateh, R., & Cheirsilp, B. (2023) Solid-state fermentation of Saba banana peel for pigment production by Monascus purpureus, *Brazilian Journal of Microbiology,* 54(1), 93–102. https://doi.org/10.1007/s42770-022-00866-3

Margono, M., Paryanto, P., Aida Nur, R., & Ainur, R. (2022) Aneka sumber pewarna alami proses: produksi dan aplikasinya untuk pewarnaan batik. Penerbit Lakeisha.

Margono, M., Paryanto, P., Hanifa, V., & Abimanyu, C. (2021) Production of natural colorant by monascus purpureus fncc 6008 using rice and cassava as carbon substrates, *Jurnal Bahan Alam Terbarukan,* 10(1), 24–30. https://doi.org/10.15294/jbat.v10i1.30486

Maxwell, O.I., Chinwuba, U.B., & Onyebuchukwu, M.G. (2019) Protein enrichment of potato peels using Saccharomyces cerevisiae via solid-state fermentation process, *Advances in Chemical Engineering and Science,* 09(01), 99–108. https://doi.org/10.4236/aces.2019.91008

Moh, M.H., Che Man, Y.B., Badlishah, B.S., Jinap, S., Saad, M.S., & Abdullah, W.J.W. (1999) Quantitative analysis of palm carotene using fourier transform infrared and near infrared spectroscopy, *JAOCS: Journal of the American Oil Chemists' Society,* 76(2), 249–254. https://doi.org/10.1007/s11746-999-0226-9

Narsing Rao, M.P., Xiao, M., & Li, W.J. (2017) Fungal and bacterial pigments: Secondary metabolites with wide applications, *Frontiers in Microbiology,* 8(JUN), 1–13. https://doi.org/10.3389/fmicb.2017.01113

Neha, T., Shishir, T., & Ashutosh, D. (2017) Fourier transform infrared spectroscopy (FTIR) profiling of red pigment produced by Bacillus subtilis PD5, *African Journal of Biotechnology,* 16(27), 1507–1512. https://doi.org/10.5897/AJB2017.15959

Noverina, N., Harlina, T., Yolandasari, D., Septianie, A., Nugraha, K., Dhalika, T., Budiman, A., Peternakan, F., & Padjadjaran, U. (2008) Valuasi nilai nutrisi tongkol jagung hasil bioproses kapang Neurospora sitophila dengan suplementasi sulpur dan nitrogen, *Jurnal Ilmu Ternak,* 8(1), 35–42. https://doi.org/10.24198/jit.v8i1.2210

Numan, M., Bashir, S., Mumtaz, R., Tayyab, S., Rehman, N.U., Khan, A.L., Shinwari, Z.K., & Al-Harrasi, A. (2018) Therapeutic applications of bacterial pigments: a review of current status and future opportunities, *3 Biotech,* 8(4). https://doi.org/10.1007/s13205-018-1227-x

O'Hare, T.J., Fanning, K.J., & Martin, I.F. (2015) Zeaxanthin biofortification of sweet-corn and factors affecting zeaxanthin accumulation and colour change, *Archives of Biochemistry and Biophysics,* 572, 184–187. https://doi.org/10.1016/j.abb.2015.01.015

Pandey, A. (2003) Solid-state fermentation, *Biochemical Engineering Journal,* 13 (November 2001), 81–84. https://doi.org/10.1016/S1369-703X(02)00121-3

Panesar, R., Kaur, S., & Panesar, P.S. (2015) Production of microbial pigments utilizing agro-industrial waste: A review, *Current Opinion in Food Science,* 1(1), 70–76. https://doi.org/10.1016/j.cofs.2014.12.002

Parra-Rivero, O., de Barros, M.P., Prado, M. del M., Gil, J.V., Hornero-Méndez, D., Zacarías, L., Rodrigo, M. J., Limón, M.C., & Avalos, J. (2020) Neurosporaxanthin overproduction by Fusarium fujikuroi and evaluation of its antioxidant properties, *Antioxidants,* 9(6), 1–18. https://doi.org/10.3390/antiox9060528

Patakova, P. (2013) Monascus secondary metabolites: Production and biological activity, *Journal of Industrial Microbiology and Biotechnology,* 40(2), 169–181. https://doi.org/10.1007/s10295-012-1216-8

Letelay, O.P., Hiariej, A., & Pesik, A. (2020) Analisis beta karoten dan vitamin pada kulit dan daging buah pisang tongka langit (Musa Troglodytarum L.) di kota Ambon, *Jurnal Agritechno, 13(1),* 24–33. https://doi.org/10.20956/at.v13i1.243

Pea, S.I., Khairuddin, & Prismawiryanti. (2020) Studi perbandingan aktivitas antioksidan xantofil dan karoten kapang oncm merah pada berbagai waktu inkubasi, *KOVALEN*: *Jurnal Riset Kimia,* 6(2), 152–157. https://doi.org/10.22487/kovalen.2020.v6.i2.11547

Pereira, A., & Maraschin, M. (2015) Banana (Musa spp) from peel to pulp: Ethnopharmacology, source of bioactive compounds and its relevance for human health, *Journal of Ethnopharmacology,* 160, 149–163. https://doi.org/10.1016/j.jep.2014.11.008

Phillips, C.M., Beeson, W.T., Cate, J.H., & Marletta, M.A. (2011) Cellobiose dehydrogenase and a copper-dependent polysaccharide monooxygenase potentiate cellulose degradation by Neurospora crassa, *ACS Chemical Biology,* 6(12), 1399–1406. https://doi.org/10.1021/cb200351y

Rana, B., Bhattacharyya, M., Patni, B., Arya, M., & Joshi, G.K. (2021) The Realm of microbial pigments in the food color market, *Frontiers in Sustainable Food Systems,* 5(March 2021), 1–14. https://doi.org/10.3389/fsufs.2021.603892

Saha, N., Samanta, A.K., Chaudhuri, S., & Dutta, D. (2015) Characterization and antioxidant potential of a carotenoid from a newly isolated yeast, *Food Science and Biotechnology,* 24(1), 117–124. https://doi.org/10.1007/s10068-015-0017-z

Said, S.D., Pontas, K., Thaib, A., Maimun, T., & Silvianti, C. (2022) Increasing crude protein content of sago dregs through solid state fermentation process, *Journal of Applied Technology,* 9(1), 1–6.

Savitri, D., Djawad, K., Hatta, M., Wahyuni, S., & Bukhari, A. (2022) Active compounds in kepok banana peel as anti-inflammatory in acne vulgaris: Review article, *Annals of Medicine and Surgery,* 84(October), 104868. https://doi.org/10.1016/j.amsu.2022.104868

Seno Aulia, A., Nur Asni, S., Anggi, R., Landiyani, P., & Eka, N. (2019) Pemanfaatan air kelapa dan limbah kecap sebagai substrat dalam produksi pigmen karotenoid, *Jurnal Sains Dan Teknologi Farmasi Indonesia,* 8(2), 48–59. http://dx.doi.org/10.58327/jstfi.v8i1.99

Singgih, M., Andriatna, W., Damayanti, S., & Priatni, S. (2015) Carotenogenesis study of neurospora intermedia N-1 in liquid substrate fermentation, *Journal of Chemical and Pharmaceutical Research,* 7(5), 842–847.

Slama, H. Ben, Bouket, A.C., Pourhassan, Z., Alenezi, F.N., Silini, A., Cherif-Silini, H., Oszako, T., Luptakova, L., Golińska, P., & Belbahri, L. (2021) Diversity of synthetic dyes from textile industries, discharge impacts and treatment methods, *Applied Sciences (Switzerland),* 11(14), 1–21. https://doi.org/10.3390/app11146255

Wang, E., Dong, C., Zhang, P., Roberts, T.H., & Park, R.F. (2021) Carotenoid biosynthesis and the evolution of carotenogenesis genes in rust fungi, *Fungal Biology,* 125(5), 400–411. https://doi.org/10.1016/j.funbio.2020.12.005

Zou, Y., Fu, J., Chen, Z., & Ren, L. (2021) The effect of microstructure on mechanical properties of corn cob, *Micron,* 146(March), 103070. https://doi.org/10.1016/j.micron.2021.103070