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立命館高等学校
スーパーサイエンスコース
SSG クラス

研究成果一覧

ショウジョウバエの行動に対する嗅覚の影響

要旨

この研究の目的は、匂いなどの環境の変化がショウジョウバエの行動にどのような影響を与えるかをよりよく理解し、親の学習能力が次世代にどのような影響を与えるかを明らかにすることである。この実験では、2 つの物質の匂いの違いによってハエの行動がどのように変化するかを知るために、3D プリンターを用いて V 字型の装置を作った。実験では絶食状態に置かれたショウジョウバエが使われた。その結果、トラック内でショウジョウバエが最も活発に活動する絶食時間は約 24 時間であることが判明した。次に、ショウジョウバエが匂いによってどの物質を餌として認識するかを調べる実験を行った。この実験では、通常の培地から酵母、プロピオン酸、およびその両方を組み合わせたものを除いた培地を作った。V 字型トラックの両端に通常培地と改良した培地をそれぞれ置き、5 匹のショウジョウバエをスタート地点に置き、約 10 分間観察した。この実験での観察から、ショウジョウバエは酵母とプロピオン酸の匂いを頼りに培地にたどり着くことが示唆された。この結果は、水で湿らせたコットンと酵母とプロピオン酸を使って実験を繰り返すことで確認された。装置内での行動に及ぼす雌雄の影響を調べたところ、ほとんど影響はなかった。そのため、個体群密度の違いを調べると、装置内での動きに違いがあることがわかった。

1. 背景

私は幼い頃から生き物に興味があり、生態や行動に特に関心があったので、行動学について研究しようと思った。高校生活という限られた時間の中で効率よくサンプル数を揃えるため、世代時間が短いショウジョウバエを用いることにした。William G. Quinn らによるショウジョウバエの条件行動に関する論文を読んだところ、それらの研究では一度に 30 匹以上のハエを用いて実験を行っていた。ヒトの場合匂いは例えば、個人で食事をするときと集団で食事をする場合などでは差が生じることが多いと感じ、多数のハエを一度の実験に使用することは本来の行動とみて良いのか疑問に感じた。また、ショウジョウバエにおいては個体群密度によって生殖行動や機能が影響を受けること、トノサマバッタにおいては個体群密度によって相変異することが知られている。そこで、私は装置内での個体密度がショウジョウバエの行動にどう影響するのかの解明に取り組むことにした。同時に、その他の要因が装置内でのハエの行動に与える影響についても検討することにした。特にハエを育てた培地の匂いをハエがどのように認識しているかについて考察した。

2. 方法

2－0. 培地の作り方

材料（表 1）を混合した。その後、それらを沸騰させ、弱火で 15 分間加熱した。火を止めた後、プロピオン酸とエタノール 6.5ml に p-ヒドロキシ安息香酸ブチルを 6.5g 混合した溶液を加えて混合した。混合物を試験管に入れ、一晩室温で静置して試験管内の湿度を下げた。

表 1. 標準培地の成分

水(mL)	270
乾燥酵母(g)	10
コーンフラワー(g)	10
米ぬか(g)	4
グルコース(g)	20
粉末寒天(g)	1.3
プロピオン酸(mL)	1.3
ヒドロキシ安息香酸/エタノール(mL)	1.3

2−1. 飼育方法

約 20 匹のハエを標準培地の入った試験管で飼育した。飼育環境の条件は、温度 23℃、明期 12 時間、暗期 12 時間である。ハエの生活環は約 2 週間のため、約 2 週間後、新しい培地にハエを移した。また、実験装置にハエを移したり、培地にハエを戻したりする際に二酸化炭素を使用した。

2−2. コンディションの確認

キイロショウジョウバエ（*Drosophila melanogaster*）の野生型（Oregon-R）は京都工芸繊維大学のショウジョウバエ遺伝資源センターより入手した。予備実験において、培養したハエを図 1 のような V 字型装置におき、片側に餌を置いてハエの動きを見たところ、全然動かなない、またはエサの方に行かない個体が多く見られ、ハエが餌の匂いによって行動するかどうかの実験ができなかった（表 2）。実験を行う前、ハエを寒天培地に移すことで絶食状態にしているのだが、今回の結果から絶食時間を 1 時間半、4 時間、5 時間、6 時間半、9 時間、24 時間と設定し、同様の実験を行った。その結果、24 時間の絶食時間が最も多く餌の方へと移動した（表 3）。したがって、以降の実験では 24 時間絶食させた個体を用いた。また、各実験においてハエの生育段階を揃えるために実験を行う日の 3~1 日前に試験管にいるハエを全て移し替え、変態後 1 ～ 4 日間の個体のみで実験を行った。さらに各実験においてハエのコンディションを確認するため、毎回、24 時間絶食させた 10 匹以上のハエを V 字型装置（片側にのみエサをおいた状態）のスタート地点におき、7 割以上のハエがエサの方に移動することを確認した。

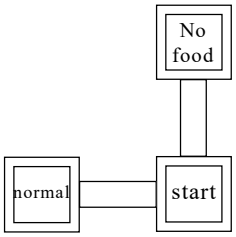

図1. V字型装置

表 2. 絶食時間の実験

	①	②	③	④	⑤	⑥
fasting duration	24h	9 h	6 h 40 min	5 h 15 min	4 h 10 min	1h 35 min
stay	0	7	7	10	11	14
moving	15	6	4	3	2	2
parameter	15	13	11	13	13	16

表 3. 実験結果(コントロール 1)

2023.04.13.16:00	①	②	③	④	total
stay	0	4	3	1	8
nomal	2	1	1	1	5
no food	3	0	1	3	7

表 4.実験結果(コントロール 2)

2023.05.03.14:00	①	②	③	④	total
stay	1	1	0	0	2
normal	4	4	5	5	18
no food	0	0	0	0	0

2−3. 匂い

V 字型の装置の片方に改造した餌（標準の餌から酵母を抜いたもの、プロピオン酸を抜いたもの、酵母とプロピオン酸の両方を抜いたもの）を、もう片方には標準の餌を置き、スタート位置に 5 匹のハエを置いて装置内での行動を観察した（図２）。また、餌からプロピオン酸と酵母を加えた溶液をコットンにしみこませ、装置の片方に置いた。もう一方は水を含ませたコットンを置いた（図３, ４）。本当にハエがそれらの匂いがある方に向かうのかを約 10 分間ビデオを撮って観察した。

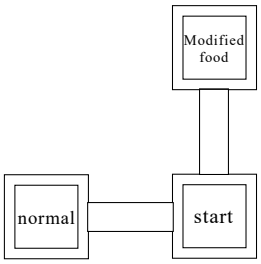

図 2. V 字型装置

2－4. 装置の形

3Dプリンターで作製したV字型またはＩ字型の装置の片方にプロピオン酸と酵母を加えた溶液を染み込ませたコットンを置き、もう一方には水を含ませたコットンを置き、スタート位置に5匹のハエを置いて装置内での行動を観察した。

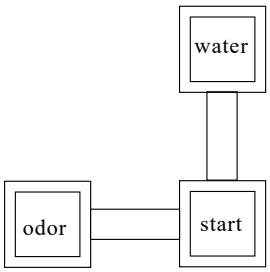

図3. V字型装置

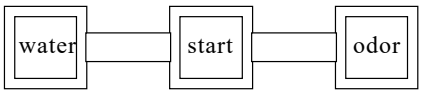

図4. I字型装置

2－5. 雌雄

V 字型の装置の片方に標準の餌を置き、もう片方には何も置かず、スタート位置に5匹のハエを置いて装置内での行動を観察した。その後、実体顕微鏡下で尾部の色の違いによって雌雄を確認した。

2－6. 個体群密度

V 字型の装置にコットンを使った匂いの実験と同様に、片方にプロピオン酸と酵母を加えた溶液を染み込ませたコットン、もう一方に水を含ませたコットンを置き、スタート位置におくハエの数が5匹の場合（同じ試験管で育ったハエ）と、1 匹の場合での実験を行い、行動を観察した。また、異なる試験管で育った5匹のハエをスタート位置に置き、同じ実験を行った。実験後、装置内でのハエの軌跡を動画の上からなぞって書き出した。それらを匂いの部分と水の部分に分け、それぞれのハエの軌跡を ImageJ で測定した。

3. 結果と考察

3－1. 匂い

V 字型の装置の片方に標準の餌、もう片方に酵母を抜いた餌、またはプロピオン酸を抜いた餌を置いて実験したところ、結果にあまり差はなかった。しかし、プロピオン酸と酵母を抜いた餌を置いて実験したところ、25 匹中 22 匹が改造前の餌の方へ向かっていった。コットンを用いた実験でも同様に、40 匹中 30 匹が酵母とプロピオン酸の匂いを染込ませたコットンの方へ向かった。この結果から、ハエが匂いによって餌として認識する物質は、酵母とプロピオン酸であることが示唆された。

表 5. 実験結果(プロピオン酸なし)

2023.04.05.10:00	①	②	③	④	⑤	total
stay	0	3	1	1	2	7
nomal	4	1	2	3	1	11
without propionic acid	1	1	2	1	2	7

表 6. 実験結果(酵母なし)

2023.04.20 14:00	①	②	③	④	⑤	total
stay	1	2	1	1	0	5
nomal	2	2	2	3	5	14
without yeast	2	1	2	1	0	6

表 7. 実験結果(プロピオン酸と酵母なし)

2023.04.21. 16:00	①	②	③	④	⑤	total
stay	0	0	0	0	0	0
nomal	5	4	5	5	3	22
without yeast & propionic acid	0	1	0	0	2	3

表 8. コットンを用いた実験の結果

2023.04.27.16:00 / 2023.04.28.16:00	①	②	③	④	⑤	⑥	⑦	⑧	total
stay	2	1	0	2	1	1	2	0	9
water	0	1	0	0	0	0	0	0	1
yeast & propionic acid	3	3	5	3	4	4	3	5	30

3－2. 装置の形

Ｉ字型の装置を用いて行った実験と V 字型の装置を用いて行った実験では同様の結果が得られた。よって、二つの形の違いは装置内でのハエの行動に影響を及ぼさないことがわかった。Timothy D. Wiggin らの研究ではＶ字型の装置を用いて実験が行われていたので私もＶ字型

の装置を使って実験を行うことにした。

表 9. 実験結果(I 字型)

2023.05.04.14:00 (I)	①	②	③	④	total
stay	1	2	0	2	5
water	0	0	0	1	1
yeast & propionic acid	4	3	5	2	14

表 10. 実験結果(V 字型)

2023.05.04.14:00 (V)	①	②	③	④	total
stay	2	3	0	0	5
water	0	1	0	2	3
yeast & propionic acid	3	1	5	3	12

3－3. 雌雄

それぞれの方向へ向かったハエの数が同じだった実験に用いた個体の雌雄を調べたところ、テスト 1 回目では、雌 4 匹、雄 1 匹、2 回目では雌 1 匹、雄 4 匹だった。これらの結果から雌雄の差が装置内のハエの行動に影響を及ぼさないことがわかった。Tim Tully らによれば、雌雄は影響しないと報告されている。一方、Damien Mercier らの論文では、雄のハエから分泌されるホルモンによってメスやオスが寄ってくることが報告されており、一概に雌雄の影響がないとは言い切れない。しかし、本実験においては、雌雄の差が見られないことから、短時間であれば影響しないと考え、他の実験では雌雄の差を考慮せずに実施した。

表 10. 軌道図(5 匹) N=10

2023.04.20.14:00	①	②	③	④	⑤	total
stay	0	2	1	1	1	5
nomal	5	3	4	4	4	14
no food	0	0	0	0	0	6
sex	M:1 F:4	M:2 F:3	M:4 F:1	M:1 F:4	M:2 F:3	M:10 F:15

M; male　F; female

3－4. 個体群密度

匂いの部分と水の部分を比較すると、ハエは匂いの部分に向かう傾向があることがわかった。また、1 個体だけの実験よりも 5 個体での実験の方が、装置内でより活発に行動していることがわかった。これらから装置内でのハエの動きに密度が関係しているかもしれない。

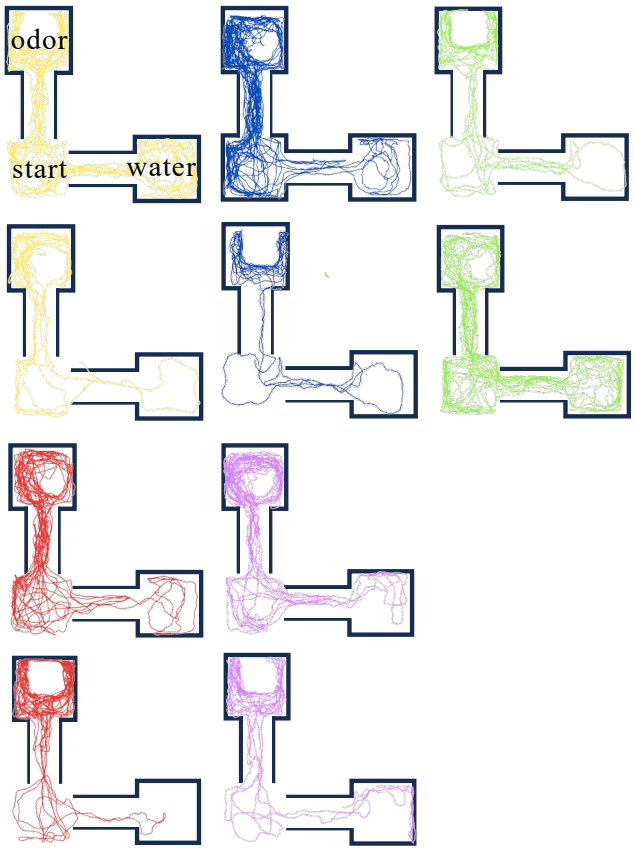

図 5. 軌道図(5 匹) N=10

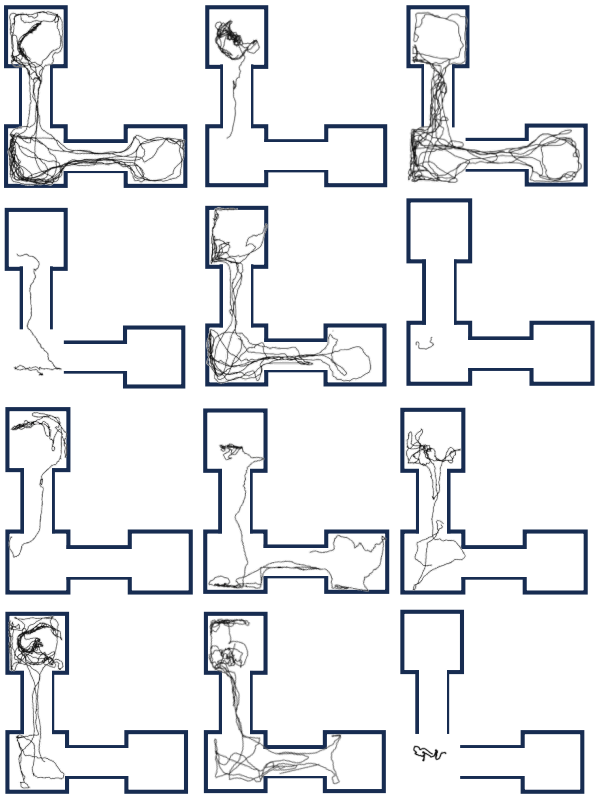

図 6. 軌道図(1 匹) N=12

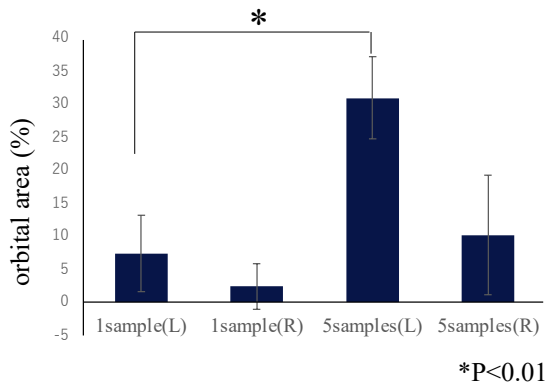

図 7. 滞在率の平均値
(L : odor part, R : water part)

4. 展望

ハエの学習能力が次世代に影響を与えるかどうかを調べる。3-1 の実験結果を用いてハエが匂いの方へ向かうような装置を作る。ハエが餌を求めて匂いがある方へ向かう通路に微量な電流を流し、匂いのある方へ行ってはいけないことを学習させる実験を行う。学習させた個体同士を交配させて生まれたハエと、学習させていない個体同士を掛け合わせて生まれたハエに同じ実験を行い、学習能力の差を測る。

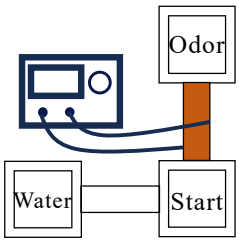

図8. V字型装置

5. 謝辞

この場を借りて、野生型のショウジョウバエを譲渡してくださった京都工芸繊維大学都丸教授、また、培地のレシピを譲渡してくださった大阪大学大学院生命機能研究科甲斐教授には、厚く御礼申し上げます。

6. 引用文献

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Olfactory Influences on Behavior in *Drosophila*

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

The purpose of this study is to better understand how changes in the environment such as smell effect the behavior of Drosophila, and to determine how the parent's ability to learn will affect the next generation. Originally designed V-shaped tracks were made for this experiment to learn how the behavior of flies changes due to the difference in odor of two substances. Drosophila placed in a fasting state were used. It was found that the best fasting time, the fasting time during which Drosophila were most active in the track, was about 24 hours. An experiment was then conducted to determine which substances Drosophila recognize as a food source due to their scent. For this experiment, mediums without yeast, propionic acid, and a combination of both were made from the normal medium. Normal medium in addition to modified different medium was placed at different ends of the V-shaped track and five Drosophila were placed at the starting point. They were observed for approximately 10 minutes. From observations made during this experiment, it is suggested that Drosophila rely on the smell of yeast and propionic acid to get to the medium. The results were confirmed by repeating the experiment using cottons dampened with water and yeast and propionic acid. When the effects of the different sexes on behavior in the apparatus were examined, there was little effect. Therefor an examination of the differences in population density revealed differences in movement within the apparatus.

Keywords: *Drosophila,*

I. Introduction

Drosophila, among many other candidates, were used for this study. That is because they are a model organism. Model organisms are organisms used to study universal life phenomena. There are some reasons why they are used in studies. One reason is that their life cycle is shorter than other organisms. The second reason is that the genome of *Drosophila* is open. In addition to this, there are many mutant *Drosophila*. Because of this, it is possible to choose mutants of *Drosophila* to use based on the research results.

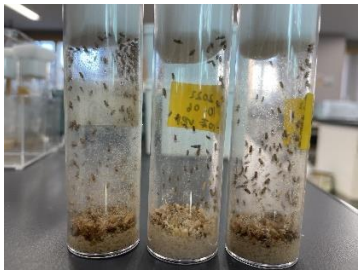


Fig.1 *Drosophila melanogaster* (Oregon-R)

II. Materials and Method

In this experiment, a normal food agar medium, a carbon dioxide bottle, equipment made by a 3D printer, a plastic sheet, an aspirator dish, and cotton were utilized. For the Condition Experiment, normal food was placed at the side of the V-shaped track, followed by placing 5 flies in a fasting state at the starting point. The covered equipment was left in place for 10 minutes, and the scene was recorded to observe the flies' movement towards the normal food. The Odor Experiments involved placing normal food and different types of food at the V-shaped track's tip and dampening cotton with water, yeast, and propionic acid at each end of the track. Five fasting flies were placed at the starting point, and the covered equipment was left for 10 minutes while recording the scene and measuring the flies' movement. Lastly, after the control experiment, flies were narcotized, and their sex was determined using microscopy.

III. Data Analysis

Pre-Experiment

In a preliminary experiment, when flies were placed at the center of the V-shaped track, as shown in Fig. 13 to observe the movement of the flies, many of them did not move at all or did not go toward the medium, making it impossible to test whether the flies acted according to the smell of the food (Table 4). Therefore, similar experiments were conducted with flies fasting for 1.5, 4, 5, 6.5, 9, and 24 hours, and we found that the flies moved toward the food most frequently after the 24-hour fasting period (Table 3). Thus, individuals fasted for 24 hours were used in subsequent experiments.

The flies' conditions were tested to increase the accuracy of the experiment. First, a normal medium was placed on one end of the V-shaped track. Then, 5 flies in a fasting state were placed at the start point. The equipment was then covered and left in place. A video recording of the scene was taken, and the number of flies that moved toward the normal medium was observed for approximately 10 minutes. A good condition was defined as one where at least 70% of all the flies went towards the normal medium. If flies were in good condition, the experiment continued.

Table 1 Fasting time

fasting duration	24 h	9 h	6.5 h	5 h	4 h	1.5 h
stay	0	7	7	10	11	14
moving	15	6	4	3	2	2
parameter	15	13	11	13	13	16

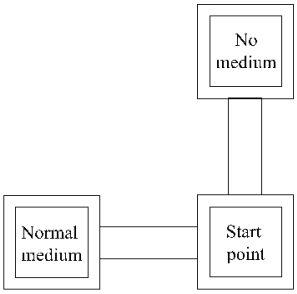


Fig.2 V-shaped track

Table 2 Result of the first control experiment

2023.04.13.16:00	①	②	③	④	total
stay	0	4	3	1	8
nomal	2	1	1	1	5
no food	3	0	1	3	7

Table 3 Result of the second control experiment

2023.05.03.14:00	①	②	③	④	total
stay	1	1	0	0	2
normal	4	4	5	5	18
no food	0	0	0	0	0

Odor Experiment 1 - Method

The purpose of this experiment is to know what odor from the normal medium is recognized by flies for use in future control experiments. First, the normal medium was placed at one end of the V-shaped track, and one of three different types of medium was placed at the other end. Then, 5 flies in a fasting state were placed at the start point. The equipment was covered and left in place. A video recording of the scene was taken, and the number of flies that moved in either direction was observed for approximately 10 minutes.

Odor Experiment 1 – Results and Discussion

The number of flies that went towards the normal medium was higher when using the medium without yeast than those without propionic acid. It might be that flies perceive propionic acid more easily, but it is difficult to generalize because the number of flies that stayed was different. When the medium without yeast and propionic acid was used, more than 80% of the flies went toward the normal medium. This suggests that the substances flies recognize as a food source due to their scent were yeast and propionic acid.

Table 4 Result of experiment (without propionic acid)

2023.04.05.10:00	①	②	③	④	⑤	total
stay	0	3	1	1	2	7
nomal	4	1	2	3	1	11
without propionic acid	1	1	2	1	2	7

Table 5 Result of experiment (without yeast)

2023.04.20 14:00	①	②	③	④	⑤	total
stay	1	2	1	1	0	5
nomal	2	2	2	3	5	14
without yeast	2	1	2	1	0	6

Table 6 Result of experiment (without yeast and propionic acid)

2023.04.21. 16:00	①	②	③	④	⑤	total
stay	0	0	0	0	0	0
nomal	5	4	5	5	3	22
without yeast & propionic acid	0	1	0	0	2	3

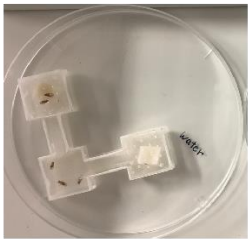


Fig.3 Photo of experiment

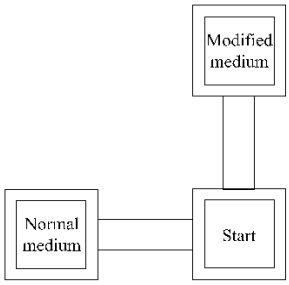


Fig.4 V-shaped track

Odor Experiment 2 – Method

To confirm the results from Experiment 1, an experiment using cotton was conducted. First, cotton was cut and put at the ends of the V-shaped track. Then, the pieces of cotton were permeated with either water or extracted yeast solution and propionic acid. Then, 5 *Drosophila* in a fasting state were placed at the starting point. The equipment was covered and left. A video recording of the scene was taken, and the number of flies that moved in either direction was observed for approximately 10 minutes.

Odor Experiment – Results and Discussion

75% of flies went toward the cotton with yeast and propionic acid. Only one fly went toward the cotton with water. This result confirmed the findings from Experiment 1.

Table 7 Result of experiment with cotton

2023.04.27.16:00 / 2023.04.28.16:00	①	②	③	④	⑤	⑥	⑦	⑧	total
stay	2	1	0	2	1	1	2	0	9
water	0	1	0	0	0	0	0	0	1
yeast & propionic acid	3	3	5	3	4	4	3	5	30

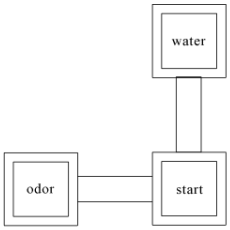


Fig.5 V-shaped track

IV. Conclusion

Analysis on the Affect of Equipment

Similar results were obtained in the experiments conducted using the I-shaped track and those conducted using the V-shaped track. Therefore, it was found that the difference between the two types of equipment did not affect the behavior of the flies on the track. The V-shaped track was used in this experiment since it was also used in the study by Timothy D. Wiggin et al.

Analysis on the Relationship Between the Sex of Flies and Their Movement

To determine the relation between sex and the movement of flies in the track, after the control experiment, flies were narcotized and divided into male and female flies using

microscopy. In Trials, ① and ③, the number of flies that went toward the normal medium was almost the same, but the number of males and females was the exact opposite. In Trials ② and ⑤, there was little difference in the number of females and males. In other words, there was no difference in behavior between the sexes.

Table 8 Result of experiment with **I-shaped track**

2023.05.04.14:00 (I)	①	②	③	④	total
stay	1	2	0	2	5
water	0	0	0	1	1
yeast & propionic acid	4	3	5	2	14

Table 9 Result of experiment with **V-shaped track**

2023.05.04.14:00 (V)	①	②	③	④	total
stay	2	3	0	0	5
water	0	1	0	2	3
yeast & propionic acid	3	1	5	3	12

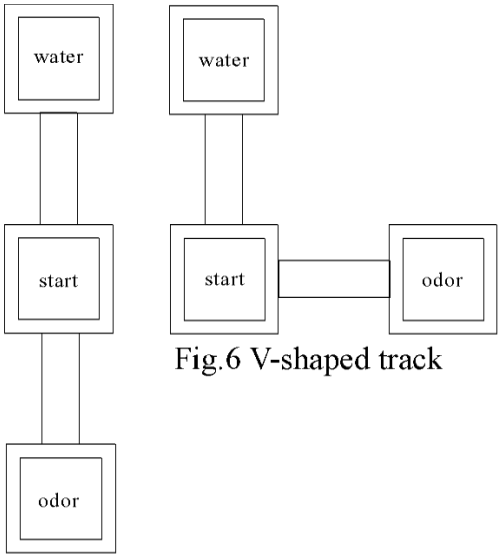


Fig.6 V-shaped track

Fig.7 I-shaped track

Table 10 Number of female and male

2023.04.20.14:00	①	②	③	④	⑤	total
stay	0	2	1	1	1	5
nomal	5	3	4	4	4	14
no food	0	0	0	0	0	6
sex	M:1 F:4	M:2 F:3	M:4 F:1	M:1 F:4	M:2 F:3	

M; male F; female


Fig. 8 Picture of *Drosophila*

Analysis on Population Density

To see if population density affects movement within the track, the following analysis was conducted. The flies' trajectories were taken in the tracks and divided into two parts (the odor part and the water part), and the area of their trajectories was measured using ImageJ. Comparing

the area with the odor and the area with water, it was found that the flies were more attracted to the area with the odor. The results also show that the five individual flies in the experiment were more active on the track than those with only one fly.

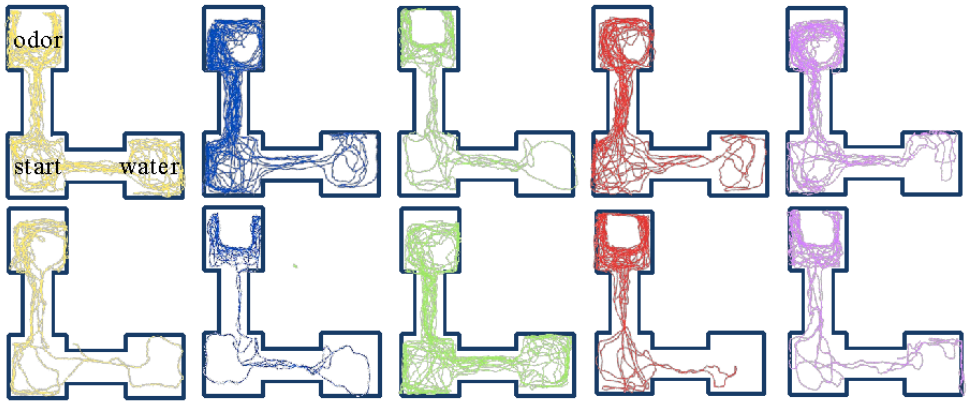


Fig. 9 Orbital map (5 flies density) N=10

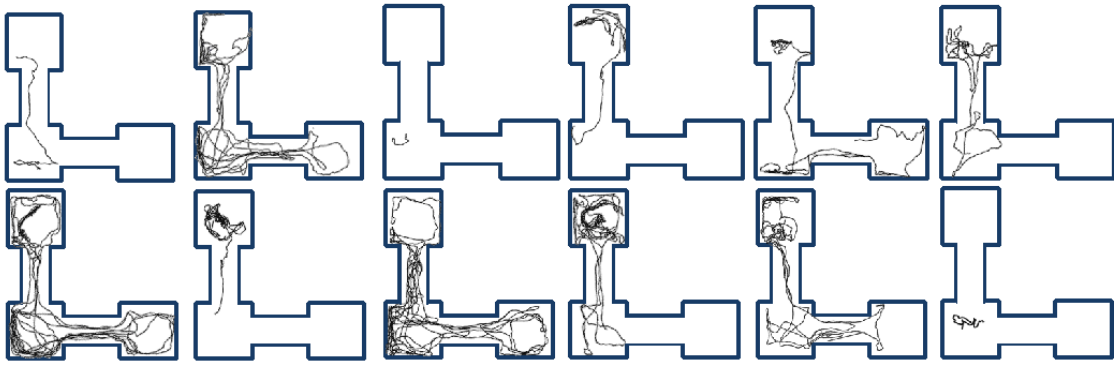
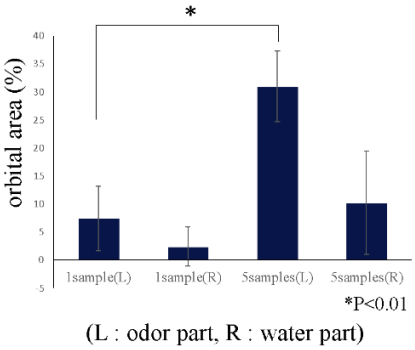


Fig. 10 Orbital map (1 fly density) N=12



(L : odor part, R : water part)

Fig. 11 Average of destination stay rate

V. Future Research

To determine if the growing medium does not contain yeast and propionic acid but still moves toward the yeast and propionic acid odor, the following three processes will be carried out: (1) Flies will be grown in the medium without yeast and propionic acid. (2) The same experiment as Experiment 2 will be conducted using flies generated on the medium without yeast and propionic acid. (3) They will be compared with those raised on a normal medium.

To determine if the behavior of the flies in Experiment 2 was due to odor by using mutants. The same experiment as Experiment 2 will be conducted using mutants. The results from using mutants will then be compared with those raised on a normal medium.

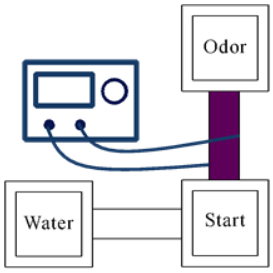


Fig. 12 V-shaped track

Finally, to determine how the parent's ability to learn will affect the next generation flies will be trained to head toward the odor. The next generation of trained flies will then be used to determine how their behavior differs from the next generation of untrained flies.

VI. Acknowledgements

I would like to express my appreciation to Dr. Masatoshi Tomaru and the KYOTO Drosophila Stock Center for providing Drosophila of the Oregon-R line for this research project. I would like to take this opportunity to thank Professor Kai of the Graduate School of Frontier Biosciences at Osaka University for providing the recipe for the culture medium.

VII. References

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Olfactory Influences on Behavior in *Drosophila*

Ritsumeikan High School

ABSTRACT

The purpose of this study is to better understand how changes in the environment such as smell effect the behavior of *Drosophila*, and to determine how the parent's ability to learn will affect the next generation. Originally designed V-shaped tracks were made for this experiment to learn how the behavior of flies changes due to the difference in odor of two substances. *Drosophila* placed in a fasting state were used. It was found that the best fasting time, the fasting time during which *Drosophila* were most active in the track, was about 24 hours. An experiment was then conducted to determine which substances *Drosophila* recognize as a food source due to their scent. For this experiment, mediums without yeast, propionic acid, and a combination of both were made from the normal medium. Normal medium in addition to modified different medium was placed at different ends of the V-shaped track and five *Drosophila* were placed at the starting point. They were observed for approximately 10 minutes. From observations made during this experiment, it is suggested that *Drosophila* rely on the smell of yeast and propionic acid to get to the medium. The results were confirmed by repeating the experiment using cottons dampened with water and yeast and propionic acid. When the effects of the different sexes on behavior in the apparatus were examined, there was little effect. Therefor an examination of the differences in population density revealed differences in movement within the apparatus.

INTRODUCTION

For this study, I decided to use *Drosophila*, among many other candidates. That is because it is a model organism. Model organisms are organisms used to study universal life phenomenon. There are some reasons why they are used in studies. One reason is that their life cycle is shorter than that of other organisms. The second reason is that the genome of *Drosophila* is open. In addition to this, there are many mutant *Drosophila*. Because of this, it is possible to choose mutants of *Drosophila* to use based on the results of this research.

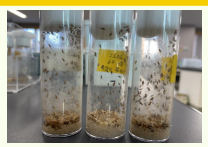


Fig.1 *Drosophila melanogaster* (Oregon-R)

MATERIAL

NORMAL MEDIUM

Table 1 Components of medium

water (mL)	270
yeast (g)	10
corn flour (g)	10
rice bran (g)	4
glucose (g)	20
agar powder (g)	1.3
propionic acid (mL)	1.3
butyl p-hydroxybenzoate/ethanol (mL)	1.3

AGAR MEDIUM

Table 2 Components of agar medium

agar powder (g)	1
water (mL)	50

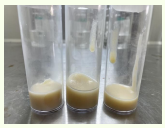


Fig.2 Normal medium

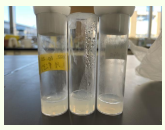


Fig.3 Agar medium

EQUIPMENT

- Carbon dioxide bottle
- Cotton
- Modified food
- Equipment
- Plastic sheet
- Dish
- Aspirator

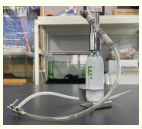


Fig.4 Carbon dioxide bottle

Fig.5 Cotton

Fig.6 Modified medium

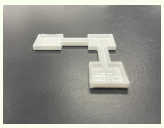


Fig.7 Equipment

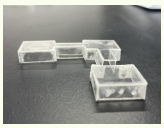


Fig.8 Plastic cover

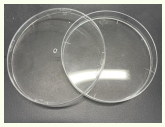


Fig.9 Dish

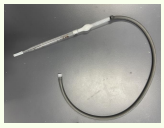


Fig.10 Aspirator

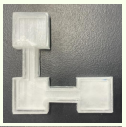
NORMAL MEDIUM

First, the materials (water, corn flour, sugar, yeast, agar powder) were measured, mixed, and made into a liquid. Next, they were heated until boiling. Once boiling, the mixture was heated over low heat for 15 minutes. After turning off the heat, the propionic acid and butyl p-hydroxybenzoate/ethanol were added and mixed. The mixture was then placed in test tubes and left overnight to decrease the humidity of the test tube.

Fig.11 Making the medium

Flies

About 20 flies were placed in test tubes containing the medium. The environmental conditions were managed to maintain temperatures under 23℃ with 12 hours of dark and 12 hours of light. After about two weeks, the next generation was born, and it was transferred to a new medium. Carbon dioxide was used as a means of transfer.



EQUIPMENT

A blueprint for a track was drawn up using Tinkercad and printed out using a 3D printer. Two types of equipment were made. A cover was made for the equipment by cutting a piece of plastic sheet to fit the equipment. The cover was removable.

Fig.12 3D printed tracks

CONDITION

First, flies that were metamorphosized were placed in the fasting state after two days. Subsequently, from among these flies, active flies climbing up the test tube were chosen for use in experiments.

PRE-EXPERIMENT

CONTROL

To increase the accuracy of the experiment, the flies' conditions were tested. First, normal medium was placed one end of the V-shaped track. Then, 5 flies in a fasting state were placed at the start point. The equipment was then covered and left in place. A video recording of the scene was taken and the number of flies that moved toward the normal medium was observed for approximately 10 minutes. A good condition was defined as one in which at least 70% of all the flies went towards the normal medium. If the flies were in a good condition, the experiment was continued.

Table 3 Result of the first control experiment

2023.04.13.16:00	①	②	③	④	total
stay	0	4	3	1	8
normal	2	1	1	1	5
no food	3	0	1	3	7

Table 4 Result of the second control experiment

2023.05.03.14:00	①	②	③	④	total
stay	1	1	0	0	2
normal	4	4	5	5	18
no food	0	0	0	0	0

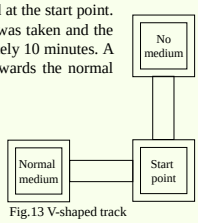


Fig.13 V-shaped track

EXPERIMENT 1

ODOR

METHOD

The purpose of this experiment is to know what odor from the normal medium is recognized by flies for use in future control experiments. First, the normal medium was placed at one end of the V-shaped track, and one of three different types of medium were placed at the other end. Then, 5 flies in a fasting state were placed at the start point. The equipment was covered and left in place. A video recording of the scene was taken and the number of flies that moved in either direction was observed for approximately 10 minutes.

EXPERIMENT 1 (Continued)

RESULT and DISCUSSION

The number of flies that went towards the normal medium was higher when using the medium without yeast than when using one without propionic acid. It might that flies perceive propionic acid more easily, but it is difficult to generalize because the number of flies that stayed were different. When the medium without yeast and propionic acid was used, more than 80% of the flies went towards the normal medium. This suggests that the substances flies recognize as a food source due to their scent were yeast and propionic acid.

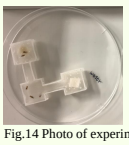


Fig.14 Photo of experiment

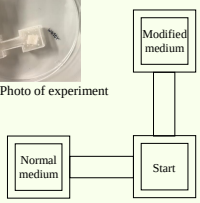


Fig.15 V-shaped track

Table 5 Result of experiment (without propionic acid)

2023.04.05.10:00	①	②	③	④	⑤	total
stay	0	3	1	1	2	7
normal	4	1	2	3	1	11
without propionic acid	1	1	2	1	2	7

Table 6 Result of experiment (without yeast)

2023.04.20 14:00	①	②	③	④	⑤	total
stay	1	2	1	1	0	5
normal	2	2	2	3	5	14
without yeast	2	1	2	1	0	6

Table 7 Result of experiment (without yeast and propionic acid)

2023.04.21. 16:00	①	②	③	④	⑤	total
stay	0	0	0	0	0	0
normal	5	4	5	5	3	22
without yeast & propionic acid	0	1	0	0	2	3

EXPERIMENT 2

ODOR

METHOD

To confirm the results from Experiment 1, an experiment using cottons was conducted. First, cotton was cut and put at the ends of the V-shaped track. Then, the pieces of cotton were permeated with either water or extracted yeast solution and propionic acid. Then, 5 Drosophila in a fasting state were placed at the starting point. The equipment was covered and left. A video recording of the scene was taken and the number of flies that moved in either direction was observed for approximately 10 minutes.

RESULT and DISCUSSION

75% of flies went toward the cotton with yeast and propionic acid. Only one fly went toward the cotton with water. This result confirmed the findings from Experiment 1.

Table 8 Result of experiment with cotton

2023.04.27.16:00 / 2023.04.28.16:00	①	②	③	④	⑤	⑥	⑦	⑧	total
stay	2	1	0	2	1	1	2	0	9
water	0	1	0	0	0	0	0	0	1
yeast & propionic acid	3	3	5	3	4	4	3	5	30

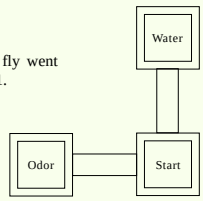


Fig.16 V-shaped track

ANALYSIS

POPULATION DENSITY

To see if population density affects movement within the track, the following analysis was conducted. The flies' trajectories were taken in the tracks, divided into two parts (the odor part and the water part), and the area of their trajectories was measured using imageJ. Comparing the area with the odor and the area with water, it was found that the flies were more attracted to the area with the odor. The results also show that the five individuals in the experiment were more active in the track than those in the experiment with only one individual.

Fig.17 Orbital map (5 flies density) N=10

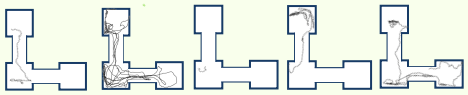
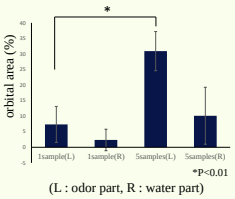


Fig.18 Orbital map (1 fly density) N=12



(L : odor part, R : water part)

Fig.19 Average of destination stay rate

FUTURE PLAN

I To determine if the growing medium does not contain yeast and propionic acid, but still moves toward to the yeast and propionic acid odor.
1. Flies will be grown in the medium without yeast and propionic acid.
2. The same experiment as Experiment 2 will be conducted using flies generated on the medium without yeast and propionic acid.
3. They will be compared with those raised on normal medium.

II To determine if the behavior of the flies in Experiment 2 was due to odor by using mutants.
1. The same experiment as Experiment 2 will be conducted using mutants.
2. They will be compared with those raised on normal medium.

III To determine how the parent's ability to learn will affect the next generation
1. Flies will be trained to head in the direction of the odor.
2. The next generation of trained flies will be used to determine how their behavior differs from the next generation of untrained flies.

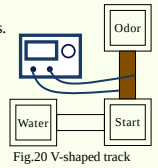


Fig.20 V-shaped track

ACKNOWLEDGMENTS

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カビの抑制に影響を及ぼす物質について

要旨

賞味期限を超えた食パンに生えたカビを見たことから,カビの発生の抑制に影響を与える物質に興味を持った。食パンと擦りおろしニンニクや練りわさびを容器に入れて一定期間,観察した結果,擦りおろしニンニクにはカビの抑制効果が認められた。現在,ニンニクの成分であるアリシンに着目し,様々な条件によりカビの抑制について研究をおこなっている。

1. 背景

中学 3 年生の頃,賞味期限が切れた食パンはどのくらい日が経てばカビが生えてくるのか,生えないようにするにはどのような工夫が必要なのか気になり,「カビの発生と抑制　食パンを利用して」という実験をおこなった。そのことがきっかけとなり,カビの探究活動を続け,以前考察することができなかった,カビの抑制の原因の解明について取り組むことにした。本研究の目的は,「食パンに生えるカビの抑制に影響を及ぼす物質の解明」である。

2. 方法

2－1. 試料

本研究は,食パン(Pasco『超塾』5 スライス入り)をカビの培地とし,サンプル(アメリカ産擦りおろしニンニク,練りわさび,レモン)を利用して,カビの発生の有無を確認した。

2－2. 実験方法

(手順 1)　培地の作成

食パンを 1 スライス用意し,食パンの耳を除き,食パン本体に手が触れないように，ピンセットと果物ナイフを使い，6 つの正方形サイズの食パン(4 cm×4 cm)に切り分け，霧吹きで水を 2 回程度(約 3 mL)かけ，空気に 20 秒程度触れさせた。

(手順 2)　3D プリンターでの台の作成

食パンとビーカーの大きさに対応させた台のパーツを 3D プリンターで作成し,組み立てた(図 1)。この台は,予備実験で使用していた厚紙で作った土台が食パンの重さに耐えられず,不安定であり,かつ食パンと土台に接着面があったことから,食パンの全ての面が空気に触れるように柱を作った。また,食パンの形が安定するようにアルミホイルケースを入れるスペースを確保しながら 2 本足で台を立たせた。

(手順 3)　組み立て

(手順 1)の食パンを,(手順 2)で製作した台にスタンプを押す時のように押し込み,食パンを手で触らないようにポリエチレン手袋を使い,組み立て,底面が 4 cm 程度のアルミホイルケースを小さくして,500 mL ビーカーの中に入れた(図 2)。また,食パンと台がくっついたものの下の空間にアルミホイルケースが収まるようにした(図 3)。そして,そのアルミホイルケースの中に様々なサンプルを入れた。

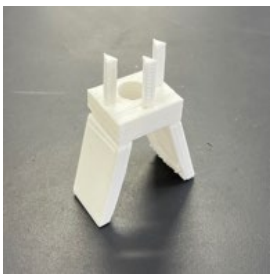


図 1. 3D プリンターで制作した台

図 2. 密閉した容器

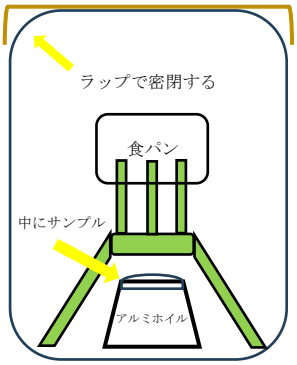


図 3. 模式図

2−3. アリシン溶液の調整方法

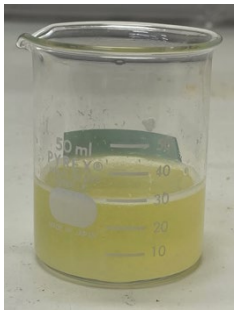
アリシン溶液はニンニクから抽出ができるアリイナーゼ酵素液をアリイン溶液に作用させて製作できる。まず,剥きニンニク 450 g を乾燥させ,粉末状にして,80%メタノールを用いて撹拌抽出を 24 時間×3 回おこなった。その後,真空ポンプを利用して減圧濃縮をおこない,250 mL ほどのアリイン溶液を製作した。

次に,ニンニクを 10 g 磨砕し,イオン交換水を用いて 100 mL で浸出した。それを 3000 rpm,2 分間で遠心分離をおこない,上清液をとり,沈澱物を確認した。その沈澱物をさらにイオン交換水を用いて 100 mL で浸出したものを pH 4 に調整した。これらのことを 2 回繰り返し,沈澱物を細かくしていった。最終的に抽出できた沈澱物を PBS(リン酸緩衝液)10 mL に溶解し,他の雑菌が生えないようにするためにトルエンを 2 滴ほど落とし,これをアリイナーゼ酵素液とした。

制作したこれらの溶液をアリイン溶液 1 mL につきアリイナーゼ酵素液 0.5 mL を反応させ,アリシン溶液と推測できるものを調整した(図 4(a)〜(c))。

(a) アリイン溶液

(b) アリイナーゼ酵素液



(c) アリシン溶液

図 4. アリシン溶液製作各種調整溶液

3. 結果と考察

3−1. 実験 1

〈結果〉

サンプルには身近にある匂いのきつい物質である。レモン(生のレモンをくし切りしたもの),擦りおろしニンニク,練りわさび(チューブ)を使用し,これらをアルミホイルケースの中に入れ,室温(25℃)で 2 週間観察をおこなった。

結果は以下の図 5〜8 のようになった。図 5,6 においては,カビは生えており,図 7,8 においてはカビの発生が抑制されていた。

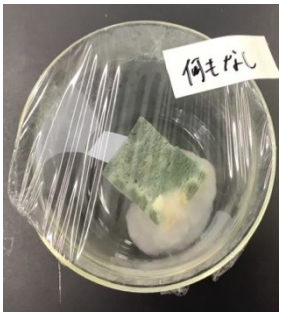


図 5. 何もなし

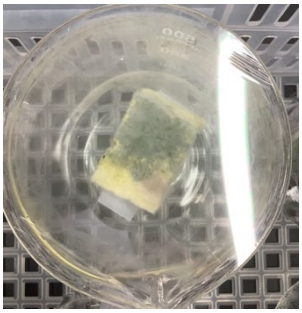


図 6. レモン

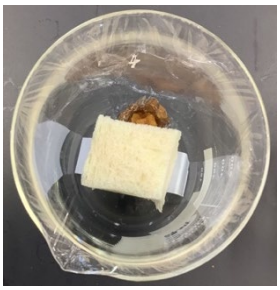


図 7. 擦りおろし
ニンニク

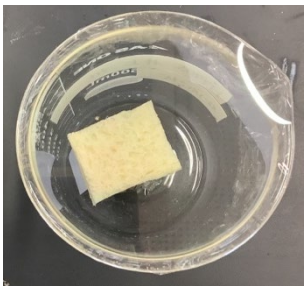


図 8. 練りわさび

〈考察〉

擦りおろしニンニクと練りわさびを入れたビーカーの食パンは,他のものと同じ状況であったにも関わらず,一つもカビが生えていないことがわかった。また,レモンを入れた食パンは,異常な量のカビが生え,黄色くなっているのがわかった。何も入れていない食パンには,緑色をした青カビが生えていた。今回の実験は匂いがカビの抑制に影響を及ぼすのではないかと考え,おこなったものであったため,レモンを入れた食パンにだけカビが生えたことには少し疑問を持った。レモンは果物の中でクエン酸含有量が 1 番多いと知られているので,生レモンの果実自体を置くのではなく,レモンを絞ってレモン汁の状態をサンプルとすれば,カビを抑制できたのではないかと考える。

この実験で一つもカビが生えていなかった擦りおろしニンニクを入れたビーカーの食パンと,練りわさびを入れたビーカーの食パンは,引き続き観察することにした。

擦りおろしニンニクと練りわさびについて,同じ実験を異なる時期で,同じ条件でいくつかおこなった。すると,2 週間後の食パンの様子は,また同じように一つもカビが生えていなかった。

これらのことから,「擦りおろしニンニク」と「練りわさび」にはカビの発生を抑制する効果があると示唆できる。

3−2. 実験 2

〈結果〉

実験 1 の結果から,サンプルの状態を変化させても,カビの発生の抑制効果は続くのかが気になり,状態を変化させやすいニンニクで実験をおこなうことにした。一つは,果物ナイフで内側に深さ 6 ㎜,長さ 7㎜ 程度の切り傷をいれたニンニクを使用し,もう一つは,ホットプレートで 5 分ほど熱を加えた擦りおろしニンニクを使用し,室温(25℃)で 2 週間観察をおこなった。

結果は以下の図 9,10 のようになった。図 9,10 ともにカビが生えていた。

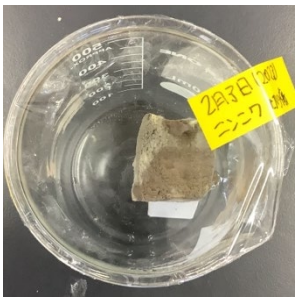


図 9. 傷をつけた
ニンニク

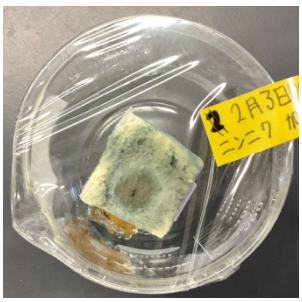


図 10. 熱を加えた
擦りおろし
ニンニク

〈考察〉

2 週間後の食パンの様子を見てみると,図 8 の傷をつけたニンニクや,図 9 の熱を加えた擦りおろしニンニクは,擦りおろしたニンニクとは異なり,カビが生えていた。これは,図 11 のニンニクの防カビ効果の仕組みが原因である。ニンニクには,アリシンという『揮発性抗菌成分』が含まれており,その成分はアリインという無臭の非タンパク質性アミノ酸が,ニンニクを擦りおろすことに

よって発生するアリイナーゼという酵素によって活性化されてできるものである。

つまり，実験 2 では，傷をつけたニンニクは，擦りおろしていないので，アリイナーゼが発生しなかったため，アリインが活性化されず，また，熱を加えた擦りおろしニンニクは，熱によって成分が失活し，カビの抑制効果がなくなったからだと考

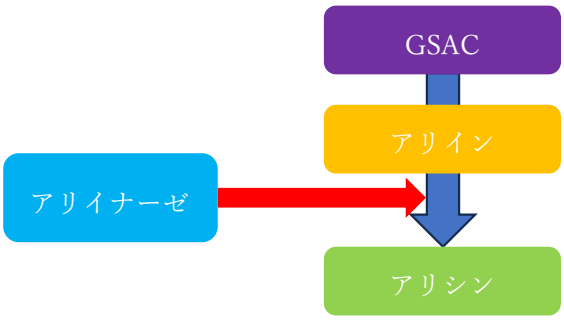


図11. ニンニクの防カビ効果の仕組み

えられる。

3－3. 実験 3

〈結果〉

実験 2 の結果から，ニンニクの状態を変化させるとカビが発生することがわかった。このことに関して調査した結果，ニンニクのカビの抑制効果には『揮発性抗菌成分』であるアリシンが関係していることがわかった。そこで，上記の 2-3 の方法でアリシン溶液の製作に取り掛かった。

製作したものをアリシン溶液と判断するためにアリイナーゼ酵素液の製作途中で取り出したニンニクの上清液と比較し，室温(25℃)で 2 週間観察をおこなった。

結果は以下の図の 12, 13 のようになった。
図 12, 13 ともにカビが生えていた。

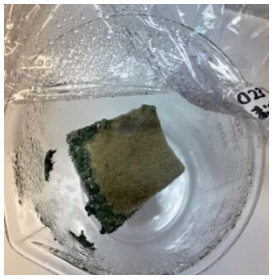


図 12. ニンニクの上清液

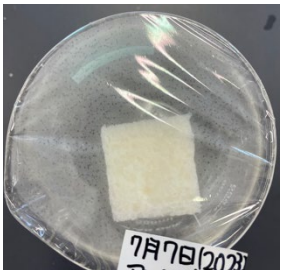


図 13. アリシン溶液

〈考察〉

2 週間後の食パンの様子を見てみると，アリシン溶液を入れたビーカーの食パンにはカビが一つも生えていなかった(図 13)。これはアリシンが食パンに生えるカビに対して，揮発性抗菌成分として反応したと示唆できる。また，ニンニクの上清液を入れたビーカーの食パンにはカビが生えていたが，この上清液はアリイナーゼ酵素液を製作する際に取り出したものであるので，ニンニクから取り出したものであったとしても抗菌成分がほとんど含まれていないものであったため，カビの発生が抑制されなかったのだと考えられる。さらに，アリインについて詳しく調査した結果，アリイン自体にも抗菌作用があることがわかった。しかし，アリイナーゼによって活性化されたアリシンと比べると，抗菌力は劣るものである。現在，それらを比較するために，アリイン溶液のみをサンプルとした実験をおこなっている。

4. 展望

これまでの実験を通して，ニンニクに含まれる揮発性抗菌成分であるアリシンがカビの発生の抑制に影響を及ぼしているということがわかった。しかし，今回のどの実験も室温(25℃)でおこなっていたため，アリシンの耐熱性について探究できていないことがわかる。アリシンは高い反応性と低い熱安定性があることが知られている(Ref. 4)。この先行研究から真空凍結乾燥ニンニクの抗菌活性は 80℃で 20 分以上加熱すると失活し，これは生ニンニクでも同様の現象が起こることが認められている。

このことから，今回の実験で製作したアリシン溶液を，0℃, 50℃, 80℃, 100℃の 4 通りで一定時間加熱し，カビの抑制効果が持続するのかを検証していく。また，アリシンの抑制効果には特有の匂いが影響していると考えられるので，温度変化によって，この匂いを取り除きつつ，カビの抑制を抑えつつ、機能する防腐剤を製作していこうと考えている。

5. 参考文献

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Ref.2　津野貞子　(1958)「ニンニク属植物の栄養的価値に関する研究：(XVI) ニンニク属植物中の Alliinase について」,ビタミン 14 巻,p659-664

Ref.3　ニンニクと健康(日本薬学会　環境・衛生部会)
URL
https://bukai.pharm.or.jp/bukai_kanei/topics/topics59.html

Ref.4　樋口智之,木村誠也　(2021)「様々な温度で加熱した真空凍結乾燥ニンニクにおける抗菌活性の耐熱性に関する研究」,日本冷凍空調学会論文集 38 巻 3 号,p243-249

Substances Affecting Mold Suppression

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

The objective of this research is to find the substances that affect the suppression of mold growing on bread. The bread was placed in a container with lemon, grated garlic, and wasabi paste, all of which had a strong odor, and observed for about two weeks. Later, focusing on allicin, a component of garlic, an experiment was conducted on mold suppression by comparing two garlic samples. One sample contained a clove of garlic cut, and the other was grated, then heated. The results showed that allicin, a volatile antimicrobial component in garlic, affected the inhibition of mold growth. From there, the focus shifted to elucidating the mechanism of the inhibitory effect of allicin on mold. Alliin was extracted from American peeled garlic and added to an alliinase enzyme solution to make an allicin solution. Future research should focus on the thermostability of allicin, concentrating on the variation of its inhibitory effect with temperature change.

Keywords: mold, growth suppression, lemon, garlic, wasabi, allicin

I. Introduction

In the third grade of junior high school, curiosity arose about the duration it took for mold to grow on expired bread and the measures required to prevent mold growth. An experiment titled "Mold Development and Control Using Bread" was conducted then. The experiment led to a desire to investigate mold further. The objective shifted to studying the causes of mold suppression, an aspect that had not been explored before.

II. Materials and Method

Materials

One slice of bread, water, atomizer, aluminum foil, wrap, 500 mL beaker, lemon, grated garlic, wasabi paste (tube), fruit knife, 3D printer, and polyethylene gloves were used.

Method

First, a slice of bread was prepared, and polyethylene gloves were worn to prevent direct contact with the bread. The bread was then cut into six squares, removing the crust. The squares were sprayed with water using an atomizer twice and left to air for 20 seconds.

Second, parts of the platform corresponding to the size of the bread and beaker were made using a 3D printer and assembled (Fig. 1).

Third, the bread from the first step was pressed into the stand made in the second step as if it was stamped, and then assembled using polyethylene gloves to prevent touching the bread with hands, and a small aluminum foil case with a base of about 4 cm was placed inside a 500 mL beaker (Fig. 2). The aluminum foil case was placed in the space under the beaker (Fig. 3). Various samples were placed in the aluminum foil case.

Fig.1 3D printed platform

Fig.2 Sealed container

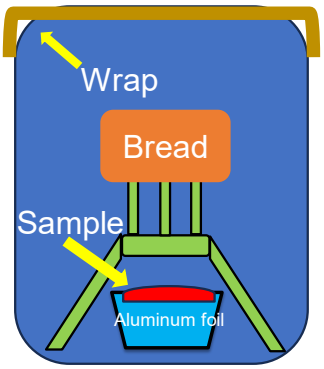


Fig.3 Schematic diagram

III. Data Analysis

Experiment 1

Lemon (fresh lemon cut into wedges), grated garlic, and wasabi paste (from a tube) was used. These were placed in aluminum foil and observed at room temperature (25°C) for two weeks. The results are shown in Figure 4.

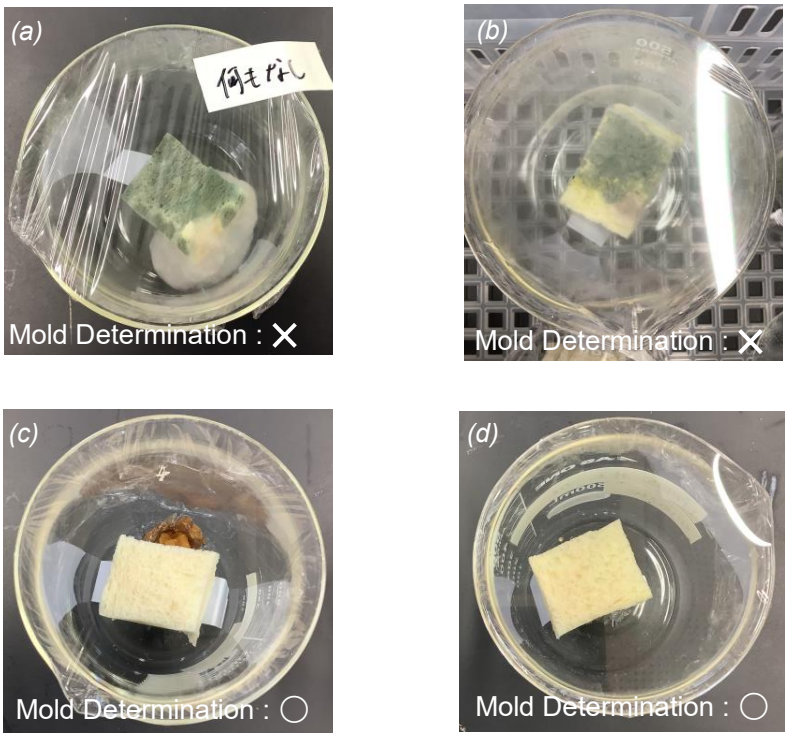


Fig.4 Bread after two weeks [*(a) Nothing (b) Lemon (c) Grated garlic (d) Wasabi paste*]

Mold Determination : Moldy…. ✕, Completely mold free…. ◯

Experiment 2

This experiment focused on whether the inhibitory effect of mold development persists when the state is changed. Another experiment was conducted with garlic, which can easily change its state. The results are shown in Figures 5 and 6.

Fig.5 A clove of garlic with small cuts

Fig.6 Heated grated garlic

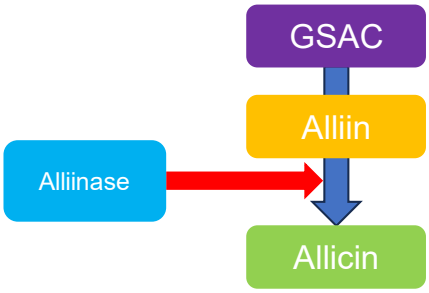
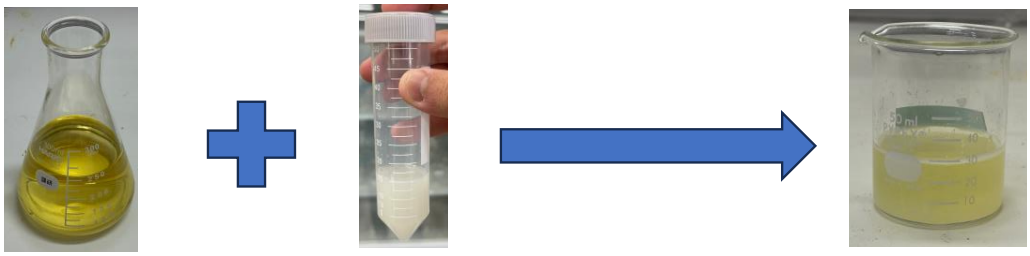


Fig.7 Mechanism of garlic's anti-mold effect

Experiment 3

From the results of Experiment 2, it was found that allicin, a "volatile antimicrobial ingredient," was responsible for the inhibitory effect of garlic on mold, so an allicin solution was made.



Alliin solution *Alliinase enzyme solution* *Allicin solution*

Fig.8 Produce of Allicin solution

To make the alliin solution, 450 g of American peeled garlic was dried, powdered, and stirred in 80% methanol for 24 h, This was done three times. The extract was then concentrated under reduced pressure using a vacuum pump. For the alliinase enzyme solution, 10 grams of garlic were ground, repeatedly centrifuged at 3000 rpm for 2 minutes, and the supernatant

solution was collected. The sediment was finely divided, the pH was adjusted to 4, and after the third centrifugation, 10 mL of PBS was dissolved in the sediment, and two drops of toluene were added to prevent bacterial contamination. The allicin solution was created using 0.5 mL of alliinase enzyme solution per 1 mL of alliin solution. The following experiment was conducted to confirm this. After two weeks, the bread in the beaker with the allicin solution did not have any mold growth (Figure 10).

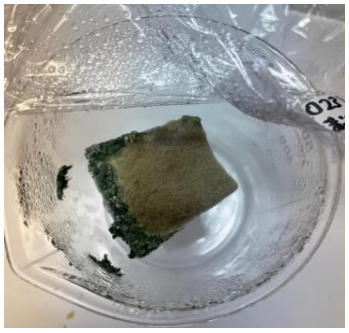


Fig.9 Garlic supernatant

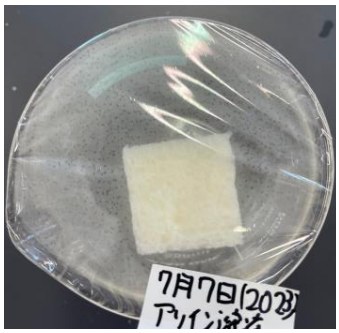


Fig.10 Allicin solution

IV. Discussion

Experiment 1

From the results of Experiment 1, it was found that none of the bread in the beaker with grated garlic and wasabi paste had mold, even though they were under the same conditions as the others. The bread in the beaker with grated garlic and the bread in the beaker with wasabi paste, both of which had no mold growth in this experiment, continued to be monitored. The same experiment was conducted with grated garlic and kneaded horseradish at different times and under the same conditions. Two weeks later, the bread was again free of any mold. These results suggest that grated garlic and wasabi paste had an inhibitory effect on mold growth.

Experiment 2

After two weeks, the bread was found to be moldy, as was seen in Fig. 5 and Fig. 6. This is due to the mechanism of garlic's anti-mold effect. Garlic contains allicin, a "volatile antimicrobial ingredient" formed when alliin is activated by the alliinase enzyme, produced when garlic is grated. Also, GSAC is the foundation of garlic's anti-mold effect. In other words, in Experiment 2, the cut garlic was not abraded, so alliin was not activated because alliinase was not generated. The grated garlic that was heated was inactivated by the heat, so it lost its mold-inhibitory effect.

Experiment 3

It is thought that the garlic supernatant contained little or no antimicrobial components.

V. Conclusions

In these experiments, it was discovered that grated garlic and kneaded horseradish act as substances inhibiting mold. Additionally, it was observed that without rubbing it down, the mold inhibitory effect cannot be attained for garlic. Furthermore, allicin, a volatile antimicrobial component in garlic, was successfully extracted.

VI. Future Research

Through previous experiments, it was found that allicin, a volatile antimicrobial ingredient in garlic, affected the inhibition of mold growth. However, since all the experiments were conducted at room temperature (25℃), the thermostability of allicin has not been explored. Future research should find the thermostability of antimicrobial activity in garlic. Furthermore, to produce a preservative that does not give off any other odor using garlic by reducing the unique odor of allicin while maintaining its mold suppression effect.

VII. Acknowledgements

I would like to take this opportunity to thank Mr. Satoshi Yanagiya, Dr. Mie Ichikawa, and Dr. Noriyuki Matsuura for their accurate advice.

VIII. References

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津野貞子 [Tuno Sadako] . (1958). ニンニク属植物の栄養的価値に関する研究:(ⅩⅥ)ニンニク属植物中の Alliinase について [Studies on the Nutritional Value of Garlic Plants: (XVI) Alliinase in Garlic Plants], ビタミン 14 巻 [Vitamins, vol. 14.], p659-664

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Substances Affecting Mold Suppression

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JSSF JAPAN SUPER SCIENCE FAIR 2023

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Abstract

The objective of this research is to find the substances that affect the suppression of mold growing on bread. The bread was placed in a container with lemon, grated garlic, and wasabi paste, all of which have a strong odor, and observed for about two weeks. Later, focusing on allicin, a component of garlic, an experiment was conducted on mold suppression by comparing two samples of garlic. One sample contained a clove a garlic that was cut and the other was grated, then heated. The results showed that allicin, a volatile antimicrobial component in garlic, had an effect on the inhibition of mold growth. From there, the focus shifted to elucidating the mechanism of the inhibitory effect of allicin on mold. Alliin was extracted from American peeled garlic an added to an alliinase enzyme solution to make an allicin solution. Future research should focus on the thermostability of allicin, concentrating on the variation of its inhibitory effect with temperature change.

Introduction

When I was in the third grade of junior high school, I was curious about how long it took for mold to grow on expired bread and what kind of measures were needed to prevent mold from growing, so I conducted an experiment titled "Mold Development and Control Using Bread". This experiment led me to want to investigate mold further. I wanted to study the causes of mold suppression, something which I had not been able to do before.

Materials & Method

〈Materials〉

one slice of bread, water, atomizer, aluminum foil, wrap, 500 mL beaker, lemon, grated garlic, wasabi paste (tube), fruit knife, 3D printer, and polyethylene gloves.

〈Method〉

【STEP 1】A slice of bread was prepared, and polyethylene gloves were worn to prevent direct contact with the bread. The bread was then cut into six squares, removing the crust. The squares were sprayed with water using an atomizer twice and left to air for 20 seconds.

【STEP 2】Parts of the platform corresponding to the size of the bread and beaker were made using a 3D printer and assembled (Fig. 1).

【STEP 3】The bread from【STEP 1】was pressed into the stand made in【STEP 2】as if it were stamped, and then assembled using polyethylene gloves to prevent touching the bread with hands, and a small aluminum foil case with a base of about 4 cm was placed inside a 500 mL beaker (Fig. 2). The aluminum foil case was placed in the space under the beaker (Fig. 3). Various samples were placed in the aluminum foil case.

Fig.1 3D printed platform

Fig.2 Sealed container

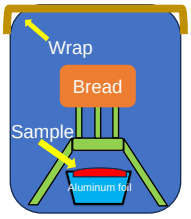


Fig.3 Schematic diagram

Experiment 1

〈Sample〉 Lemon (Fresh lemon cut into wedges), Grated garlic, Wasabi paste(from a tube)

These were placed in aluminum foil and observed at room temperature (25°C) for two weeks.

〈Result & Discussion〉

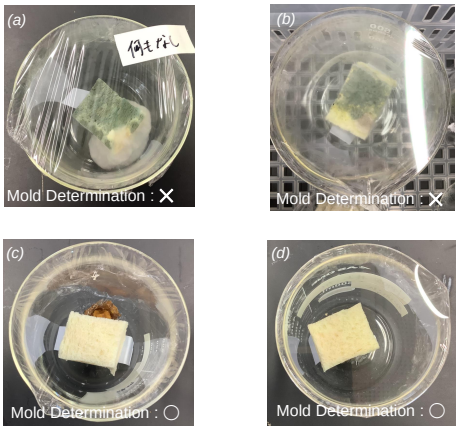


Fig.4 Bread after two weeks 〔(a) Nothing (b) Lemon (c) Grated garlic (d) Wasabi paste〕

Mold Determination : Moldy‥‥✕, Completely mold free‥‥○

From the results of Experiment 1, it was found that none of the bread in the beaker with grated garlic and wasabi paste had mold, even though they were under the same conditions as the others. The bread in the beaker with grated garlic and the bread in the beaker with wasabi paste, both of which had no mold growth in this experiment, were continued to be monitored. The same experiment was conducted with grated garlic and kneaded horseradish at different times and under the same conditions. Two weeks later, the bread was again free of any mold. These results suggest that grated garlic and wasabi paste had an inhibitory effect on mold growth.

Experiment 2

〈Sample〉 This experiment focused on whether the inhibitory effect of mold development persists when the state is changed. Another experiment was conducted with garlic, which can easily to change its state.

〈Result & Discussion〉

Fig.5 A clove of garlic with small cuts

Fig.6 Heated grated garlic

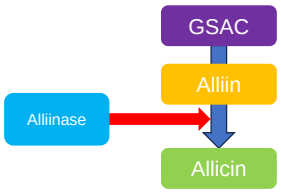
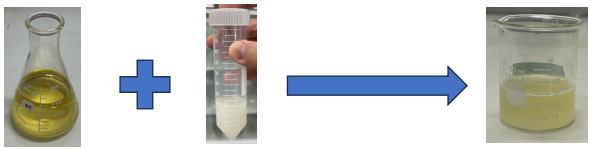


Fig.7 Mechanism of garlic's anti-mold effect

After two weeks, the bread was found to be moldy, as was seen in Fig. 5 and Fig. 6. This is due to the mechanism of garlic's anti-mold effect. Garlic contains allicin, a "volatile antimicrobial ingredient" that is formed when alliin is activated by the alliinase enzyme, which is produced when garlic is grated. Also, GSAC is the foundation of garlic's anti-mold effect. In other words, in Experiment 2, the cut garlic was not abraded, so alliin was not activated because alliinase was not generated, and the grated garlic that was heated was inactivated by the heat, so it lost its mold inhibitory effect.

Experiment 3

From the results of Experiment 2, it was found that allicin, a "volatile antimicrobial ingredient," was responsible for the inhibitory effect of garlic on mold, so an allicin solution was made.



Alliin solution *Alliinase enzyme solution* *Allicin solution*

Fig.8 Produce of Allicin solution

To make the alliin solution, 450 g of American peeled garlic was dried, powdered, and stirred in 80% methanol for 24h, This was done three times. The extract was then concentrated under reduced pressure using a vacuum pump. For the alliinase enzyme solution, 10 g of garlic was ground, centrifuged repeatedly at 3000 rpm for 2 min, the supernatant solution was taken, the sediment was finely divided, adjusted to pH 4, and after the third centrifugation, 10 mL of PBS was dissolved in the sediment and 2 drops of toluene was added to keep bacteria out. The allicin solution was created using 0.5 mL of alliinase enzyme solution per 1 mL of alliin solution. The following experiment was conducted to confirm this.

〈Result & Discussion〉

Fig.9 Garlic supernatant

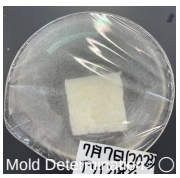


Fig.10 Allicin solution

After two weeks, the bread in the beaker with the allicin solution did not have any mold growth (Fig. 10). It is thought that the garlic supernatant was one that contained little or no antimicrobial components.

Future Plan

Through previous experiments, it was found that allicin, a volatile antimicrobial ingredient in garlic, had an effect on the inhibition of mold growth. However, since all the experiments were conducted at room temperature (25℃), the thermostability of allicin has not been explored. Future research should elucidate the thermostability of antimicrobial activity in garlic using Ref.1 as a prior research.

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❁Ref.1 樋口智之 [Higuchi Tomoyuki], 木村誠也 [Kimura Seiya]. (2021). 様々な温度で加熱した真空凍結乾燥ニンニクにおける抗菌活性の耐熱性に関する研究 [Heated at various temperatures. Study on the thermostability of antimicrobial activity in vacuum freeze-dried garlic], 日本冷凍空調学会論文集38巻3号 [Transactions of the Japan Society of Refrigerating and Air Conditioning Engineers, Vol. 38, No. 3], p243-249

❁Ref.2 津野貞子 [Tuno Sadako] . (1958). ニンニク属植物の栄養的価値に関する研究:(XⅥ) ニンニク属植物中のAlliinaseについて [Studies on the Nutritional Value of Garlic Plants: (XVI) Alliinase in Garlic Plants], ビタミン14巻 [Vitamins, vol. 14.], p659-664

❁Ref.3 山本敬男 [Yamamoto Takeo] et al, (1995), にんにく製品中のアリイン,アリシンの含量について [Alliin and Allicin Content in Garlic Products], 山梨衛公研年報 [Annual Report of the Yamanashi Institute of Public Health], p11-14

アントシアニンを用いた日焼け止めクリームの開発

要旨

この研究は３つの問題を解決することを目的としている。1 つ目は、日焼け止めが及ぼす人体への影響である。2 つ目は、日焼け止めが及ぼす海の生物への影響である。3 つ目は、世界のワイン産業での食品廃棄の問題である。日焼け止めは日常的に多くの人々の体に塗布されており、その成分は皮膚に吸収され、そこには人体に有害な化学物質、たとえば、オキシベンゾンなどが含まれている。また、人々が日焼け止めを塗った後に海に入ると、それらの化学物質が水中に溶けてサンゴや海の生き物に悪影響を及ぼすことも分かっている。一方で、世界のワイン産業では年間 1,200 万トン近くのブドウの搾りかすが廃棄されている、しかし、ブドウの皮にはアントシアニンという色素が豊富に含まれている。アントシアニンは光防御特性があることで知られている。そこで我々は、ブドウの皮のアントシアニンを用いて、食品廃棄の削減ができ、人体に無害で、海の生き物にも悪影響がない、という三つの利点のある日焼け止めを作ろうと考えた。またこの研究はシンガポールの National Junior College との国際共同課題研究である。

1. 背景

市販の日焼け止めにはオキシベンゾンやパラベンなどの有害な成分が含まれている。世界のワイン産業では、毎年 1,200 万トンものブドウの搾りかすが廃棄されている、ブドウの皮にはアントシアニンが豊富で、搾りかすの質量の 50%を占める。ブドウのアントシアニンはデルフィニジン、シアニジン、ペチュニジン、ペオニジン、マルビジンの 3-o-モノグルコシドである（ref.1）。アントシアニンは植物細胞の細胞質内のフラボノイド経路を経由して生成される水溶性の色素で、植物の赤、青、紫の色の原因となる。

光は光合成の主なエネルギー源であるが、強い光の条件下ではアントシアニン細胞の液胞は強い光による光阻害及び抗酸化反応から葉緑体を保護し、過剰な高エネルギー粒子を吸収することによって光による化合物の異化反応を防ぐ。たとえば、ナスでは太陽の光が当たらないヘタの下の部分は青紫色が少し薄くなっている（ref.2）。このことから、アントシアニンの光吸収の特性を利用することで、より安全な日焼け止めクリームを作製できると考えられる。この研究では、ブドウに含まれるアントシアニンを使った日焼け止めを開発することでブドウのアントシアニンの紫外線防御特性を調査した。

2. 方法

2−1. ブドウのアントシアニンからの日焼け止めクリームの作製（日本）

2-1-1. アントシアニンの抽出

ブドウ(*Vitis vinifera*)の皮を剥き、皮を液体窒素(-169℃)で凍結し、乳棒とすり鉢を用いて細かく砕き、アントシアニンの抽出率を高めようとした。これをバイオフリーザーで-20℃で 11

日間保管した後、すりつぶしたブドウの皮と0.1%のHClを質量比2.5:1の割合で混合し、ホットスターラーを使用し、プレート温度を50℃に設定し、2.5時間熱した。その後冷蔵庫(4℃)で保管した。

2-1-2. アントシアニンの精製

2-1-1の液体を桐山ろうと（ADVANTEC No.2）で吸引濾過し、その濾液を遠心分離機で4000 rpmで5分間、6000 rpmで5分間、8000 rpmで30分間遠心分離し,沈殿物を取り除いた。

2-1-3. アントシアニンの定量

ブドウの皮からアントシアニンを抽出した後pH Differential法によりアントシアニンの定量を行った。300 μLのアントシアニン溶液を3 mLのpH 1,4,7の緩衝液とそれぞれ混合し、それらを石英キュベットに入れ、紫外可視分光光度計で測定した。

2−2. クリームとの混合

2-2-1. 水相の調整

アントシアニン抽出液6 g,グリセリン20 gをイオン交換水10 mLと混合し、ホットスターラーで80℃、3分間加熱した。

2-2-2. 油相の調整

ステアリン酸20 gとセチルアルコール4 gを混合し、ホットスターラーで80℃、10分間加熱した。

2-2-3. 相の混合

水相と油相をホットスターラーで80℃、30分間撹拌しながら混合し、pH試験紙でpHが8になるまで、少量のトリエタノールアミンを加えた。

2-3. 日焼け止めの紫外線防護の効果の測定

メチレンブルーの水溶液（濃度は結果2-4参照）に、二酸化チタン0.05 gを加えた。ミニUVトランスイルミネーター(Ultra-Lum, Inc., UVB-10, 300 nm)の上に、4.5 cm × 6.5 cmの長方形の穴を開けたアルミホイルを、穴が紫外線照射範囲の上になるように敷き、その穴の上に、スライドガラス2枚の間にセロハンテープ3枚分の厚さの日焼け止めクリームを挟んだもの（①とする）と、スライドガラスを、日焼け止めクリームを挟まずに2枚重ねたもの（②とする）をUVトランスイルミネーターの上に置いた。酸化チタン、メチレンブルー、イオン交換水の混合液5 mLをバイアルに注ぎ、それを①と②の上に3個ずつ置いた。そしてUVトランスイルミネーターから紫外線を5分間、10分間、15分間照射し、メチレンブルーの溶液の青色がどれ程脱色されたかを確認した。

図1. 紫外線照射の実験の様子

2-4. 2-3 で用いたメチレンブルーの溶液の濃度の定量

2-3で用いた溶液をイオン交換水で2倍希釈したものの吸光度を、紫外可視分光光度計を用いて測定し、それをランベルト・ベールの法則にしたがって、メチレンブルーの溶液のモル濃度

を定量した。

ランベルト・ベールの法則

$$A = \varepsilon cl$$

A=メチレンブルーの吸光度

ε=665 nm でのメチレンブルーのモル吸光係数 91000 L/(mol・cm) (Nishizaka et al. 1993)

c=メチレンブルーのモル濃度

l=セルの長さ(1 cm)

3. 結果と考察

3－1. 緩衝化されたブドウのアントシアニンの抽出液について

アントシアニンは pH によって構造が変化し、その構造に応じて光の吸収波が変化する。図 3～7 の通り、pH 1,4,7 で吸収スペクトルが変化することから、抽出液がアントシアニンであると判断した。pH 1,4,7 に緩衝化されたアントシアニン溶液の pH 値はそれぞれ 0.4, 3.7, 6.7 であった。 pH 1.1, 3.0, 5.0 における最大吸収波長の文献値はそれぞれ 521.5 nm, 523.0 nm, 532.0 nm である。

図 2. 遠心分離した後のブドウのアントシアニン抽出液

表 1. それぞれの緩衝化されたアントシアニン溶液の pH 値

緩衝液	pH 値
pH 1 に緩衝化されたアントシアニン	0.4
pH 4 に緩衝化されたアントシアニン	3.7
pH 7 に緩衝化されたアントシアニン	6.7

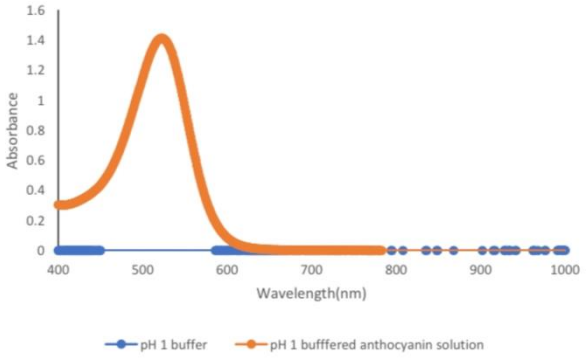

図 3. pH 1 に緩衝化されたアントシアニン溶液の吸収スペクトル

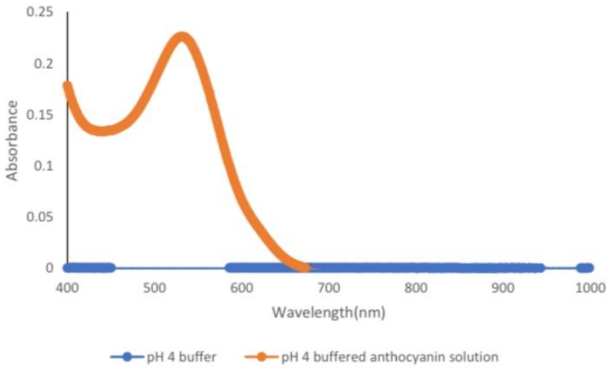

図 4. pH 4 に緩衝化されたアントシアニン溶液の吸収スペクトル

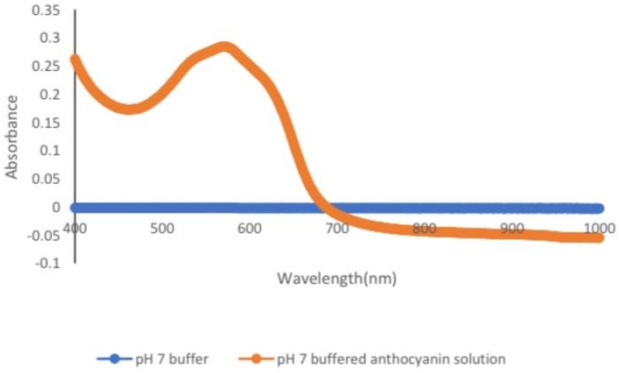

図 5. pH 7 に緩衝化されたアントシアニン溶液の吸収スペクトル

また、紫外可視分光光度計を用いて紫外線の吸収スペクトルも読み取った。読み取った結果吸光度が高すぎた原因としては、測定溶液の濃度が高すぎて正確に測定できなかったことが考えられる。

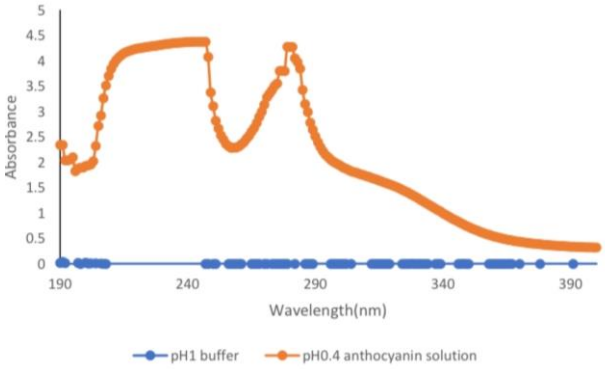

図 6. pH 1 に緩衝化されたアントシアニン溶液の紫外領域の吸収スペクトル

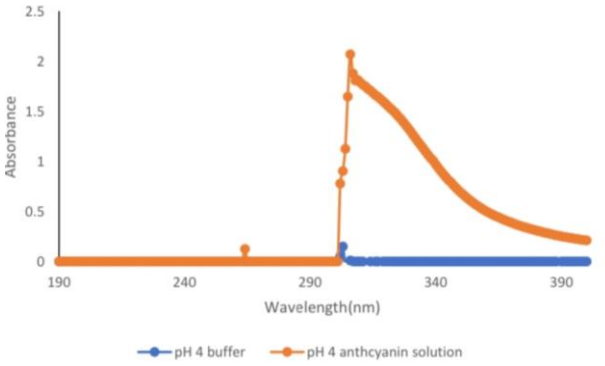

図 7. pH 4 に緩衝化されたアントシアニン溶液の紫外領域の吸収スペクトル

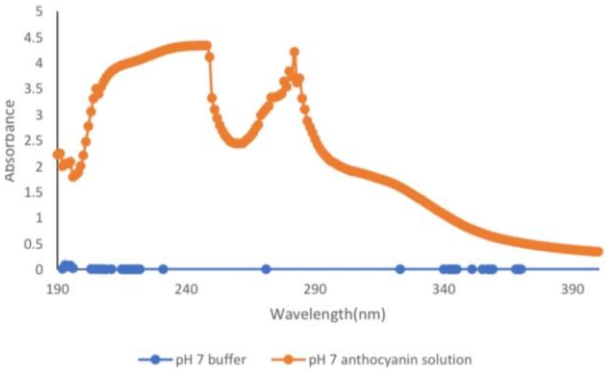

図 8. pH 7 に緩衝化されたアントシアニン溶液の紫外領域の吸収スペクトル

3－2. ブドウのアントシアニンを用いて作製した日焼け止めについて

pH 試験紙で日焼け止めクリームの pH を読みとり、pH が 8 になるまでトリエタノールアミンを加えた。

図 9．ブドウのアントシアニンを用いて作製した日焼け止めクリーム

3－3. 日焼け止めクリームの紫外線防護の効果について

プラスチック容器に入れたメチレンブルーと二酸化チタンの混合液を、紫外線を照射しなかったもの、スライドガラスに挟んだ日焼け止めクリームの下から紫外線照射機で 5 分、10 分、15 分紫外線を照射したもの、スライドガラス 2 枚の間に何も挟まずに 5 分、10 分、15 分紫外線を照射したものの 7 つの溶液のメチレンブルーの脱色の違いは次の図 10 のようになった。

図 10. (左から)メチレンブルーと二酸化チタンの混合液に紫外線を照射しなかったもの、日焼け止めを挟んだスライドガラスの上で 5 分、10 分、15 分紫外線を照射したもの、日焼け止めを挟まずにスライドガラスの上で 5 分、10 分、15 分紫外線を照射したもの

図 10 のように、メチレンブルーの溶液は、スラ

イドガラスの上に日焼け止めを挟まずに紫外線を照射したものに比べて、日焼け止めを挟んで照射したものの方が、脱色の度合いが小さくなっている。
このことから、この日焼け止めクリームは紫外線防護の特性があると言える。

2-4. 実験 2-3 で用いたメチレンブルーの溶液の濃度について

実験 2-3 に用いたメチレンブルーの溶液を 2 倍希釈したものの吸光度は 665 nm で 0.27 であった。これを$A = \varepsilon cl$に代入して、算出した濃度を 2 倍すると、メチレンブルーのモル濃度は、5.89 $\times 10^{-6}$ mol/L ということが分かった。

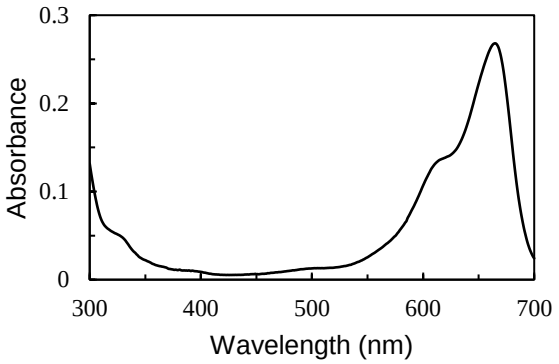

図 11. 実験 2-3 で用いたメチレンブルーの溶液を 2 倍希釈したものの吸収スペクトル

4. 今後の予定

4-1. 対照実験

2-4. の実験を、アントシアニンの抽出液を入れていないクリーム、SPF30 の市販の日焼け止めでも同様の実験を行い、実験結果で得られた紫外線カットの効果が本当にアントシアニンの抽出液によるものなのかを検証し、また市販の日焼け止めとの性能を比較する。

4-2. 均質性の確認

クリームの滑らかさ（粗粒度）と凝集を顕微鏡で分析する。

4-3. SPF の測定

クリームを測り、100 mL メスフラスコに移し、エタノールで希釈する。その溶液 1 mL を 10 mL メスフラスコに移し、エタノールで量を調節する。吸光度の測定は、290 ～ 320 nm の範囲で 5 m 間隔で行う。アントシアニンの吸光度値を得た後、式により SPF を算出する。

$$\mathrm{SPF(Spectrometry)} = \mathrm{CF} \times \mathrm{23EE}(\lambda) \times \mathrm{I}(\lambda) \times \mathrm{Abs}(\lambda)$$

CF＝10（補正係数），
EE(λ)=波長 λ における放射線の発赤効果,
I(λ) = 波長 λ における太陽光の強度,
Abs(λ) = 波長 λ の吸光度

4-4. 耐水性の測定

実用的な日焼け止クリームを作製するため、日焼け止めクリームの耐水性を検証する。

5. 謝辞

実験方法やデータ分析などこの国際共同課題研究で有益なアドバイスをくださった National Junior College の Shan Shan Lee 先生にこの場を借りて厚く御礼申し上げます。また、立命館高校の市川美恵博士には生物の分野において実験方法について貴重なアドバイスを沢山していただき、紫外線照射機の貸与や紫外可視分光光度計の使い方、グラフの分析の仕方等を指導してくださり、とても感謝しております。松浦紀之博士には化学的な視点からグラフの分析の指導と吸引濾過機の貸与をしていただき、深く感謝しております。そしてシンガポールとの国際共同課題研究をするにあたり、Joseph Greenleaf 先生、廣松光一郎先生に研修を引率していただきました。深く感謝しております。そして国際課題研究を担当してくださった弓削亨先生に感謝申し上げます。共同研究者である齊藤玲澄さん、脇長世莉さん、Mo Thant Cin さん、Ricthika Suradren さん、Jocelyn Winata さんには、この約 7 ヶ月間共にディスカッションや実験を行い、

何度も助けられました。ありがとうございました。

最後に、本論文を執筆するにあたり協力してくださったすべての方に厚くお礼申し上げます。

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Exploring the Photoprotective Capabilities of Anthocyanin

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

The theme of this research focused on three problems. First, the effects of sunscreen on the human body. Second, the effects of sunscreen on marine life. Third, finding a use for food waste from the wine industry. Sunscreen is applied daily to many people's bodies, and the ingredients in sunscreen get absorbed by the skin into the bloodstream. Some of these ingredients may contain harmful compounds. Also, if we enter the sea after applying sunscreen, some of it can come off in the water, causing harm to marine life. Meanwhile, pomace, the dry or pulpy residue of grapes consisting of grape seeds and skins, is something that the global wine industry produces close to 12 million tons of each year. It is typically discarded during wine production; however, research on grape pomace has revealed that it is rich in anthocyanins. Anthocyanins have photoprotective capabilities. Therefore, if it were possible to make sunscreen out of grape skins, it would solve these three problems. This research was done as part of an International Collaborative Research Project with National Junior College in Singapore.

Keywords: sunscreen, pomace, grapes, anthocyanin, photoprotection

I. Introduction

In conventional sunscreen, there are a lot of harmful ingredients. In the global wine industry, 12 million tons of grape pomace is produced every year. The skins of grapes, high in anthocyanins, make up 50% of this pomace by weight. According to Costa et al. (2014), “Grape anthocyanins are the 3-O-monoglucosides of delphinidin, cyanidin, petunidin, peonidin, and malvidin.” Anthocyanins are water-soluble pigments produced via the flavonoid pathway in the cytoplasm of the colored plant cell. They are responsible for the deep red, blue, and purple pigments found in plants.

Light is the main source of energy for photosynthesis. However, under strong light conditions, plants may capture more light than photo utilization capacity. So, plants develop their systems to protect themselves from these photooxidative stresses, and anthocyanin is a prime example. In the case of eggplants, most of the color is deep purple, but the bottom of the calyx, which is not exposed to sunlight, has a slightly lighter blue-purple color (Anthocyanin, 2023). Thus, anthocyanins may be a safer alternative for photo-protection. The UV-inhibiting properties of anthocyanins found in grapes and the optimal proportion for maximum sun protection are investigated and compared in this research.

II. Materials and Method

1. Making Sunscreen from Grape Skin

1.1: Extraction of Anthocyanin

First, the grapes (*Vitis vinifera*) were peeled to remove their skins. Then they were frozen using liquid nitrogen. Finally, they were finely ground using a mortar and pestle, allowing for the complete rupture of cells and, thus, very high anthocyanin extraction rates. The prepared raw material was kept at -20 °C until extraction.

For extraction, the grape skins were mixed with 0.1% HCl at a ratio of 2.5:1, W/W. The resulting mass was heated in a water bath at 50°C for 2 hours using a hot stirrer. After that, it was stored in a refrigerator.

1.2: Purification of Anthocyanin

The crude extract was filtered using a suction filter. After that, it was centrifuged at 4000 pm for 5 minutes, 6000 rpm for 5 minutes, and 8000 rpm for 30 minutes. There was a precipitate, which was removed. The main factors considered were the purity, yield, operating components, and production cycle of the target substance.

1.3 Quantification of Anthocyanin

After obtaining the anthocyanin extract from the grape pomace, quantification of the concentration of anthocyanin was done through the pH Differential Method. 300 L of anthocyanin solutions was added to 3 mL of buffers. Each of the pH 1, pH 4, and pH 7 buffered anthocyanin solutions were placed in a cuvette and then into a UV-vis spectrophotometer to read the absorbance of UV light.

2. Mixing with Creme

2.1 Aqueous Phase Preparation

6g of anthocyanin extract 20g of Glycerin were dissolved in deionized 10 mL Water to be heated to 80°C for 3 minutes.

2.2 Oil Phase Preparation

20g of Stearic acid and 4g of Cetyl alcohol were mixed and heated at 80°C for 10 minutes.

2.3 Mixing Phase

Oil phase was added to the aqueous phase at 80°C with continuous stirring for 30 minutes till a uniform emulsion was formed. Then, triethanolamine was added till the pH value became 8. The pH value was measured using a pH test paper.

3. Measurement of the Photoprotective Capabilities of Sunscreen

35g of methylene blue solution (see results for concentration) was mixed with 0.05g of titanium dioxide. A piece of aluminum foil with a 4.5 cm × 6.5 cm rectangular hole was placed on top of a Mini Size UV Transilluminator (Ultra-Lum, Inc., UVB-10, 300 nm) with the hole above the UV irradiation area. Over the hole, place sunscreen with the sickness of three sheets of cellophane tape between two glass slides (referred as ①), and then stack two slide glasses without sandwiching the sunscreen (referred as ②) was placed. A mixture of titanium dioxide and methylene blue solution was poured into six vials (5 mL each), and three vials each were placed on top of ① and ②. UV light was then irradiated from the UV transilluminator for 5, 10, and 15 minutes to check how much the methylene blue solution was decolorized. Experiments were conducted in the dark.

Fig.1 Setup of UV irradiation

4. Quantification of the Concentration of Methylene Blue Solution Used in Experiment 3

The absorbance of methylene blue solution used in experiment 4 diluted twice with ion-exchanged water was measured using an UV-vis spectrophotometer, and the molar concentration of the methylene blue solution was calculated using the Beer-Lambert Law, represented by the formula: $A = \varepsilon cl$

A = absorbance of methylene blue solution;

ε = molar extinction coefficient of methylene blue at 665 nm (91,000 L/(mol・cm)) (Nishizaka et al., 1993);

c = molar concentration of methylene blue solution; l = cell length (1 cm)

III. Result and Discussion

About the Buffered Anthocyanin Solution

Anthocyanins change their structure depending on the pH value, and the wavelength of light absorbs changes depending on the structure. Therefore, since the absorption spectrum changed at pH 1, 4, 7, it was determined that the extracted liquid was anthocyanin. The pH values of pH 1, 4, and 7 buffered anthocyanin solutions were 0.4, 3.7, and 6.7.

According to reference 3, the maximum absorption wavelength at pH 1.1, pH 3.0, and pH 5.0 was 521.5 nm, 523.0 nm, and 532.0 nm.

Table.1 pH value of each buffered anthocyanin solution

Solution	pH value
pH1 buffered anthocyanin	0.4
pH 4 buffered anthocyanin	3.7
pH 7 buffered anthocyanin	6.7

Fig.2 Centrifuged liquid

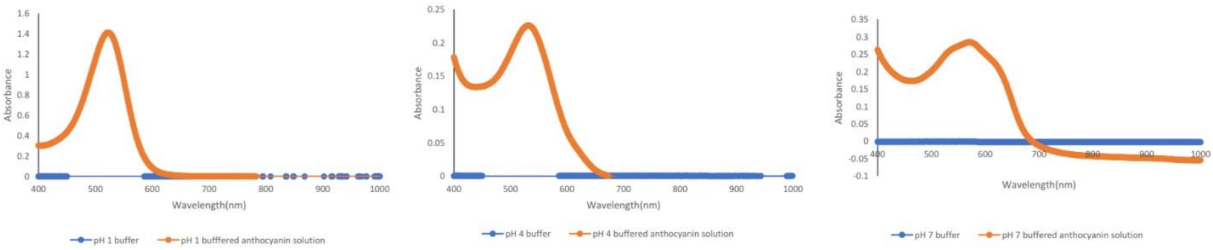

Fig.3 Graphs showing the absorption spectrum of pH 1, 4, and 7 buffered anthocyanin solutions

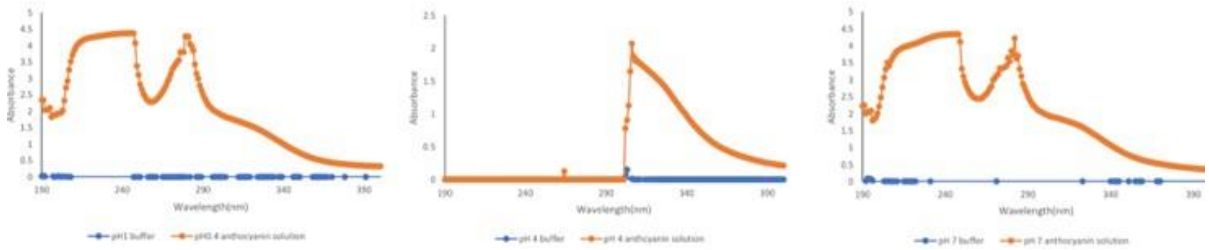

Fig.4 Graphs showing the UV absorption spectrum of pH 1, 4, and 7 buffered anthocyanin solutions

A possible cause of the absorbance value of UV light being too high is that the concentration of the measurement solution was too high and could not be measured accurately.

About the Sunscreen Made with Anthocyanins Extracted from Grape Skin

The pH value of the sunscreen was read using a pH test paper and it was 8.

Fig.5 Sunscreen made with anthocyanins extracted from grape skin

The Photoprotective Capabilities of Sunscreen

The mixture of methylene blue and titanium dioxide in a viral (5 mL each) was exposed to UV light for 5, 10, and 15 minutes with a UV irradiator from under a sunscreen sandwiched

between two glass slides, without anything between the two glass slides, and no UV light. The difference in methylene blue decolorization of the seven solutions is shown in Figure 6 below.

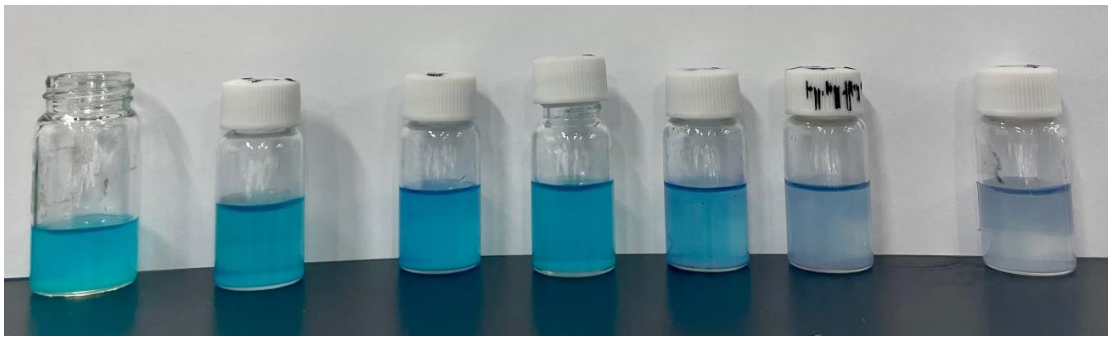

Fig.6 (From left to right) Methylene blue solution without UV irradiation, UV irradiated for 5, 10, 15 minutes from under two glass slides with sunscreen in between, and UV irradiated for 5, 10, 15 minutes from under two glass slides without sunscreen in between

As shown in Figure 6, the degree of discoloration of the methylene blue solution is smaller when it is exposed to UV light from below with a sunscreen between the glass slides than when it is exposed to UV light from below without the sunscreen between the glass slides. From this result, it can be said that this sunscreen has photoprotective capabilities.

The Concentration of Methylene Blue Solution Used in Experiment 3

The absorbance of the solution of methylene blue used in experiment 4, diluted twofold with ion-exchange water, was 0.27 at 665 nm. By substituting this absorbance into the formula and doubling the calculated concentration, the molar concentration of methylene blue was found to be 5.89×10^{-6} mol/L.

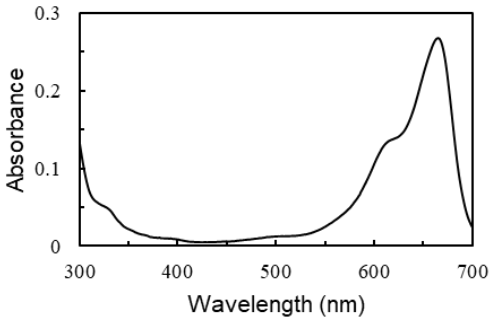

Fig.7 The absorption spectrum of solution of methylene blue used in experiment 4 after it was diluted twofold with ion-exchange water

IV. Conclusion

In conclusion, sunscreen prototypes containing anthocyanin extracts of grapes were successfully formulated, with significant photoprotective effects observed when tested for with the set up using methylene blue-titanium dioxide solution.

V. Future Research

Control Experiment

The same experiment as in experiment 3 should be conducted with a cream without anthocyanin extract and a commercial sunscreen with SPF 30 to verify whether the photoprotective effect obtained in the experiment is really due to the anthocyanin extract and to compare its performance with that of the commercial sunscreen.

Homogeneity Test

Creams will be analyzed under a microscope for grittiness and aggregations.

SPF Determination

To determine the SPF of the cream, it should be transferred to a 100 mL volumetric flask and diluted to volume with ethanol. Then, 1 mL aliquot is to be transferred to a 10 mL volumetric flask, and the volume is to be adjusted with ethanol. The absorption data is to be obtained in the range of 290-320 nm every 5 m interval. After obtaining absorbance values of anthocyanins, SPF is to be calculated using the following formula:

$SPF(Spectrometry) = CF \times 23EE(\lambda) \times I(2) \times Abs(\lambda)$

CF = 10 (Correction Factor); $EE(\lambda)$ = Erythemogenic effect of radiation at wavelength λ;

$I(\lambda)$ = Intensity of solar light at wavelength λ; $Abs(\lambda)$ = Absorbance of wavelength λ

Water Resistance Test

Creams should also be tested in terms of their water resistance to determine their viability.

VI. Acknowledgements

I would like to take this opportunity to thank Dr. Shan Shan Lee of National Junior College for his useful advice on experimental methods and data analysis for this international joint research project. I am also incredibly grateful to Dr. Mie Ichikawa of Ritsumeikan High School for providing me with a lot of valuable advice on experimental methods in the field of biology, and for lending me a UV irradiation machine and teaching me how to use a UV-visible spectrophotometer and how to analyze graphs. I am deeply grateful to Dr. Noriyuki Matsuura for his guidance on graph analysis from a chemical perspective and for lending me a suction filtration machine. I would like to extend my thanks to Mr. Joseph Greenleaf and Mr. Koichiro Hiromatsu for leading the training for the International Collaborative Research Project with Singapore. I would also like to express my gratitude to Mr. Toru Yuge, who oversaw the International Collaborative Research Project. I would also like to thank Ms. Ann Flanagan for their guidance in writing my dissertation in English. Finally, I would like to thank my collaborators, Ms. Asumi Saito, Ms. Seri Wakinaga, Ms. Mo Thant Cin, Ms. Ricthika Suradren, and Ms. Jocelyn Winata, who helped me many times during our discussions and experiments together for the past seven months. Thank you very much.

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Exploring the Photoprotective Capabilities of Anthocyanin

RITSUMEIKAN

JSSF JAPAN SUPER SCIENCE FAIR 2023

Ritsumeikan High School

Abstract

The theme of this research focused on three problems. First, the effects of sunscreen on the human body. Second, the effects of sunscreen on marine life. Third, finding a use for food waste from the wine industry. Sunscreen is applied daily to many people's bodies, and the ingredients in sunscreen get absorbed by the skin into the bloodstream. Some of these ingredients may contain harmful compounds. Also, if we enter the sea after applying sunscreen, some of it can come off in the water causing harm to marine life. Whereas, pomace, the dry or pulpy residue of grapes consisting of grape seeds and skins, is something that the global wine industry produces close to 12 million tons of each year. It is typically discarded during wine production, however, research on grape pomace has revealed that it is rich in anthocyanins. Anthocyanins have photoprotective capabilities. Therefore, if it were possible to make sunscreen out of grape skins, it would solve these three problems. Since the types of grapes available in Japan and Singapore are different, grapes available in each country were used to investigate whether the effectiveness of sunscreen changes depending on the type of grape. To make sunscreen that solves the food waste problem, while containing little to no chemicals, aloe vera is also used in the cream.

Introduction

In conventional sunscreen, there are a lot of harmful ingredients. In the global wine industry, 12 million tons of grape pomace is produced every year. The skins of grapes, which are high in anthocyanins, make up 50% of this pomace by weight. Anthocyanins are water-soluble pigments produced via the flavonoid pathway in the cytoplasm of the colored plant cell. They are responsible for the deep red, blue and purple pigments found in plants.

Light is the main source of energy for photosynthesis. However, under strong light conditions, plants may capture more light than for photoutilisation capacity. So plants develop their own systems to protect themselves from these photooxidative stress and anthocyanin is a prime example of this. Thus, anthocyanins may be a safer alternative for photo-protection. We will be investigating and comparing the UV-inhibiting properties of anthocyanins found in grapes, and the optimal proportion for maximum sun protection.

Experiment 1: Extraction of Anthocyanin

First, the grapes were peeled to remove their skins (Fig.1), Then they were frozen using liquid nitrogen. Finally, they were finely ground using a mortar and pestle (Fig.2). This allowed for the complete rupture of cells and thus very high anthocyanin extraction rates.

The prepared raw material was kept at -20℃ until extraction. After that, it was frozen by liquid nitrogen and then was ground.

For extraction, the grape skins were mixed with 0.1% HCl at a ratio of 2.5:1, W/W(Fig.3). The resulting mass was heated in a water bath at 50℃ for 2 hours using a hot stirrer. After that, it was stored in a refrigerator.

Fig.1 Peeled grapes

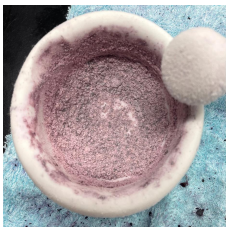

Fig.2. Frozen using liquid nitrogen

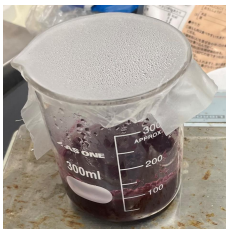

Fig.3 Mixed with 0.1% HCl

Experiment 2: Purification of Anthocyanin

The crude extract was filtered using a suction filter. After that, it was centrifuged at 4000 rpm for 5 minutes; 6000 rpm for 5 minutes; and 8000 rpm for 30 minutes.

There was a precipitate, so it was removed.

The main factors considered were the purity, yield, operating components, and production cycle of the target substance.

Fig.4 Suction filter

Fig.5 Suction filtering

Fig.6 Filtered liquid

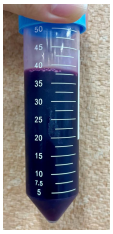

Fig.7 Filtered liquid

Fig.8 Centrifuge

Fig.9 Centrifuge

Fig.10 Centrifuged liquid

Fig.11 Precipitate

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Experiment 3: Quantification of Anthocyanin

After obtaining the anthocyanin extract from the grape pomace, quantification of the concentration of anthocyanin was done through the pH Differential Method. 300 µL of anthocyanin solutions was added to 3 ml of buffers. Each of the pH 1, pH 4, and pH 7 buffered anthocyanin solutions were placed in a cuvette and then into a UV-vis spectrophotometer.

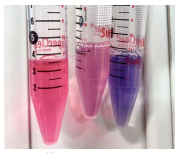
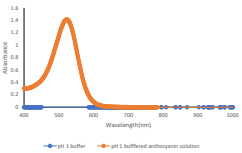


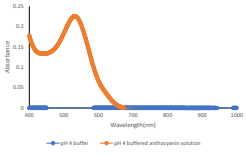
Fig.12 Buffered anthocyanin solutions
(left: pH 1, middle: pH 4, right: pH 7)

Table 1 pH value of each buffered anthocyanin solution

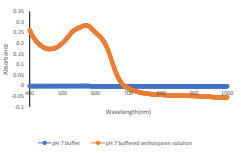
Solution	pH value
PH 1 buffered anthocyanin	0.4
PH 4 buffered anythocyanin	3.7
PH 7 buffered anthocyanin	6.7



Graph 1



Graph 2

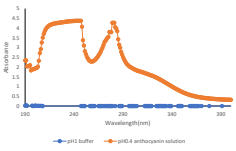


Graph 3

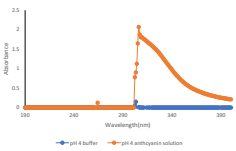
Fig.13 Graph 1, 2, 3 : Absorption spectrum of pH 1, 4, 7 buffer and pH 1, 4, 7 buffered anthocyanin solutions

Anthocyanins change their structure depending on the pH value, and the wavelength of light absorbs changes depending on the structure. Therefore, since the absorption spectrum changed at pH 1, 4, 7, it was determined that the extracted liquid was anthocyanin. The pH values of pH 1, 4 and 7 buffered anthocyanin solutions was 0.4, 3.7, and 6.7.

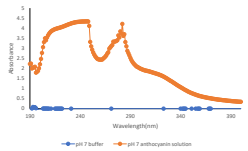
According to the reference 3, the maximum absorption wavelength at pH 1.1, pH 3.0, pH 5.0 was 521.5 nm, 523.0 nm, 532.0 nm.



Graph 4



Graph 5



Graph 6

Fig.14 Graph 4, 5, 6 : UV Absorption spectrum of pH 1, 4, 7 buffer and pH 1, 4, 7 buffered anthocyanin solutions

The absorbance of UV light was read using a UV-vis spectrophotometer. A possible cause of the absorbance value being too high is that the concentration of the measurement solution was too high and could not be measured accurately.

Sunscreen Prototypes

Fig.15 Mixed with White Petrolatum

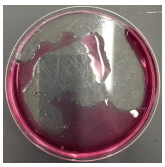


Fig.16 Mixed with glycerin

The extracted anthocyanin solution was mixed with glycerin and white petrolatum at a ratio of 1:1, weight by weight. When it is mixed with white petrolatum, it becomes sticky, and when it is mixed with glycerin, it becomes liquid, so neither is the best ingredient for sunscreen.

Future Plan

Experiments to be done in the future are Experiments 4,5,6, and 7.

[Experiment 4: Make it mildly acidic]

A strong acid has a higher preventative power, so it must be made a weak acid while maintaining that power. Because if it remains a strong acid, it cannot be applied to the skin.

[Experiment 5: Test the viability as sunblock]

Anthocyanins are chemical compounds, so they may decompose at high temperatures. To be a viable sunblock it needs to remain heat stable under a temperature at which people apply sunscreen. It is necessary to consider whether the effectiveness of sunscreen can be maintained and what to do if it cannot be maintained.

[Experiment 6: Mix with aloe vera]

Aloe vera cream will be used to make a creamy sunscreen. Aloe vera cream is naturally derived, so it has no negative effects on people or the environment.

[Experiment 7: With ready-made]

The Experiment 6 mixture and ready-made products will be tested to see how much UV protection they provide.

Acknowledgment

We would like to take this opportunity to thank Ms. Shan Shan Lee at National Junior College in Singapore, Dr. Mie Ichikawa and Mr. Toru Yuge at Ritsumeikan High School for mentoring us during this collaborative research and providing useful advice.

抹茶を用いた水溶液中の銅(Ⅱ)イオンの捕集除去実験

要旨

抹茶は茶葉を砕いたもので､日本の伝統的な飲み物である。抹茶にはポリフェノール､タンニン、アミノ酸、カフェインなどが含まれおり、抹茶の成分のおおよそ10%はタンニン酸である。 タンニンの構造にはベンゼン環が含まれており、ベンゼン環に直接結合したヒドロキシ基は金属イオンに配位することができる。 合成樹脂であるフェノール樹脂は、フェノールとホルマリンを組み合わせることで得られることが知られている。 この技術を適用すると、フェノールの代わりにタンニンが金属イオンとの結合を利用して水から重金属イオンを除去できる可能性がある。 そこで、抹茶とタンニン酸を使って水中の金属イオンの除去を試みた。

私たちは抹茶、タンニン酸を使い、水中の重金属イオンの除去を実験した。また、抹茶、タンニン酸をホルマリンを用いて高分子化した際の効果も実験した。これらの実験結果からホルマリン処理をする前の抹茶とタンニン酸でも十分に水中の銅イオンを除去できた。しかし、ホルマリン処理をした後のタンニン酸は少し除去率が増えたが期待していたほどの結果は得られなかった。また、ホルマリン処理後の抹茶は固くて砕ききれていなかったため予想よりも低い除去効率となった。ホルマリン処理をする際には、温度と時間が全てのタンニン酸と抹茶を反応させるために重要なことが分かった。

1. 背景

重金属は自然界に低濃度で存在しており、その一部は私たちが生きていくために必要な必須元素として知られている。しかし、湖沼などの環境水中に銅(Ⅱ)イオン Cu^{2+}、水銀(Ⅱ)イオン Hg^{2+}、鉛(Ⅱ)イオン Pb^{2+}などの重金属イオンが排出されると､水質汚染につながる｡水中に存在する場合、人や生物に摂取される可能性があり、健康被害を引き起こすことがある。たとえば、鉛やカドミウムは神経系や腎臓に悪影響を与えることが知られている。また、水中存在は水生生物の成長や繁殖に悪影響を与えることもある。重金属が食物連鎖を通じて上位の生物に蓄積されることもあり、生態系全体に広がる可能性がある。そして、産業廃水や鉱業などの産業活動によって水中に放出された重金属イオンは、地域の水源や水道水に含まれる可能性があり、飲料水や農業用水の品質が悪化すると考えられる。水中の重金属イオンが固体物質や混濁物と結合して分散されたり、溶存したりしているため重金属イオンは一般的に水処理プロセスで取り除くことが難しい。このような問題は地域や状況によって異なるが一般的に、重金属イオンの水中存在は環境および健康に対する潜在的なリスクがある。そのため、環境水中の重金属イオンを簡易かつ迅速に分離することは、重要なことであると考えた。

様々な植物に含まれるポリフェノールは、古くから食品、染色剤、塗料、樹脂などに利用されてきた。ポリフェノールの分子構造中にはフェノール性のヒドロキシ基-OH があるため、重金属イオンに配位することができる。そのため、ポリフェノールは重金属イオンの捕集剤として利用されてきた。先行研究では、コーヒー、グァバ、紅茶などのポリフェノールを含む食品を使って水中の銅(Ⅱ)イオンの捕集除去実験を行い、除去できることがすでに示されている。

そこで本実験では、天然素材を利用して水中の重金属イオンを除去する方法を考えた。この実験

は日本の伝統的な飲み物である抹茶に焦点を当てた。 抹茶には約 10%の抹茶ポリフェノールが含まれている。抹茶ポリフェノールには、ベンゼン環に直接結合したヒドロキシ基が含まれている。 プロトンを含むヒドロキシレートは、ヒドロキシ基から除去され、金属イオンに配位することができます。 また、抹茶に含まれており、構造が似ているタンニン酸も使って実験を行った。 また、抹茶を高分子化することで、さらに多くの重金属イオンを吸着できるのではないかと考えた。

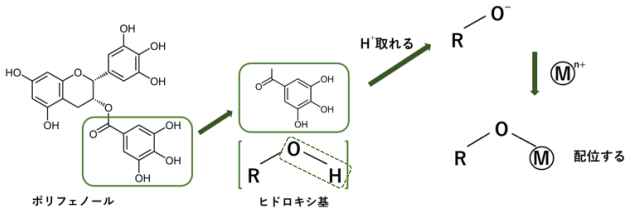


図 1, 抹茶ポリフェノールの構造と金属イオンの配位

2. 方法

2−1. ホルマリン処理

この実験では抹茶、タンニン酸それぞれにホルマリン処理を行った。抹茶は市販の京都府産のもの使用した。タンニン酸はポリフェノールの一種であるため、比較実験として使った。ナス型フラスコに抹茶 1.0 g に対してホルマリン(37%ホルムアルデヒド水溶液)5.0 mL、0.10 mol/L 硫酸 20.0 mL を加え、60℃の水浴中で２時間撹拌した。ホルマリン処理後、アスピレーターでろ過した。沈殿物をイオン交換水 100 mL で洗浄し、遠心分離をすることで上澄み液を取り除き、数回行うことで未反応のホルマリンを取り除いた。その後、自然乾燥させて乳鉢で粉砕した。 実験は、抹茶 1.0 g と 10.0 g、タンニン酸 1.0 g と 5.0 g を各 1 回ずつ行った。

図 2, 攪拌

図 3, 洗浄後

2−2. 水中の銅(Ⅱ)イオンの捕集除去

次にホルマリン処理する前の抹茶とタンニン酸とホルマリン処理後の抹茶とタンニン酸を使い水溶液中の銅イオンの補修除去実験を行った。

抹茶に含まれる水溶性のポリフェノールは，分子量が比較的小さいため銅(Ⅱ)イオンに結合する。しかし、生じた錯イオンは水に溶けやすく，水中から銅(Ⅱ)イオンを捕集除去することは難しいと予想される。そこで高校化学で学習したフェノールとホルマリンの反応から，メチレン基によって架橋されたプラスチックである「フェノール樹脂」の合成反応を応用することで水溶性のポリフェノールを重合できないかと考えた。

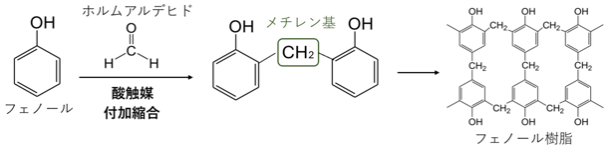


図 3, フェノール樹脂の合成スキーム

銅（Ⅱ）イオンを含む水溶液(模擬廃液)に抹茶またはホルマリン処理抹茶を加え、30 分間撹拌して金属イオンを除去した。ビーカーに一定量の銅(Ⅱ)イオンを含む水溶液、抹茶 0.25 g、ヨウ化カリウム 0.60 g をいれて、スターラーで 30 分攪拌した。水中の銅(Ⅱ)イオンの適量はヨウ素滴定を使って行った。ビュレットを用いて 0.1 mol/L のチオ硫酸ナトリウムを加え、滴定した。この操作は複数回行った。ホルマリン処理後の抹茶、ホルマリン処理前のタンニン酸、ホルマリン処理後のタンニン酸についても同様の条件で除去率を調べた。抹茶を用いるときは液体を一度吸引ろ過してから滴定を行った。なぜなら抹茶の色が濃く、ヨウ素滴定の色の変化がわからないからである。

私たちは，ポリフェノールが高分子化すると水に不溶な固体となって結合した銅(Ⅱ)イオンは濾過によって物理的に容易に取り除くことができると言う仮説を立てた。

図 4, 濾過前後、滴定後の色の変化

図 5, 実験手順

3. 結果と考察

3－1. ホルマリン処理

得られたホルマリン処理抹茶の色は暗褐色で、ホルマリン処理タンニン酸は薄い褐色であった。

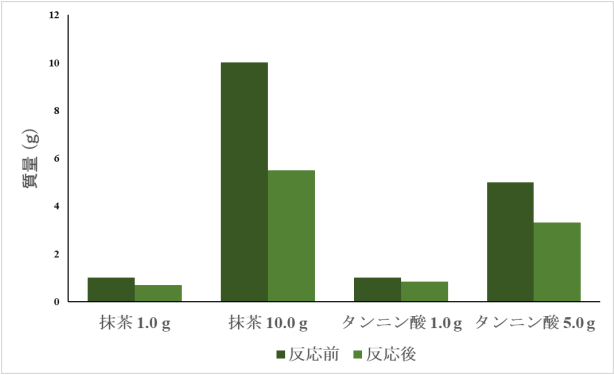


図 6, ホルマリン処理前後の質量

このグラフは、ホルマリン処理前の抹茶とタンニン酸の質量と、ホルマリン処理後の抹茶とタンニン酸の質量を示している。抹茶は 1.0 g と 10.0 g、タンニン酸は 1.0 g と 5.0 g を 1 回ずつホルマリン処理したものでる。

グラフからわかるように、いずれの質量もホルマリン処理前よりホルマリン処理後の方が小さくなっている。抹茶 1.0 g とタンニン酸 5.0 g は質量が小さく、ほとんどホルマリンで重合できた。10.0 g の抹茶と 5.0 g のタンニン酸は質量が大きく、1.0 g の抹茶とタンニン酸よりも長時間反応させたが、すべての抹茶とタンニン酸を重合させることはできなかった。そのため、未反応の抹茶やタンニン酸は洗い流され、抹茶やタンニン酸の 1.0 g よりも質量が大幅に減少したと考察した。これより、質量を大きくすると重合させるための条件が難しくなると考えられる。

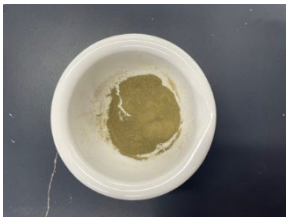


図 7, 抹茶+HCHO

図 8, タンニン酸+HCHO

3－2. 水中の銅(Ⅱ)イオンの捕集除去

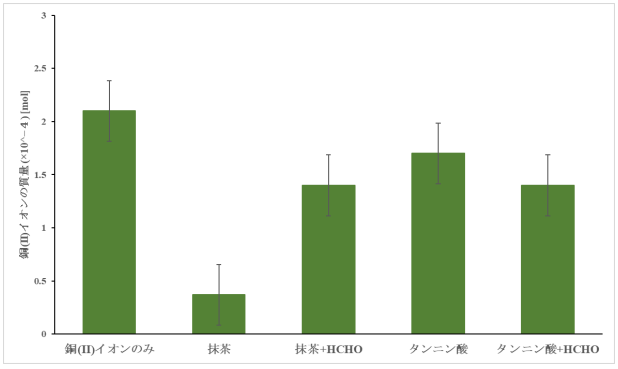


図 9, 水中の銅(Ⅱ)イオンの質量

このグラフは、ヨウ素滴定により算出した、抹茶とタンニン酸による金属イオン除去後の水溶液中の銅(Ⅱ)イオンの物質量を示している。

$Na_2S_2O_3$aq[mol/L]×drop volume/1000[L]=Amount of copper(II) ion [mol]

この式を使用して水溶液中の銅(Ⅱ)イオンの量を測定した。左から銅(Ⅱ)イオンのみ、抹茶、ホルマリン処理後の抹茶、タンニン酸、ホルマリン処理後のタンニン酸である。

捕集除去剤として抹茶を用いたときの銅(Ⅱ)イオンの除去効率は 82%で最も高い割合で銅(Ⅱ)イオンを除去していることがわかった。一方でホルマリン処理抹茶を用いたときの除去効率は 59%で、ホルマリン処理をして高分子化することで逆に大きく除去率が低下していて、私たちの仮説、抹茶を高分子化することで、さらに多くの重金属イオンを吸着できるのではないか、に反した結果になった。その理由は、ホルマリン処理前の抹茶の手触りはさらさらしていたのに対して、ホルマリン処理後の抹茶の手触りは十分に粉砕されなかったためざらざらしていた。このことから、ホルマリン処理後の抹茶は砕けず粒子が大きく、ホルマリン処理前の抹茶に比べて表面積が小さく、除去効率が悪かったため、ホルマリン処理前のものよりも除去率が悪くなったと考えられる。

ポリフェノールと比較のために実験したタンニン酸で実験すると、タンニン酸は 33%、ホルマリン処理タンニン酸は 59%となり、タンニン酸はホルマリン処理し、高分子化させることで除去率が上がったことから、抹茶とタンニン酸ではホルマリン処理の前後で逆の結果になった。
抹茶とタンニン酸を比べてみると、抹茶の方が除去率がタンニン酸よりも高くなっている。

図 10, 粉砕前抹茶

図 11, 粉砕前タンニン酸

4. 展望

この実験の目的は、天然素材を用いて水中の金属イオンを除去することであった。この研究の仮説は、ホルマリン処理による高分子化によって金属イオンの捕集除去率が高まるというものであった。しかし、この仮説はタンニン酸では証明できたが、抹茶を使った結果は予想と違った。その理由は、ホルマリン処理後に抹茶が十分に粉砕されなかったからであると考える。

この実験から、抹茶とタンニン酸は水から金属イオンを除去できることがわかった。

私たちの将来の実験の予定はホルマリン処理で抹茶とタンニン酸の量が減らないように攪拌時間を長くする予定だ。水中の銅(Ⅱ)イオンの捕集除去の将来のプランはホルマリン処理前後の抹茶の表面積の違いを、顕微鏡的な粉末分布を測定し計算することで比較することである。また、粉末を使用すると有効表面積を維持することが困難だったため、表面積の差を少なくするために、粉末抹茶の代わりに茶葉を使用したい。

天然素材を重金属イオンの除去剤としてうまく利用することができれば、廃棄物の再利用につながるのではないかと考える。また、ポリフェノールだけでなくタンニンでも重金属イオンを除去できることがわかった。これにより、タンニンを含むほかのものでも除去剤に使用できるのではないかと考える。

5. 謝辞

的確な助言をくださった松浦紀之先生、柳谷賢志先生、市川美恵先生、そしてゼータ電位を測定していただき、分析に関する助言と援助をいただいた立命館大学生命科学部応用科学科の松川雄太教授に厚く御礼を申し上げます。
また、執筆の過程でお世話になったすべての先生方に感謝の意を表したいと思います。

6. 引用文献

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Collecting and Removing Heavy Metal Ions in Water Using Matcha

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

Matcha is made from crushed tea leaves and is a traditional Japanese drink. It contains tannins, amino acids, and caffeine, with 10% of its components being tannic acid. The structure of tannin includes a benzene ring, and the hydroxy group directly attached to this ring can bind to metal ions. It is known that phenol resin, a synthetic resin, is obtained by combining phenol with formalin. Building on this technique, using tannins instead of phenols could facilitate the removal of heavy metal ions from water through their binding properties. Therefore, the experiment used matcha and tannic acid to remove metal ions from water. First, formalin treatment was applied for the polymerization of both matcha and tannic acid. The experiment showed that substances with a smaller mass polymerized effectively, but those with larger masses were not fully formalized and were washed away with water, resulting in a reduced powder yield. Next, iodometric titration, a quantitative method for measuring copper (II) ions, was used to determine their concentration. It was found that both matcha and tannic acid, even before formalin treatment, adsorbed copper (II) ions effectively. However, the adsorption capacity of tannic acid improved after formalin treatment, whereas matcha performed better before the treatment. This difference is attributed to the clumping of matcha post-formalin treatment, which made it difficult to crush.

Keywords: matcha, tannic acid, heavy metal removal, polymerization, adsorption

I. Introduction

Heavy metals are found in low concentrations in nature, and some of them are known as essential elements necessary for survival. However, when heavy metal ions are present in environmental water sources such as lakes and ponds, they negatively affect human health and ecosystems due to their harmful effects. Previous studies have already shown that it can be removed with coffee husks.

Therefore, this experiment studied a method to remove heavy metal ions from water using natural materials. This experiment focused on matcha, a traditional Japanese drink. Matcha contains about 10% matcha polyphenols. Matcha polyphenols contain a hydroxy group attached directly to the benzene ring. Hydroxylates with a proton removed from the hydroxy group can coordinate with metal ions. Using this property, we tried to collect and remove heavy metal ions from water. The tannic acid in matcha is also used. In this study, the research team wondered if it could adsorb even more heavy metal ions by making matcha a polymer.

II. Materials and Method

Experiment 1: Formalin Treatment

In this experiment, commercially available matcha from Kyoto Prefecture and tannic acid (a type of polyphenol) were treated with formalin. For this, 1.0 g of matcha was mixed with 5.0 mL of formalin and 20.0 mL of 0.10 mol/L sulfuric acid in a 100 mL eggplant-shaped flask. The mixture was stirred at 60°C for 2 hours. Post-treatment, the matcha was filtered to remove formalin, washed with 100 mL of ion-exchanged water, air-dried, and ground with a mortar and pestle. This process was repeated with two different quantities of matcha (1.0 g and 10 g) and tannic acid (1.0 g and 5.0 g).

Fig.1 Matcha mixture being stirred at 60ºC

Fig.2 Washed matcha mixture

Experiment 2: Removal of Metal Ions in Water

This experiment evaluated the ability of matcha and tannic acid, both pre-and post-formalin treatment, to remove copper ions from an aqueous solution. 0.25g of formalin-treated matcha powder was stirred in a copper (II) ion solution for 30 minutes, followed by the addition of 0.60g of potassium iodide. Sodium thiosulfate was then titrated into the solution, but due to matcha's dark color, titration results were indistinct. To address this, suction filtration with Celite was performed before titration to dilute the color. The copper removal rate was calculated using the formula: $Na_2S_2O_3$ [mol/L] × drop volume / 1000 [L]. The removal rates of matcha and tannic acid, both with and without formalin treatment, were compared under similar conditions.

Fig.3 Aqueous solution containing copper (II) ions, matcha, and potassium iodine

Fig.4 Suction filtration with Celite performed before titration to dilute the color

Fig.5 Matcha solution after filtration

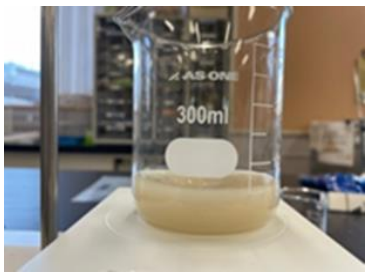

Fig.6 Matcha solution after iodine titration

III. Data Analysis

Experiment 1: Formalin Treatment

Results from Experiment 1 indicate that 1.0 g of matcha and tannic acid formed small lumps, with almost the entire amount polymerizing with formalin. However, in the case of 10.0 g of matcha and 5.0 g of tannic acid, despite their larger mass allowing for a longer reaction time, not all the mixture could be polymerized. This led to the hypothesis that the unreacted matcha and tannic acid were washed away, resulting in a significant decrease in mass compared to the samples with 1.0 g of matcha and tannic acid.

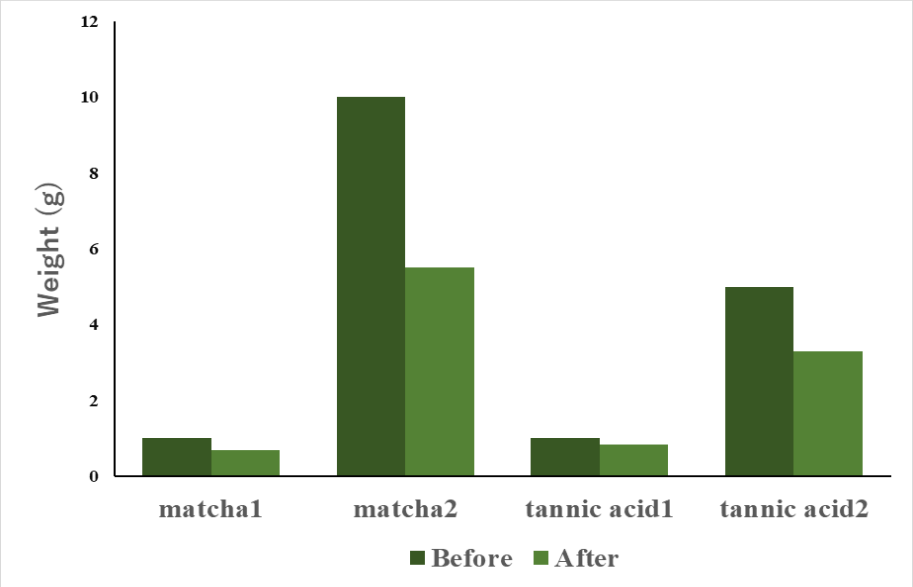

Fig.7 Masses of matcha and tannic acid before and after formalin treatment

Experiment 2: Removal of Metal Ions in Water

In Experiment 2, it was observed that matcha post-formalin treatment was more resistant to breaking and had larger particle sizes. This resulted in a reduced surface area compared to the matcha before formalin treatment, leading to a lower efficiency.

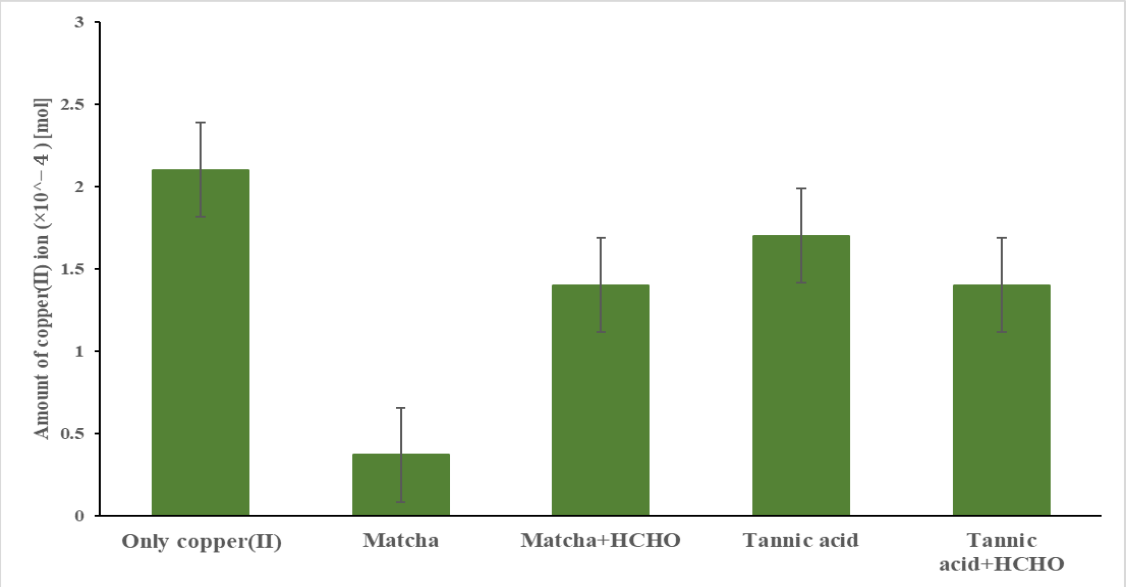

Fig.8 Amount of copper (II) ions in the aqueous solution after attempting removal of metal ions by matcha and tannic acid, calculated by iodine titration. From left to right: copper (II) ion only, matcha, matcha after formalin treatment, tannic acid, and tannic acid after formalin treatment.

IV. Discussion

Experiment 1: Formalin Treatment

The color of the obtained formalin-treated matcha was dark brown, and the color of formalin-treated tannic acid was light brown. As shown in Figure 7, all of the masses of matcha and tannic acid were smaller after formalin treatment. Due to their larger mass, 10.0 g of matcha and 5.0 g of tannic acid could react for a longer time than 1.0 g of matcha and tannic acid, but the entire mixture could not be polymerized. Therefore, we considered that unreacted matcha and tannic acid were washed away, and the mass decreased significantly compared to 1.0g of matcha and tannic acid.

Experiment 2: Removal of Metal Ions in Water

It was found that the removal efficiency of copper (II) ions when matcha was used as a collection and removal agent was 82%, which was the highest rate of removal of copper (II) ions. On the other hand, the removal efficiency when formalin-treated matcha was used was 59%. The removal rate decreased

significantly when formalin treatment was used to make matcha into a polymer. The original hypothesis was that if matcha was made into a polymer, the removal efficiency would be significantly lower. The results contradicted the hypothesis that this would enable the adsorption of even more heavy metal ions. The reason for this is that matcha before formalin treatment had a smooth texture, whereas matcha after formalin treatment had a rough texture because it was not sufficiently ground. From this, it was hypothesized that the surface area of matcha before formalin treatment was larger than that of matcha after treatment, which may make it easier for hydroxyl groups to coordinate with copper (II) ions.

In an experiment using tannic acid, which was used for comparison with polyphenols, tannic acid was 33%, and formalin-treated tannic acid was 59%. Tannic acid was treated with formalin and made into a polymer, which increased the removal rate. Matcha and tannic acid had opposite results before and after formalin treatment. Comparing matcha and tannic acid, matcha has a higher removal rate.

V. Conclusion

The results from the experiments proved that matcha and tannic acid before formalin treatment can sufficiently remove copper ions from water, and that tannic acid after formalin treatment has a slightly higher removal rate. However, the results were not as high as expected. In addition, the matcha was hard after formalin treatment and could not be crushed completely, which was thought to have impacted its effectiveness.

The experiment demonstrated that matcha and tannic acid can potentially remove metal ions from water, though the treatment process influences their effectiveness. During the formalin treatment, temperature and time found to be important factors in allowing all the tannic acid to react with the matcha.

VI. Future Research

The stirring time should be increased to avoid reducing the amount of matcha and tannic acid during formalin treatment. The difference in surface area of matcha before and after formalin treatment should also be compared by measuring and calculating the microscopic powder distribution.

It was difficult to maintain an effective surface area when using powders. Tea leaves should be used instead of powdered matcha to reduce the difference in surface area.

Also, at the JSSF poster session, we received many questions about how to apply the results of this experiment to the real world. Therefore, the experiment will continue to think about how our experiments can affect society.

VII. Acknowledgements

We would like to express our deep gratitude to our research supervisors, Satoshi Yanagiya, Dr. Mie Ichikawa, and Dr. Noriyuki Matsuura, for their patient guidance, enthusiastic encouragement, and helpful critiques of this research work. We would also like to thank Mr. Yuta Matsukawa of the College of Life Sciences in the Department of Applied Chemistry at Ritsumeikan University for their advice and assistance in the data analysis and for helping us gather information for this research. In addition, we would also like to extend our thanks to all the teachers who helped us throughout the writing process. Finally, we would like to thank our families and classmates for their support and encouragement these past two years.

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Collecting and Removing Heavy Metal Ions in Water Using Matcha

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Introduction

Matcha is crushed tea leaves, and it is a traditional Japanese drink. Matcha contains tannins, amino acids, and caffeine. 10.57% of matcha's component are tannic acid. The tannin structure contains a benzene ring, and the hydroxy group directly attached to the benzene ring can coordinate to metal ions. It is known that phenol resin, a synthetic resin, can be obtained by combining phenol with formalin. Applying this technique, tannins instead of phenols could potentially remove heavy metal ions from water by utilizing their binding with the metal ions. For this reason, we tried to remove metal ions from water using matcha and tannic acid.

Materials

- Matcha
- Formalin
- Sulfuric acid
- Tannic acid
- Copper ion(II)
- Rotor
- Ion exchange water
- Round bottom flask
- Triangular flask
- Hole pipette

Fig.1 Matcha

Fig.2 Water Bath

This research focused on Matcha

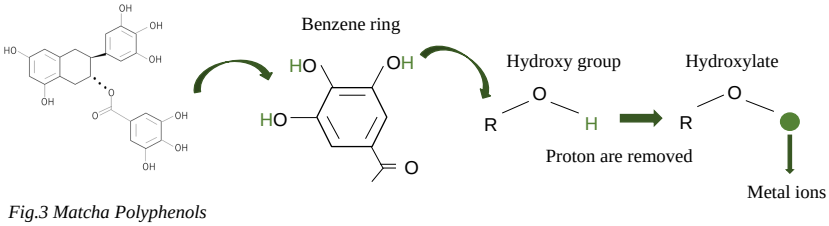

Fig.3 Matcha Polyphenols

Matcha consists of about 10% matcha polyphenols. Matcha polyphenols contain a hydroxy group which attaches directly to the benzene ring. Hydroxylates with a proton removed from the hydroxy group can bond to metal ions. By using this property, we tried to collect and remove heavy metal ions from water.

Experiment 1

Method

1. Formalin treatment

Formalin treatment was used for the polymerization of Matcha and of tannic acid.

The Matcha used in this experiment was produced in Kyoto, Japan. 5.0 mL of formalin and 20.0 mL of 0.10 mol/L sulfuric acid were added per 1.0 g of Matcha in a 100 mL eggplant-shaped flask and stirred at 60°C for 2 hours (*Fig.4*). After formalin treatment, the matcha was filtered through an aspirator to remove the formalin (*Fig.5*). The Matcha was then washed with 100 mL of ion-exchanged water (*Fig.6*). Then, it was dried and crushed. The experiment was conducted once for each amount of 1.0 g and 10 g of Matcha and 1.0 g and 5.0 g of tannic acid.

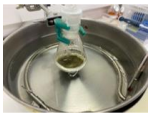

Fig.4 Stirred at 60℃

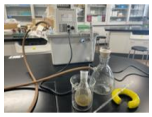

Fig.5 Filtered

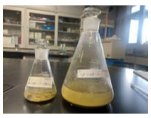

Fig.6 Washed

Result and Discussion

1.0 g of Matcha and tannic acid produced a small mass, almost all of them could be polymerized with formalin. 10.0 g of Matcha and 5.0 g of tannic acid had larger masses, so which allowed them to react for a longer time than the 1.0 g Matcha and tannic acid, but all of the mixtures could not be polymerized. Therefore, unreacted Matcha and tannic acid were washed away, and the mass decreased by a lot more than 1.0 g of Matcha or tannic acid.

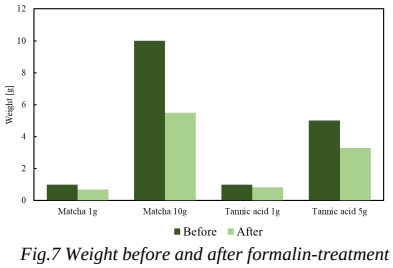

Fig.7 Weight before and after formalin-treatment

Experiment 2

Method

2. Removal of metal ions in water

Iodometric titration, a quantitative method for copper(II) ions, was used to determine the amount of copper(II) ions.

0.25 g of formalin-treated matcha powder was added to the solution containing copper(II) ions and stirred for 30 minutes to remove the metal ions (*Fig.8*). 0.60 g of potassium iodide was added. While stirring with a stirrer, sodium thiosulfate was added using a burette and titrated for one hour. The removal rates of Matcha powder without formalin, tannic acid after formalin treatment, and tannic acid without formalin treatment were also examined under similar conditions. The same experiment was conducted with tannic acid.

$Na_2S_2O_3$aq[mol/L]×drop volume/1000[L]= Amount of copper(II) ion [mol]

Fig.8 Matcha before filtration

Fig.9 Matcha after filtration

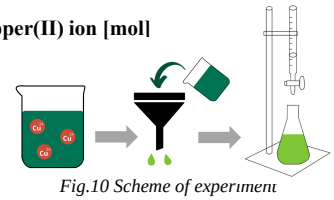

Fig.10 Scheme of experiment

Result and Discussion

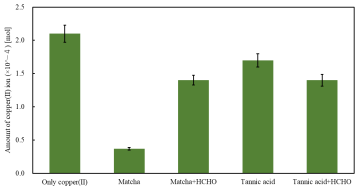

Fig.11 Amount of copper(II) ions

Fig.12 Matcha + HCHO

Fig.13 Tannic acid + HCHO

Matcha and tannic acid before formalin treatment also sufficiently adsorbed copper(II) ions.
Comparing tannic acid before formalin treatment and tannic acid after formalin treatment, the latter adsorbed copper ions better.
Comparing Matcha before formalin treatment and tannic acid after formalin treatment, Matcha before formalin treatment adsorbed more copper(II) ions.

Matcha after formalin treatment was difficult to crush, but tannic acid after formalin treatment quickly crumbled into powder.
Therefore, it is thought that the Matcha after formalin treatment was unbroken and had larger particles, and the surface area was smaller than that of Matcha before formalin treatment, resulting in poor removal efficiency.

Future Plan

- The difference in the surface area of Matcha before and after formalin treatment should be compared by measuring and calculating the microscopic powder distribution.
- Using a powder made it difficult to maintain an effective surface area. In order to reduce the difference in surface area, tea leaves will be used instead of powdered Matcha.

References & Acknowledgements

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傘の形状の違いと表面に残る雨水の関係について

要旨

雨が降った後に傘に残る水滴は屋内の床を濡らしてしまう。現在この問題を防ぐ方法として日本の多くの商業施設ではポリエチレン製の傘袋を採用している。しかし昨今のプラスチックゴミを減らして環境負荷を抑制するという社会の要求に対してこの方法は適しているとは言えない。この問題を根本的に解決するためには、建物内に雨水を持ち込まぬよう、傘の表面についた雨水を建物外でできるだけ取り除きやすくすることが必要だと考えられる。本研究では特に傘の形状に注目してこの問題の解決策を目指した。一般的にコンビニエンスストア等で販売されているビニール傘の表面はポリエステルでできている。そのため、同じ素材であるポリエステル製のラミネートフィルムで、傘の開く角度の異なる7つのサンプルを作製し、雨水を模した霧吹きで水を吹きかける実験を行い、傘の開く角度と傘に残る雨水量の関係を調べた。その結果、傘の開く角度が小さくなるにつれて、単位面積あたりの雨水の量も減少することがわかった。

1. 背景

雨が降った際に日本人のほとんどは傘を使用する。使い終わった後、濡れた傘をそのまま屋内へ持ち込むと、床が濡れてしまう。この問題の解決方法としてポリエステル製の傘袋を使う方法がある。しかしながら、使い捨てであるためこの方法は環境への負荷が大きい。そこで根本的な解決方法として、屋内へ持ち込む前に傘の表面に付着した水滴を除去しやすくなるよう、傘を改良することが考えられる。

既に行われている方法として撥水加工を施すことが挙げられるが、これは一時的なもので時間が経つと効きづらくなることもあり、今回は傘の形状のみに着目し、水滴が残らないような傘の最適角度を実験によって調べることとした。

2. 方法

2.1. サンプル制作

本研究では初めにサンプルを製作し、その後実験を行った。サンプル制作の手順は以下のとおりである。

手順① ケント紙を、コンパスカッターを用いて半径6 cmの円状に切り取った。(図1)

手順② 中心角を330°, 315°, 300°, 285°, 270°, 255°, 240°とし、分度器を用いて計測し手順①で作製した円を加工した。

手順③ 手順②で作成された円を、ラミネーターを用いてラミネートした。その際、切り取った円の重なりを瞬間接着剤用の“のりしろ”として残した。

手順④ 手順③で作製したものを円錐状に丸め、瞬間接着剤で固定した。

手順⑤ 2種類のスマートフォンのアプリケーションを使用し水平な状態で写真を撮影し、分析した。(図2)

手順⑥ 手順⑤から得られた値と中心角から計算される値を比較しグラフにまとめた。

サンプルに使用した材料は、ケント紙とラミネートフィルムである。傘の表面が滑らかでなければ、表面の小さな凹凸に水が溜まることで実験結果に生じる誤差が大きくなると考え、滑

らかと平らという２つの特徴を持っているケント紙が適していると判断した。またラミネートフィルムはビニール傘に使われている素材と同じ素材が使用されているので、こちらも実験に適していると判断した。

図１　切り取られたケント紙

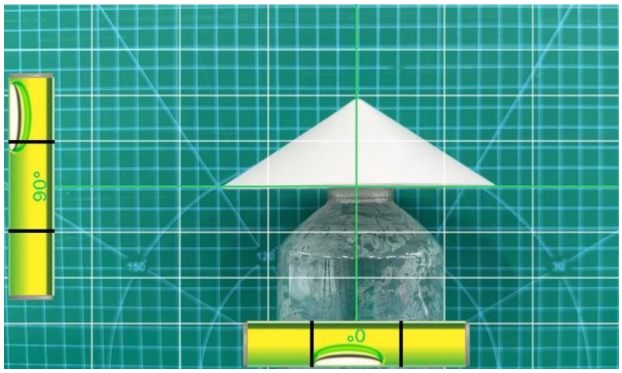


図２撮影したサンプル

2.2. サンプルへの雨滴の散布実験

サンプル制作後、実験を行った。実験の手順は以下の通りである。

手順①　実験前に温度と湿度を測定した。

手順②　電子天秤の上に受け皿を置き、その上に木片を置いた。

手順③　サンプルを木片の上に置いた。

手順④　図 3 に示すように、金網を使って傘の上端から 29.5cm の高さに霧吹き器を設置した。

手順⑤　サンプルに霧吹きで水（約 10g）を噴霧した。

手順⑥　全体を秤量し、水が受け皿に落ちないようにセームタオルを用いてサンプルを取り除いた。

手順⑦　受け皿に付着した水を秤量し、算出した。

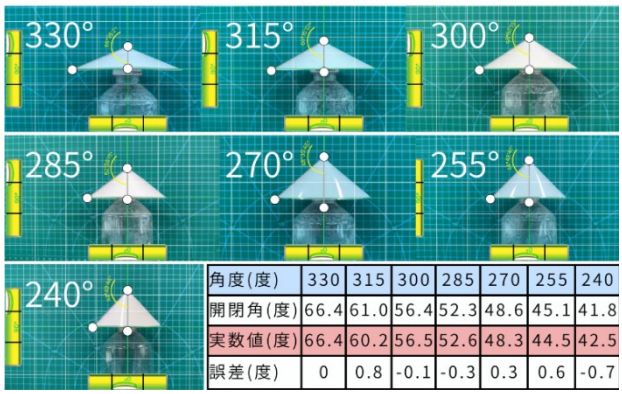
この実験では、霧吹きから出る水を雨に見立て、使用した水は室温に戻した。また、サンプルが受け皿に直接置かれた場合、サンプル下部に水が付着し、実験結果に影響が出ることを考慮し、手順③の木片を使用した。また、風の影響は考慮していない。

図３　実験の様子

3. 結果と考察

3.1. サンプルの開閉角度の妥当性の検討

２種類のスマートフォン用アプリケーションを使用しサンプルの水平状態を保った上で写真を撮影したものを図４に示す。



角度(度)	330	315	300	285	270	255	240
開閉角(度)	66.4	61.0	56.4	52.3	48.6	45.1	41.8
実数値(度)	66.4	60.2	56.5	52.6	48.3	44.5	42.5
誤差(度)	0	0.8	-0.1	-0.3	0.3	0.6	-0.7

図 4　中心角と開閉角の関係とその誤差

傘の表面と傘の中心を通る垂直な直線の間の角度を「開閉角」とすると、その値は上図中の表の二行目に示される。また計算方法は、以下の式を用いた。

開閉角 ＝ 弧 sin(中心角/360)

使用した中心角の範囲では、中心角から計算される開角から計算される開角は sin の逆関数であり、この関数は直線で近似できる。上記の表から、理論値と実数値との誤差は 1° 以内に収まっているため、この模型は実験に用いるに適しているとみなした。

3. 2.　実験

今回は 2 日間で計 6 回の実験を行った。2 日間の気温と湿度は、1 日目が 25℃：40%、2 日目が 26℃：37%と大きな差はなかった。

結果を各角度の箱ひげ図にまとめた。緑色は 1 日目の平均、青色は 2 日目の平均を表す。オレンジは全体の平均を表し、オレンジの点線はその近似線を表している。図 5 のグラフは単位表面積あたりの水量に関するものである。また、図 6 のグラフは水平投影面積あたりの水量を示しており、これらの面積は以下の計算式より算出される。

・表面積あたりの水量

$$M \times \frac{360}{\theta} \times \frac{1}{\pi r^2}$$

・水平投影面積当たりの水量

$$M \times (\frac{360}{\theta})^2 \times \frac{1}{\pi r^2}$$

M＝水量の平均値（g）

r＝半径(cm)

θ＝中心角(°)

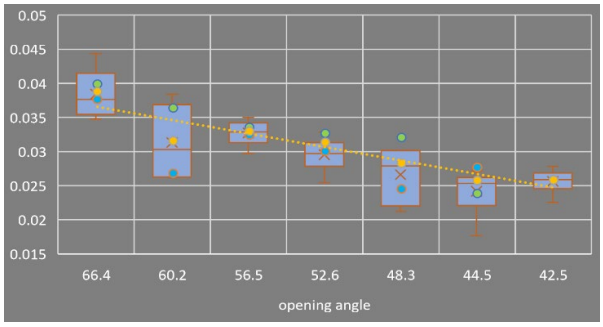


図 5 表面積あたりの水量のグラフ

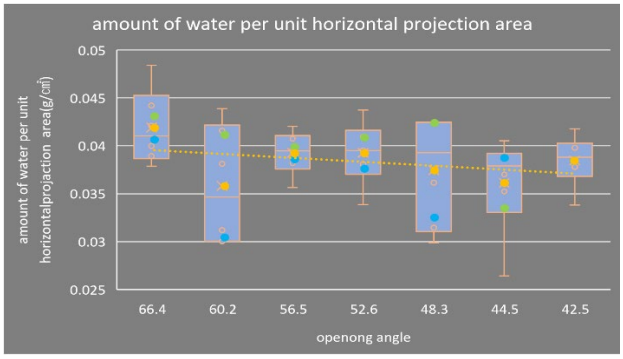


図 6 水平投影面積あたりの水量のグラフ

単位面積当たりの水量は、開閉角が変化するにつれて、ほぼ単純に減少する。開傘角度が大きいものほど、近似直線と実測値の平均値との幅が大きいのは、開閉角の違いによる落ちる水滴の大きさによるものだと考えられる。

これには傘の縁に水が滞留していることも大きな要因であった。また、霧吹きから噴射された水が傘の表面に落ちた際、表面に留まっていた水が他の水滴に吸収されて流れ落ちる。この現象は開閉角が小さいものほど多く見られ、開閉角が小さいものは測定のたびに値が変化することが多かった。

4. 展望

本研究から、市販の傘に付属している「露先」という部品は、布を伸ばすだけでなく、水を落としやすくするという役割も果たしていると考えられた。そう考えた理由は、実験中(図 7 を参照)のように、サンプルの縁により多くの水が溜まっていたことが関係している。このような現象は、本物の傘を使っているときには起こりにくい。また、小さい角度ほど縁の面積が少ないということからも縁に適した角度と頂点に適した角度が異なっており、それらを組み合わせることでより良い結果が得られると考えられた。

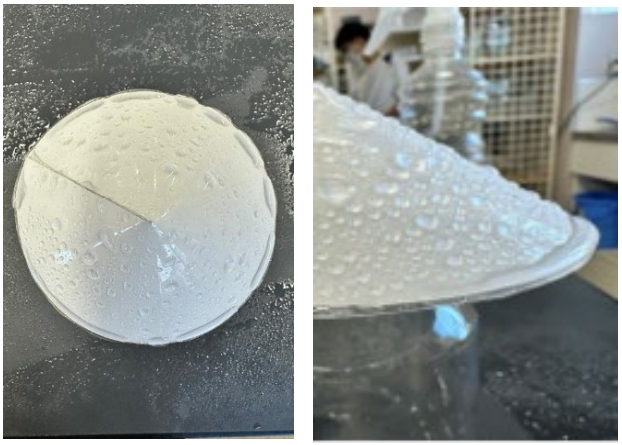


図 7. (左)鉛直上方より撮影 (右)水平方向より撮影

今回の実験では傘のサンプルは骨の部分が直線であったが、一般に販売、流通している多くの傘は直線ではない。そこで今後の研究では、2 つ以上の角度を組み合わせた傘の形状や、滑らかな曲線のサンプルを作れば、今回の結果と比較することができるだろう。2 つ以上の角度を組み合わせる場合、上部には大きな角度を用い、端部には小さな角度を用いる。また表面張力の大きさは水の温度にも依存する。そこで、次は雨の温度に近い 0℃付近の水を用いて実験を行う。

今回用いたような霧吹きによってつくられるサイズの雨滴の温度は、地上の気温とさほど変わらないと考えられるが、大粒の雨であれば地上の温度よりも低くなることも考えられる。次は水滴の大きさの調節や水温を変更し実験を行う。これらの実験が終了し、理想的な形状を決定したのち、さまざまな素材の中で、どの素材が一番適しているかを考えることができる。例えば、晴雨兼用傘は綿や麻でできており、ビニール傘とその他の日傘の違いを考えることも可能である。

5. 引用文献

・Angle Master 360.(2019).Angle master(Version 5.02)[スマートフォン]app store.

・DIY 水平器-カメラで確認しながら水平を確認できる(Version 1.04)[スマートフォン]app store.

The Relationship between the Shapes of Umbrellas and the Number of Raindrops that Remains on the Surface

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

After it rains, many raindrops remain on the surface of the umbrella. Then, the umbrella is closed, and raindrops fall to the floor. There are ways to prevent this problem, but many commercial facilities in Japan have adopted polyethylene umbrella bags. However, this method harms the environment because it produces a lot of plastic waste. At the root of this problem is the water that is brought into the building, and the solution to this problem is to remove as much rainwater as possible from the surface of the umbrella outside of the building. This research does not focus on temporary solutions such as waterproof umbrellas, but the shape of umbrellas which would be a permanent solution. This research focuses on the opening angle of an umbrella, which allows water to drop more easily to the ground. Typically, the surface of the umbrella is made of polyester. This research made seven samples of laminated film made of polyester at different angles. As a result, as the opening angle of the umbrella decreases, the amount of rainwater per unit area also decreases. Samples were made at the central angle. But for the range of central angles used in this study, the opening angle calculated from the central angle is an inverse function of sin, and a straight line can approximate this function. In future research, the number of experiments will increase, and the material of samples will vary.

Keywords: umbrella, shape, opening angle, surface, raindrops, remain

I. Introduction

After it rains, many raindrops remain on the surface of the umbrella. Then, when the umbrella is closed, the raindrops fall to the floor. One way to prevent this problem is to use plastic umbrella bags. However, this produces a lot of waste, leads to environmental problems, and wet plastic bags require more energy to deal with. Thus, it can be suggested that changing the shape of the umbrella will improve efficiency in removing surface raindrops more easily. In this research, seven sample umbrellas with different opening angles were made. Then the water fired from the misting sprayer was used as rain to record the state of removing water.

II. Materials and Method

Making Samples

Kent paper, a compass, scissors, a protractor, super glue, a laminator, laminating film, compass cutter, and plastic clay were used to make samples. The materials used for the samples were Kent paper and laminated film. It was assumed that if the paper were not smooth and flat, water would be held in the small holes, which could lead to errors in the experiment results. However, Kent paper is smooth and flat, which was suitable for this study. Also, laminate film is the same material used for plastic umbrellas, so it was also determined to be suitable. Seven kinds of different shapes of samples were made and experimented upon.

First, Kent paper was cut into circles with a radius of 6 cm using a compass cutter. These circles were then cut as shown in Figure 1. The central angles were 330°, 315°, 300°, 285°, 270°, 255°, and 240°. After this, they were laminated using a laminator and circles were cut out. The cut-out circle overlap was left as an instant adhesive allowance. Next, each was rolled up into a conical shape and fixed with super glue. Finally, two apps were used to measure the angle of a

photo taken horizontally to compare with the theoretical value. One app checks the horizontality of the iPhone. Another app measures the angle between two lines.

Fig.1 Kent paper with center corner cut out

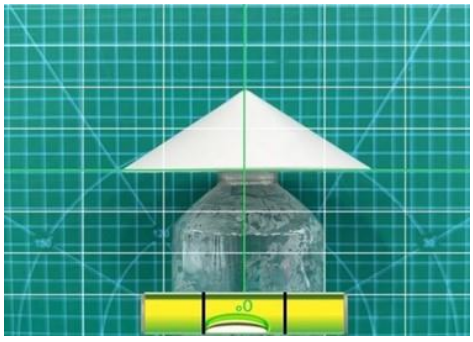


Fig.2 Sample viewed from the side

Experiment

For this experiment, materials such as a saucer, a wood piece (50 mm square), a plastic bottle, a misting sprayer, military gloves, an electronic balance, tap water, a wire net, a chamois towel, and a thermometer and hygrometer were utilized.

Initially, the ambient temperature and humidity were measured to set a baseline for the experiment. Following this, a saucer was placed on the electronic balance, and a piece of wood was positioned atop it.

The next step involved placing the model on the wood piece. This assembly was weighed, and the data were recorded in a table. A wire net was positioned to simulate rainfall to hold a misting sprayer 29.5 cm above the umbrella's top, as illustrated in Figure 2.

Subsequently, the samples were sprayed with approximately 10 g of water using the misting sprayer. After spraying, each sample, now bearing water, was weighed again. A chamois towel was used to remove the sample carefully to prevent water from dripping onto the saucer.

The final step of the procedure was to weigh the water collected on the saucer. This measurement was used to calculate the umbrella's effectiveness in shedding water.

Fig.3 Experiment setup

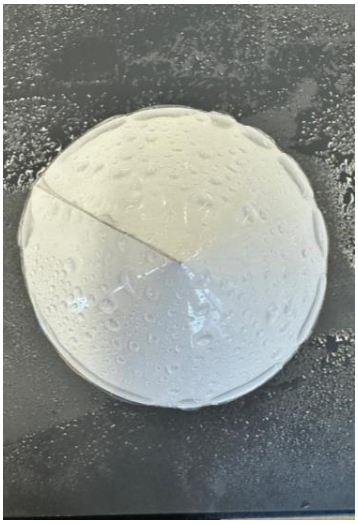


Fig.4 View from above

Fig.5 View from the side

In this experiment, the water emitted from the misting sprayer was simulated as rain, and the water used was returned to room temperature. Also, a piece of wood was used to ensure that there would not be errors in the values. If this were not used, the sample would be placed directly on the saucer. In this case, the water would be on the bottom of the sample, and it would be impossible to remove the sample. So, a piece of wood prevents this from happening. In Addition, since sufficient water was applied to the umbrella, the effect of wind is not considered.

III. Data Analysis

Making Samples

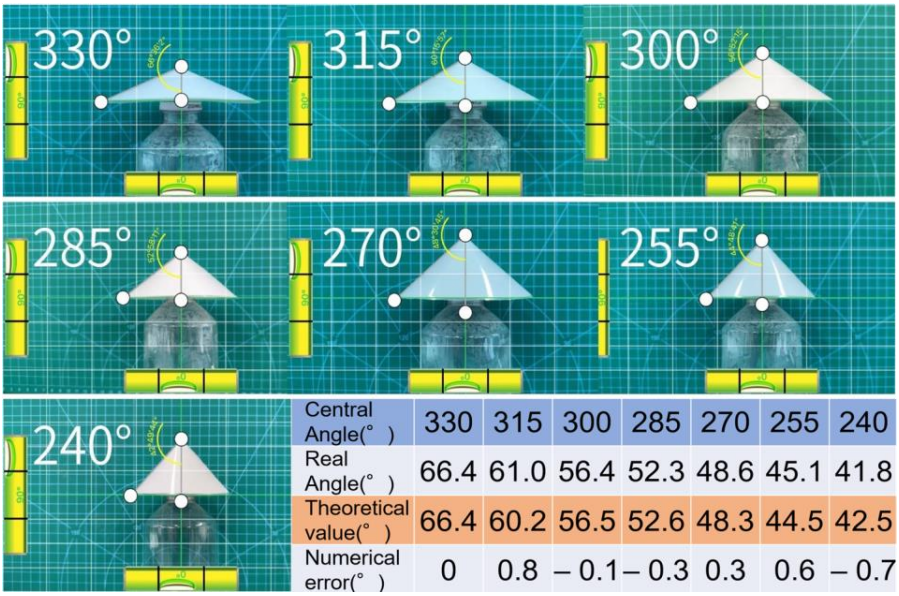
The angle between the surface of the sample and the vertical axis is called the opening angle. These calculations of angles are as follows:

- The opening angle = arcsin(θ/360)
- The Amount of Water per unit Surface Area

  = M*360/θ/r ²*PI
- The Amount of Water per unit of Horizontal Projection

  Area = M/(360/0) ²*pI

The theoretical values are in the second row, and the measured values are in the third row of Figure 6. The difference between them is less than 1 degree in each column. So, these were considered suitable to use in the experiment.



Central Angle(°)	330	315	300	285	270	255	240
Real Angle(°)	66.4	61.0	56.4	52.3	48.6	45.1	41.8
Theoretical value(°)	66.4	60.2	56.5	52.6	48.3	44.5	42.5
Numerical error(°)	0	0.8	– 0.1	– 0.3	0.3	0.6	– 0.7

Fig.6 Relationship between center angle and opening angle and their errors

Experiment

A total of six experiments were conducted over two days. The temperature and humidity on the two days did not differ significantly: 25°C:40% on Day 1 and 26°C:37% on Day 2. Therefore, the results were combined into a box-and-whisker diagram for each angle. The green color represents the average of Day 1, and the blue color represents the average of Day 2. Orange represents the total mean, and the orange dotted line represents its approximate line. Figure 7 is related to the amount of water per unit surface area. Figure 8 shows the amount of water per horizontal projection area.

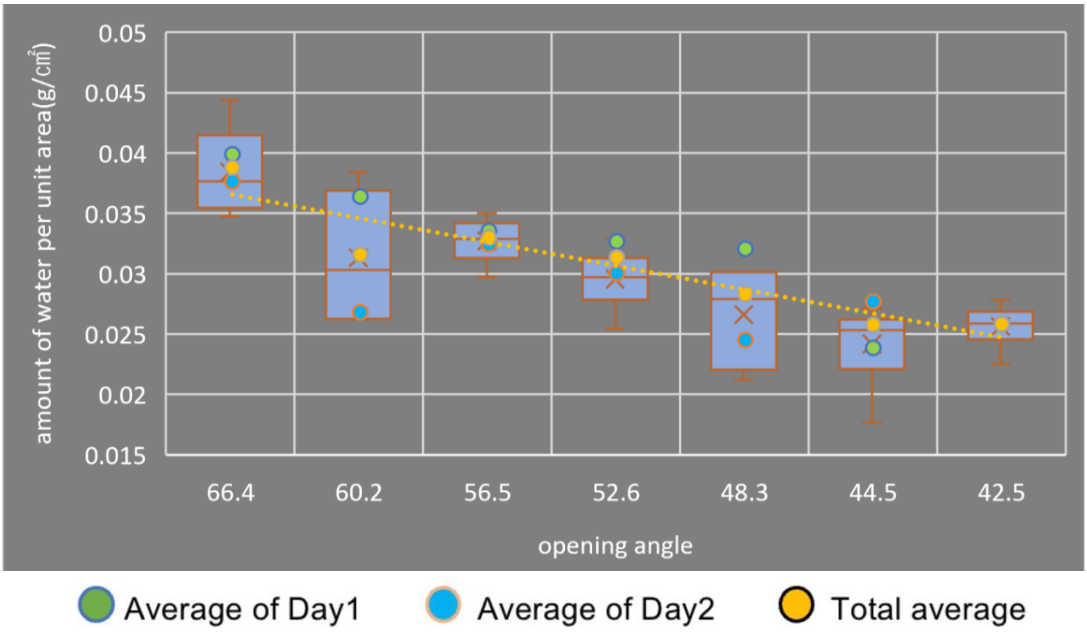


Fig.7 Amount of water per unit of surface area for each opening angle.

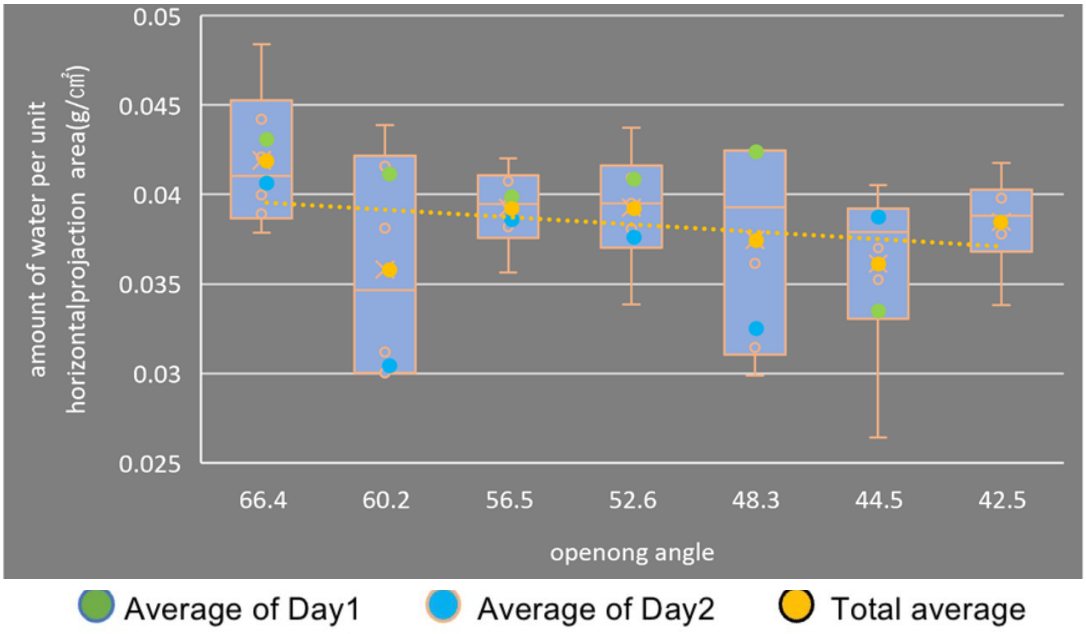


Fig.8 Amount of water per unit of the horizontal projection area

IV. Discussion

As illustrated in Fig. 7, an analysis of the data reveals a notable trend: the amount of water retained per unit area on the umbrella samples tends to decrease as the opening angles change.

This decrease in water retention is more pronounced in umbrellas with larger opening angles. A key factor contributing to this trend is the variation in the speed at which water flows off the umbrella at different angles. Water accumulation at the umbrella's rim also played a significant role in this phenomenon.

Moreover, it was observed that when water from the misting sprayer landed on the umbrella's surface, the existing water droplets absorbed the new ones and flowed downwards. This process was more commonly seen in samples with smaller opening angles. As a result, the measured values for umbrellas with smaller opening angles showed more variability with each measurement.

V. Conclusion

From this research, it was thought that the "dew-tip" component on commercial umbrellas not only stretches the cloth but also plays a role in facilitating water removal. This thought is because of the phenomenon of water remaining on the edges of the cloth. This phenomenon is unlikely to occur when using a real umbrella. In addition, the angles suitable for the edges and those suitable for the vertices were different, and it was thought that combining them would yield better results.

VI. Future Research

In this experiment, the sample of the umbrella was straight. However, most umbrella canopies are not straight. So, for future research, if shapes of umbrellas combining two or more angles or a smooth curved sample are made, it would be possible to compare the results with the present results. When combining two or more angles, a large angle would be used for the top and a smaller angle for the edges. In addition, the magnitude of surface tension also depends on the temperature of the water. Therefore, the next experiment would use water near 0°C, close to the

rain temperature. After finding the optimal shape, experiments. Which material is best suited for various materials can be considered. For example, plastic umbrellas are made of cotton and hemp, and it is possible to consider the difference between a plastic umbrella and a parasol.

VII. Acknowledgements

We would like to thank our advisors, Dr. Mie Ichikawa and Mr. Ryojiro Tsujimoto, for their helpful advice and guidance throughout our research project.

VIII. References

Angle Meter 360. (2019). Angle Meter (Version 5.02) [Mobile App]. Apple Store. https://apps.apple.com/jp/app/angle-meter-360/id1393860479

DIY 水平器-カメラで確認しながら水平を確認できる [DIY leveler-Leveling can be checked with the camera]. (2023). (Version 1.04) [Mobile App]. Apple Store. https://apps.apple.com/jp/app/DIY 水平器-カメラで確認しながら水平を確認できる/id6449055203

The Relationship between the Shapes of Umbrellas and the Amount of Raindrops that Remains on the Surface

Ritsumeikan High School

Abstract

After it rains, many raindrops often remain on the surface of the umbrella. Moreover, when the umbrella is closed, raindrops fall onto the floor. Currently, there are ways to prevent this problem, but many commercial facilities in Japan have adopted the use of polyethylene umbrella bags. However, this method is harmful to the environment because it produces a lot of plastic waste. At the root of this problem is the water that is brought into the building, and the solution to this problem is to remove as much rainwater as possible from the surface of the umbrella outside of the building. This research does not focus on temporary solutions such as waterproof umbrellas, but the shape of umbrella which would provide a permanent solution. This research focuses on the opening angle of an umbrella which allows water to drop more easily to the ground. Typically, the surface of the umbrella is made of polyester. This research made seven samples at different angles made of laminated film, made of polyester. As a result, as the opening angle of the umbrella decreases, the amount of rainwater per unit area also decreases. Samples were made at the central angle. But for the range of central angles used in this study, the opening angle calculated from the central angle is an inverse sin function, and this function can be approximated by a straight line. For future research, the number of experiments will increase, and the material of samples will vary.

Introduction

After it rains, many raindrops often remain on the surface of the umbrella. When the umbrella is closed, these raindrops fall to the floor. One way to prevent this problem is by using plastic umbrella bags. However, this produces a lot of waste and leads to environmental problems. Thus, it can be suggested that changing the shape of the umbrella could improve its efficiency to remove surface raindrops more easily. In this research, seven sample umbrellas with different opening angles were made. Then, a mist was used to imitate rain and the removal of water was recorded as shown in Fig. 6.

Materials and Methods

Sample making----------

(Materials)

Kent paper, Compass, Scissors, Protractor, Super glue, Laminator, Laminating film, Compass cutter, Plastic clay

(Methods)

1) Kent paper was cut into a radius of 6 cm circles by using a compass cutter.
2) (1) were cut as shown in (Fig.1).The central angles were 330°, 315°, 300°, 285°, 270°, 255°, and 240°.
3) (2) was laminated by using a laminator and circles were cut out. During this time an overlap was left in the cut-out circles as an allowance for instant adhesive.
4) (3) was rolled up into a conical shape and fixed with super glue.
5) Two apps were used to measure the angle of a photo taken in a horizontal state to compare with the theoretical value.

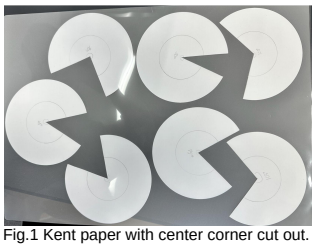


Fig.1 Kent paper with center corner cut out.

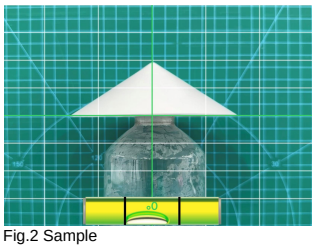


Fig.2 Sample

Experiment----------

(Materials)

Saucer, Wood (50 mm square), Plastic bottle, Misting sprayer, Military gloves, Electronic balance, Tap water, Wire net, Chamois towel, Thermometer and Hygrometer

(Methods)

1) The temperature and humidity were measured before the experiment.
2) A saucer was placed on the electronic balance and a piece of wood was placed on top of it.
3) The model was placed on a piece of wood, which was weighed and data was put in a table.
4) A wire net was used to place a misting sprayer 29.5 cm above the top of the umbrella as shown in (Fig.2).
5) Samples were sprayed with water (about 10 g) by using a misting sprayer.
6) (5) was weighed and the sample was removed by using a chamois towel to prevent water from falling onto the saucer.
7) The water on the saucer was weighed and calculated.

Fig.3 Experiment

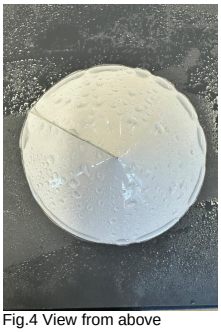
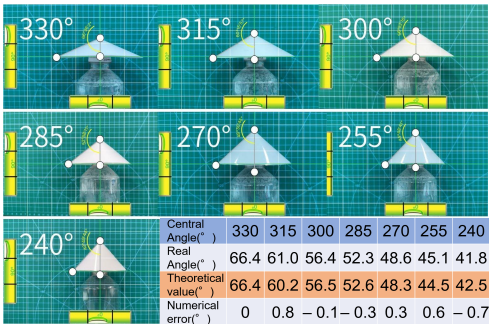


Fig.4 View from above

Fig.5 View from side

Results



Central Angle(°)	330	315	300	285	270	255	240
Real Angle(°)	66.4	61.0	56.4	52.3	48.6	45.1	41.8
Theoretical value(°)	66.4	60.2	56.5	52.6	48.3	44.5	42.5
Numerical error(°)	0	0.8	−0.1	−0.3	0.3	0.6	−0.7

The opening angle
= arcsine(θ/360)

The amount of water per unit surface area
= M*360/θ/r²*PI

The amount of water per unit horizontal projection area
= M/(360/θ)²*PI

θ: Central angle
M: Average of Amount of Water
r: radius

Fig.6 Relationship between center angle and opening angles and their errors.

The angle between the surface of sample and vertical axis is called the opening angle. The theoretical values are in the second row and the measured values are in the third row of Fig. 6. The difference between them is less than 1 degree in each column.

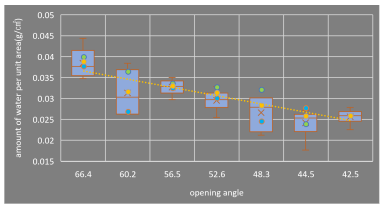
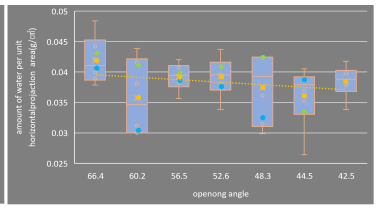


Fig.7 Graphs related to the amount of water per unit of surface area.



Average of Day1 Average of Day2 Total average

Fig.8 Graphs related to the amount of water per unit of horizontal projection area.

This time, a total of six experiments were conducted over two days. The temperature and humidity on the two days did not differ significantly: 25°C:40% on the first day and 26°C:37% on the second day. Therefore, the results were combined into a box-and-whisker diagram for each angle. The green color represents the average of Day 1, and the blue color represents the average of Day 2. Orange represents the total mean, and the orange dotted line represents its approximate line. And the left graph is related to the amount of water per unit surface area. And the right graph shows the amount of water per horizontal projection area.

Discussion

The amount of water per unit area decreases gradually as the opening angles change as shown in (Fig.7). The reason for the larger range between the approximate straight line and the average of the measured values for those with larger opening angles was the difference in the speed at which water flows at different angles. Also, the fact that the water was retained at the rim of the umbrella was a major factor. In addition, when the water that was sprayed from the misting sprayer fell on the surface of the umbrella, the water that stayed on the surface was absorbed by other drops and flowed down. This appeared more frequently for those with smaller opening angles, so the values for those with smaller opening angles often changed with every measurement.

Conclusions / Future Plan

From this research, it was thought that the “dew-tip” component on commercial umbrellas not only stretches the cloth, but also plays a role in facilitating water removal. The reason for this thought is because of the phenomenon of water remaining on the edges of the cloth. This phenomenon is unlikely to occur when using a real umbrella. For future research, real plastic umbrellas should be used to consider the role of dew-tips and use the results to create a model for future experiments. In this experiment, the sample of the umbrella was straight. However, most umbrella canopies is not straight. So, if a shape combining two or more angles or a smooth curved sample is produced, it would be possible to compare the results with the present results. After finding the optimal shape, experiments should be conducted with a cotton/hemp blend fiber as used in sunshade umbrellas.

References

Angle Meter 360. (2019).*Angle Meter* (Version 5.02) [Mobile app]. Apple Store.https://apps.apple.com/jp/app/angle-meter-360/id1393860479

DIY水平器-カメラで確認しながら水平を確認できる [DIY leveler-Leveling can be checked with the camera] (2023). (Version 1.04) [Mobile app].Apple Store.

和音に最適な周波数の比

要旨

この研究の目的は、和音の響きを良くするために最適な周波数の比を求めることである。楽器の調律法として一般的な平均律は、最良の響きを持つ和音を奏でることはできない。より良い和音を奏でるためには、音程を調整する必要がある。和音の美しさは、周波数の比の最小公倍数と密接な関係があると考えられる。この考えを元に、重要な和音に最適な周波数の比を求めた。メジャーコードは 4:5:6、マイナーコードは 10:12:15、オーギュメントコードは 16:20:25、ディミニッシュコードは 5:6:7、サスフォーコードは 6:8:9 である。これらの比を活用することで、作曲家や音楽家が綺麗な和音で曲を演奏し、新しい音楽を創造できるようになるだろう。

1. はじめに

1－1. 背景

私たちが普段から耳にするドレミファソラシの音には、それぞれに決まった周波数が割り当てられている。このように音の高さの関係を一定の方法によって整理したものを音律という。現在広く使われている音律は平均律といい、ピアノなどあらゆる楽器の調律に用いられる。しかし複数音を同時に鳴らした時の響きがイマイチだという欠点がある。そこで音の高さを微調整することで響きを改善できると考えた。

1－2. 和音とは

和音とは周波数の異なる二つ以上の音を同時に鳴らしたときの合成音のことをいう。人が心地良いと感じる和音は、周波数の比が簡単な整数比で表されると言われており、これには倍音の一致やズレが関係している。ピアノなどの楽器で音を鳴らすと、基本となる音（基音）だけでなく倍音も同時に鳴る。2 つの音の周波数がわずかに異なる時、うなりが生じるため和音が濁って聞こえる。うなりは基音だけでなく倍音同士でも生じる。例えばドミソの和音は周波数の比が 4:5:6（純正律の場合）となる。それぞれの倍音の周波数が（12,20,24,30…で）一致するためうなりが生じず、心地良い響きとなる。

表 1 和音の心地良さと倍音の関係

	基音	2 倍音	3 倍音	4 倍音	5 倍音	6 倍音
ド	4	8	12	16	20	24
ミ	5	10	15	20	25	30
ソ	6	12	18	24	30	36

1－3. 平均律とは

平均律とは現在一般的に使われている音律で、1 オクターブを 12 等分したものだ。音の高さの間隔が均等であるため、キーを変えても演奏が可能だという大きな利点がある。そのためピアノなどあらゆる楽器は平均律で調律されている。しかし平均律の和音は、周波数の比が簡単な整数比で表すことができない。そのため倍音同士でうなりが生じて、和音の響きが綺麗にならないという欠点がある。

1－4. 純正律とは

純正律とは和音の響きの綺麗さを重視した音律だ。ドミソの和音は周波数の比が 4:5:6 となる。簡単な整数比で表すことができるため、和音の響きが心地よい。しかし和音の響きが綺麗にならない和音もある。レファラの和音は周波数の比が 27:32:40 となる。簡単な整数比とは言えないため、和音の響きはあまり良くない。

1－5. 最適な和音

和音の綺麗さをより正確に調べることは可能だろうか。周波数の比の最小公倍数が小さい和音は合成音の周期が短いため、より心地良く聞こえると考えた。純正律では、ドミソの和音の周波数の比は 4:5:6 なので最小公倍数は 60、レファラの和音の周波数の比は 27:32:40 なので最小公倍数は 4320 となる。したがって、最小公倍数の小さいドミソの和音の方がレファラの和音よりも綺麗だと考えられる。和音の綺麗さは最小公倍数の小ささで決まると仮定して研究を進めることにした。

2. 実験方法と結果

2－1. 使用したもの

数字を大量に扱うために Google Apps Script と Google スプレッドシートを使用した。また Scale Workshop という入力した音程を手軽に鳴らせる Web ページを使用し、実際に和音を聴き比べながら実験を行った。

2－2. 実験 1 の和音

実験 1 の目的はよく使われる和音の最適な周波数の比を最小公倍数から求めることだ。よく使われる和音を以下の表 2 にまとめた。3 つの音で構成される和音（3 和音）の実験から始めた。ただし扱う和音は 1 オクターブの範囲に収まるものとする。1 オクターブとはある音とその 2 倍の周波数を持つ音との間隔のことだ。つまり 1 オクターブに収まる和音は、周波数の比を構成する最大値が最小値の 2 倍未満である場合のみ成り立つ。

表 2 コード一覧

	コード名	読み方	構成音（根音がドの場合）
3和音	M	メジャー	ド ミ ソ
	m	マイナー	ド ミ♭ ソ
	aug	オーギュメント	ド ミ ソ#
	dim	ディミニッシュ	ド ミ♭ ソ♭
	sus4	サスフォー	ド ファ ソ
4和音	6	シックス	ド ミ ソ ラ
	7	セブンス	ド ミ ソ シ♭
	M7	メジャー・セブンス	ド ミ ソ シ
	m7	マイナー・セブンス	ド ミ♭ ソ シ♭
	mM7	マイナー・メジャー・セブンス	ド ミ♭ ソ シ
	dim7	ディミニッシュ・セブンス	ド ミ♭ ソ♭ シ♭♭
	7(♭5)	セブンス (フラッテッド・フィフス)	ド ミ ソ♭ シ♭
	m7(♭5)	マイナー・セブンス (フラッテッド・フィフス)	ド ミ♭ ソ♭ シ♭
	7sus4	セブンス・サスフォー	ド ファ ソ シ♭

2－3. 実験 1

2－3－1. 比のデータを収集する

1 オクターブに収まる 3 和音の周波数の比を求めて表に書き込んだ。1 オクターブに収まる 3 和音を、周波数の比が小さい順に求めるプログラムを作成し実行した。3:4:5、4:5:6、4:5:7 と続いた。また周波数の比を構成する 3 つの数値の最小公倍数を求めた。

表 3 周波数の比と最小公倍数

周波数の比（音 1：音 2：音 3）			最小公倍数
3	4	5	60
4	5	6	60
4	5	7	140
4	6	7	84
5	6	7	210
5	6	8	120
⋮			

2−3−2. 最適な比に並び替える

3 つの数値の最大公約数が書かれた列を作成した。最大公約数が 2 以上になる列を表示しないフィルタをかけることで、6:8:10 のように約分可能な周波数の比を取り除いた。また必要な和音は最小公倍数の小さいものだけなので、最小公倍数の小さい順に並び替えた。

表 4 最適な周波数の比に並び替え

周波数の比（音 1：音 2：音 3）			最小公倍数	最大公約数
3	4	5	60	1
4	5	6	60	1
10	12	15	60	1
12	15	20	60	1
6	8	9	72	1
8	9	12	72	1
4	6	7	84	1

⋮

2−3−3. 比から構成音を求める

表 4 の比で奏でられる和音はどんな音で構成されているのか知る必要があった。まずそのために 3 音は平均律のどの音に最も近いかを調べる方法を考えた。平均律ではどの音の周波数に $2^{1/12}$ をかけても半音上の音になるという特徴がある。表 5 は平均律の音の周波数の比率とその音とみなす範囲を表している。図 1 はその音とみなす範囲を表している。

表 5 平均律の音程（ドを 1 とする場合）

音名	周波数の比率	その音とみなす範囲
ド	1	1 ～ $2^{0.5/12}$
ド#	$2^{1/12}$	$2^{0.5/12}$ ～ $2^{1.5/12}$
レ	$2^{2/12}$	$2^{1.5/12}$ ～ $2^{2.5/12}$
レ#	$2^{3/12}$	$2^{2.5/12}$ ～ $2^{3.5/12}$
ミ	$2^{4/12}$	$2^{3.5/12}$ ～ $2^{4.5/12}$
ファ	$2^{5/12}$	$2^{4.5/12}$ ～ $2^{5.5/12}$
ファ#	$2^{6/12}$	$2^{5.5/12}$ ～ $2^{6.5/12}$
ソ	$2^{7/12}$	$2^{6.5/12}$ ～ $2^{7.5/12}$
ソ#	$2^{8/12}$	$2^{7.5/12}$ ～ $2^{8.5/12}$
ラ	$2^{9/12}$	$2^{8.5/12}$ ～ $2^{9.5/12}$
ラ#	$2^{10/12}$	$2^{9.5/12}$ ～ $2^{10.5/12}$
シ	$2^{11/12}$	$2^{10.5/12}$ ～ $2^{11.5/12}$
ド	2	$2^{11.5/12}$ ～ 2

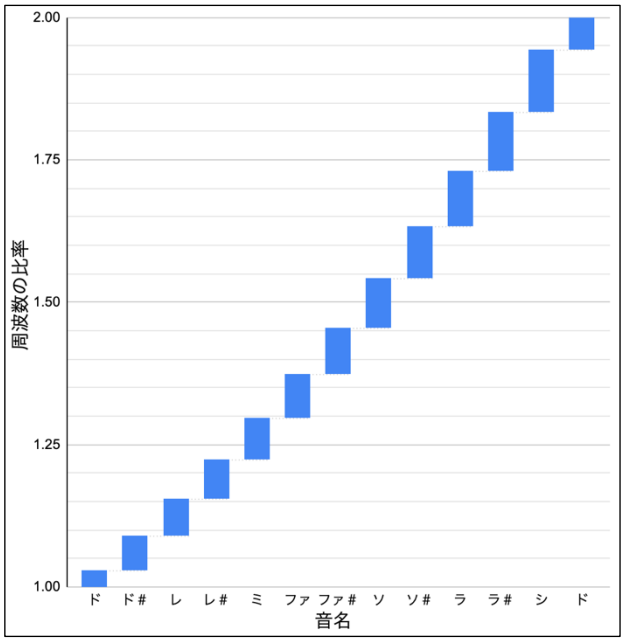


図 1 その音とみなす範囲

例えば 4:5:6 の周波数の比を持つ和音では、比の最小値を 1 とした時 1.00:1.25:1.50 になる。1.00 はド、1.25 はミとみなし、1.50 はソとみなせるから構成音はドミソであることがわかる。表 6 は表 4 で求めた周波数の比が何の音で構成されている和音かをまとめたものだ。

表 6 周波数の比に対応する音

最小公倍数	ド	ド# レ♭	レ	レ# ミ♭	ミ	ファ	ファ# ソ♭	ソ	ソ# ラ♭	ラ	ラ# シ♭	シ
60	3					4				5		
60	4				5			6				
60	10			12				15				
60	12				15					20		
72	6					8		9				
72	8		9					12				
84	4					6					7	

⋮

2－3－4. 最適な周波数の比を求める

表 2 と表 6 の構成音が一致する和音を調べることで 3 和音に最適な周波数の比を求め、表 7 にまとめた。

表 7 3 和音に最適な周波数の比

コード名	構成音	最適な周波数の比	最小公倍数
M	ド　ミ　ソ	4:5:6	60
m	ド　ミ♭　ソ	10:12:15	60
sus4	ド　ファ　ソ	6:8:9	72
dim	ド　ミ♭　ソ♭	5:6:7	210
aug	ド　ミ　ソ#	16:20:25	400

2－3－5. 4 和音に最適な周波数の比を求める

3 和音の時と同じ手順で行った。4 和音を構成する 4 つの数値を書き出し、最小公倍数の小さい順に並べ替え、最大公約数が 1 だけを表示した。また、それら 4 つの数値からなる和音が何の音で構成されるか表 8 にまとめた。

表 8 4 和音の周波数の比

周波数の比 (音 1 : 音 2 : 音 3 : 音 4)	最小公倍数	ド	ド# レ♭	レ	レ# ミ♭	ミ	ファ	ファ# ソ♭	ソ	ソ# ラ♭	ラ	ラ# シ♭	シ
8 10 12 15	120	8				10			12				15
9 10 12 15	180	9		10			12				15		
10 12 15 18	180	10			12				15			18	
12 15 18 20	180	12				15			18		20		
10 12 15 16	240	10			12				15	16			
12 15 16 20	240	12				15	16				20		
15 16 20 24	240	15	16				20			24			
12 14 18 21	252	12			14				18			21	
12 14 16 21	336	12			14		16					21	
14 16 21 24	336	14		16					21		24		

16	21	24	28	336	16					21		24			28
5	6	8	9	360	5			6					8		9
6	8	9	10	360	6					8		9		10	
8	9	10	12	360	8		9		10			12			
8	9	10	15	360	8		9		10						15

⋮

表 2 と表 8 の構成音が一致する和音を調べ、4 和音に最適な周波数の比を求めた。

表 9 4 和音に最適な周波数の比

コード名	構成音	最適な周波数の比	最小公倍数
M7	ド ミ ソ シ	8:10:12:15	120
m7	ド ミ♭ ソ シ♭	10:12:15:18	180
6	ド ミ ソ ラ	12:15:18:20	180
7sus4	ド ファ ソ シ♭	16:21:24:28	336
7	ド ミ ソ シ♭	4:5:6:7	420
m7(♭5)	ド ミ♭ ソ♭ シ♭	5:6:7:9	630
7(♭5)	ド ミ ソ♭ シ♭	20:25:28:35	700
dim7	ド ミ♭ ソ♭ シ♭♭	25:30:35:42	1050
mM7	ド ミ♭ ソ シ	10:12:15:19	1140

2－4. 実験 1 の課題点

実験 1 のやり方には少し問題があった。小さい数値を持つ周波数の比から表に書き込むプログラムを実行したことにより、大きい数値を持つ周波数の比を処理するまでに時間がかかったことだ。3 和音では扱う数値が 3 つだけなので大きな問題ではない。しかし 4 和音の場合、4:5:6:7 から始めて 30:57:58:59 までしか処理できなかったため、大きい数値を持つ最小公倍数が小さい比を見つけることができていない可能性がある。つまり実験 1 で求めた「和音に最適な周波数の比」は完璧ではない可能性がある。

2－5. 実験 1 の課題点の解決策

解決策として考えられたのは、ある数値の約数から 3 つの数値や 4 つの数値を取ってくることだ。1 から 2000（4 和音の最適な周波数の比の最小公倍数が 2000 を超えることはないと考えられるから十分な数値と言える）まで書き込み、約数の個数と約数を求めた。これらの約数から 1 オクターブに収まる 3 和音や 4 和音の周波数の比を求めることで、最小公倍数が小さい順に比を求めることができると考えている。現在検証を進めているところだ。

表 10 約数

数値	約数の個数	約数
1	1	1
2	2	1 2
3	2	1 3
4	3	1 2 4
5	2	1 5
6	4	1 2 3 6
7	2	1 7
8	4	1 2 4 8
9	3	1 3 9
10	4	1 2 5 10
11	2	1 11
12	6	1 2 3 4 6 12
⋮		
2000	20	1 2 4 5 10 16 …

2－6. 実験 2 の目的

実験 2 の目的は実験 1 で求めた和音に最適な周波数の比を活用し、音程を調整することだ。純正律を基盤にして考え、心地悪いレファラの和音の響きを改善する。

2－7. 実験 2

2－7－1. C メジャースケールにおけるダイアトニックコード

C メジャースケールとはドの音から始まる長音階のことで、「ドレミファソラシ」の 7 音で構成されている。C メジャースケールにおけるダイアトニックコードとは「ドレミファソラシ」の 7 音で作ることができる基本的な和音のことだ。3 和音の場合「ドミソ」「レファラ」「ミソシ」「ファラド」「ソシレ」「ラドミ」「シレファ」の 7 種類となる。これらは C、Dm、Em、F、G、Am、Bdim と書くことができる。これらは C メジャースケールにおいて最も重要な和音であるため、最適な周波数の比で鳴らせる必要があった。

2－7－2. C メジャースケールの音程を考え直す

純正律ではドを 1 としたときの音程の周波数の比率は以下のようになっている。

表 11 純正律の音程

ド	レ	ミ	ファ	ソ	ラ	シ
1/1	9/8	5/4	4/3	3/2	5/3	15/8

これらの音程で作ることができるダイアトニックコード 7 種類の周波数の比を表 12 にまとめた。

表 12 からわかるように、Dm コード（レファラ）と Bdim コード（シレファ）の周波数の比が実験 1 で求めた最適な周波数の比と一致していないことがわかる。Dm コードと Bdim コードを最適な周波数の比にするために音程を調整した。表 13 はダイアトニックコードを弾くときにどの音程を使えば最適になるかをまとめたものだ。Dm コード（レファラ）を弾くときはレの音程を 9/8 から 10/9 に少し下げることで、最適な周波数の比である 10:12:15 を実現した。また Bdim コード（シレファ）を弾くときはファの音程を 4/3 から 21/16 に少し下げることで、最適な周波数の比である 5:6:7 を実現した。

表 12 ダイアトニックコードの周波数の比

コード名	C	Dm	Em	F	G	Am	Bdim
構成音	ドミソ	レファラ	ミソシ	ファラド	ソシレ	ラドミ	シレファ
コードの種類	M	m	m	M	M	m	dim
周波数の比	4:5:6	27:32:40	10:12:15	4:5:6	4:5:6	10:12:15	45:54:64
最適な周波数の比	4:5:6	10:12:15	10:12:15	4:5:6	4:5:6	10:12:15	5:6:7

表 13 ダイアトニックコードの最適な音程

	ド	レ	ミ	ファ	ソ	ラ	シ
C	1/1		5/4		3/2		
Dm		10/9		4/3		5/3	
Em			5/4		3/2		15/8
F	1/1			4/3		5/3	
G		9/8			3/2		15/8
Am	1/1		5/4			5/3	
Bdim		9/8		21/16			15/8

3. 考察

Dm コードや Bdim コードを弾くときに、これらの調整した音程に切り替えることができたらより綺麗に曲を演奏できると考えられる。しかし実際に人間が複数の音程を使い分けるのは難しいだろう。

4. 今後の展望

①　より多くの和音の最適な音程を求める

4 和音のダイアトニックコードやノンダイアトニックコードであるセカンダリードミナントなどのよく使われる和音に対応するために、音程の調整の仕方を音楽理論から考える必要がある。

②　楽器アプリを作る

状況に応じて最適な音程を使い分けるのは難しいので、和音を弾くと自動的に最適な音程に調整される楽器を作る。Unity というゲームエンジンで制作し、スマホやパソコンで演奏できるようにする予定だ。

③　曲を聴き比べる

平均律の楽器、純正律の楽器、最適な音程に自動調整される楽器をアプリ上で曲を演奏し、聴き比べる。これにより本当に曲が心地良く聞こえるのかを調べ、実用性があるか確かめる必要がある。

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Optimal Frequency Ratio for Chords

G12 SSG Course

Ritsumeikan High School

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Abstract

This research aims to determine the optimal frequency ratios to enhance chord quality. While equal temperament, a commonly used tuning method for instruments like the piano, has its merits, it cannot produce the best-sounding chords. To address this issue, adjusting the intervals is essential to obtain better-sounding chords. The beauty of chords is closely linked to the least common multiple (LCM) of their frequency ratios. Through this research, optimal frequency ratios have been identified for various chord types: Major chords: 4:5:6, Minor chords: 10:12:15, Augmented chords: 16:20:25, Diminished chords: 5:6:7, and Suspended 4th chords: 6:8:9. Utilizing these ratios helps musicians create more beautiful chords. For future research, an instrument will be created to be used on a computer or mobile phone. This instrument will be able to adjust optimal intervals automatically.

Keywords: frequency ratio, chord quality, least common multiple, interval

I. Introduction

A chord is a composite sound when three or more notes of different pitches are played simultaneously. It produces harmony, which sounds better when its frequency ratio is expressed as a simple integer ratio.

Equal temperament, widely used today, is one octave divided into 12 parts where the ratios between adjacent notes are equal. Since the intervals are equal, it is possible to play in different keys. However, it does not produce a beautiful chord sound because the frequency ratios of the chords cannot be expressed in integer ratios.

Just intonation is an excellent temperament for making beautiful-sounding chords. In just intonation, the C major chord (C-E-G) sounds beautiful. This is because the frequency ratio is 4:5:6, a simple integer ratio. However, the D minor chord (D-F-A) does not sound good. This is because the frequency ratio is 27:32:40, which is not a simple integer ratio. It is considered that more beautiful chords can be played by adjusting the intervals of the D minor chord.

Chords with smaller LCM frequency ratios could sound more beautiful because of the shorter period of the composite waveforms. In just intonation, the frequency ratio of the C major chord (C-E-G) is 4:5:6, so its LCM is 60; the frequency ratio of the D minor chord (D-F-A) is 27:32:40, so its LCM is 4320. Therefore, the C major chord with the LCM of 60 is considered more beautiful than the D minor chord with the LCM of 4320.

II. Materials and Method

A MacBook Air M1 is used for the experiments.

III. Data Analysis

Step 1: Sort Frequency Ratios

The frequency ratios of the triads in Table 1 were set so that the largest value was less than twice the smallest value within the same octave. The order of LCM was sorted from the smallest to the largest. Only ratios with the greatest common divisor (GCD) of 1 were listed. Table 1 indicates the triads that fit in one octave which sound better toward the top.

Table.1 Optimal frequency ratio of triads

Frequency ratio			LCM	GCD
3	4	5	60	1
4	5	6	60	1
10	12	15	60	1
12	15	20	60	1
6	8	9	72	1
8	9	12	72	1

Step 2: Examine Notes from Ratios

The frequency ratio of basic chords was examined to determine which notes were used for the chord based on the frequency ratio that was obtained in Step 1. For example, the top row of Table 2 shows that a chord with a frequency ratio of 3:4:5 is composed of the notes C-F-A.

Table.2 Relation between a frequency ratio and notes

C	C# Db	D	D# Eb	E	F	F# Gb	G	G# Ab	A	A# Bb	B
3					4				5		
4				5			6				
10			12				15				
12				15					20		
6					8		9				
8		9					12				

Step 3: List Components of Chords

The component notes from basic chords were confirmed. Table 3 lists the notes that compose the basic chords: Major (maj), Minor (min), Augmented (aug), Diminished (dim), and Suspended 4th (sus4).

Table.3 List of chord types and their component notes

Chord type	Component notes		
maj	C	E	G
min	C	Eb	G
aug	C	E	G#
dim	C	Eb	Gb
sus4	C	F	G

Step 4: Determine Optimal Ratios

The optimal frequency ratio for each chord was determined by considering Step 2 and Step 3. Table 4 lists the optimal frequency ratios for basic chords: Major: 4:5:6, Minor: 10:12:15, Augmented: 16:20:25, Diminished: 5:6:7, and Suspended 4th: 6:8:9.

Table.4 Optimal frequency ratios for each chord

Chord type	Ratio	LCM
maj	4 : 5 : 6	60
min	10 : 12 : 15	60
aug	16 : 20 : 25	400
dim	5 : 6 : 7	210
sus4	6 : 8 : 9	72

IV. Discussion

Mathematically right things are not always right to hear. We might have been already used to listening to songs that are not right.

V. Conclusion

The least common multiple determined the optimal frequency ratio of basic chords. This allowed for the adjustment of intervals in the D minor chord and B diminished chord, as they did not sound optimal in just intonation, ultimately achieving the desired frequency ratio.

VI. Future Research

In future research, the primary goal is to discover an improved method for calculating frequency ratios. This is crucial because the current method faces challenges when dealing with numerous ratios and small common multiples. Additionally, the aim is to develop a musical instrument capable of automatically adjusting to the ideal interval when playing chords. This

innovation is prompted by the difficulty of manually selecting the correct interval based on the musical context, and the goal is to simplify this process through automation.

VII. Acknowledgements

I wish to thank Mr. Koichiro Hiromatsu for his good advice.

VIII. References

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Optimal Frequency Ratio for Chords

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Abstract

This research aims to determine the optimal frequency ratios to enhance chord quality. While equal temperament, a commonly used tuning method for instruments like the piano, has its merits, it cannot produce the best-sounding chords. To address this issue, adjusting the intervals is essential to obtain better-sounding chords. The beauty of chords is closely linked to the least common multiple (LCM) of their frequency ratios. Through this research, optimal frequency ratios have been identified for various chord types: Major chords: 4:5:6, Minor chords: 10:12:15, Augmented chords: 16:20:25, Diminished chords: 5:6:7, and Suspended 4th chords: 6:8:9. Utilizing these ratios helps musicians create more beautiful chords. For future research, an instrument will be created to be used on a computer or mobile phone. This instrument will be able to adjust optimal intervals automatically.

Introduction

Chord

A chord is a composite sound when three or more notes of different pitches are played at the same time. It produces harmony and the harmony is said to sound better when its frequency ratio is expressed as a simple integer ratio.

Equal Temperament

Equal temperament, which is widely used today, is one octave divided into 12 parts where the ratios between adjacent notes are equal. Since the intervals are equal, it is possible to play in different keys. However, it does not produce a beautiful chord sound because the frequency ratios of the chords cannot be expressed in integer ratios.

Just Intonation

Just intonation is an excellent temperament for making beautiful sounding chords. In just intonation, the C major chord (C-E-G) sounds beautiful. This is because the frequency ratio is 4:5:6, which is a simple integer ratio. However, D minor chord (D-F-A) does not sound good. This is because the frequency ratio is 27:32:40, which is not a simple integer ratio. It is considered that by adjusting the intervals of the D minor chord, more beautiful chords can be played.

Beauty of Chords

Chords with smaller LCM of frequency ratios could be considered to sound more beautiful because of the shorter period of the composite waveforms. In just intonation, the frequency ratio of the C major chord (C-E-G) is 4:5:6, so its LCM is 60; the frequency ratio of the D minor chord (D-F-A) is 27:32:40, so its LCM is 4320. Therefore, the C major chord with the LCM of 60 is considered more beautiful than the D minor chord with the LCM of 4320.

Experiment 1

Aim

To determine the optimal frequency ratio of basic triads.

Materials

Basic triads on the right were used for Experiment 1:

- Major chord
- Minor chord
- Augmented chord
- Diminished chord
- Suspended 4th chord

Step 1: Sort Frequency Ratios

1. The frequency ratios of the triads into Table 1 was set so that the largest value was less than twice the smallest value within the same octave.
2. The order of LCM was sorted from the smallest to the largest.
3. Only ratios with the greatest common divisor (GCD) of 1 was listed.

Table 1 indicates the triads that fit in one octave which sound better toward the top.

Table 1 Optimal frequency ratios of triads

Frequency ratio			LCM	GCD
3	4	5	60	1
4	5	6	60	1
10	12	15	60	1
12	15	20	60	1
6	8	9	72	1
8	9	12	72	1

Step 2: Examine Notes from Ratios

The frequency ratio of basic chords was examined to determine which notes were used for the chord based on the frequency ratio that was obtained in Step 1.

For example, the top row of Table 2 shows that a chord with the frequency ratio of 3:4:5 is composed of the notes C-F-A.

Table 2 Relation between a frequency ratio and notes

C	C# Db	D	D# Eb	E	F	F# Gb	G	G# Ab	A	A# Bb	B
3					4				5		
4				5			6				
10			12				15				
12				15					20		
6					8		9				
8		9					12				

Step 3: List Components of Chords

The component notes from basic chords was confirmed.

Table 3 lists the notes compose the basic chords: Major (maj), Minor (min), Augmented (aug), Diminished (dim), and Suspended 4th (sus4).

Table 3 List of chord types and its component notes

Chord type	Component notes		
maj	C	E	G
min	C	Eb	G
aug	C	E	G#
dim	C	Eb	Gb
sus4	C	F	G

Step 4: Determine Optimal Ratios

The optimal frequency ratio for each chord was determined by considering Step 2 and Step 3.

Table 4 lists the optimal frequency ratios for basic chords: Major: 4:5:6, Minor: 10:12:15, Augmented: 16:20:25, Diminished: 5:6:7, and Suspended 4th: 6:8:9.

Table 4 Optimal frequency ratios for each chord

Chord type	Ratio	LCM
maj	4 : 5 : 6	60
min	10 : 12 : 15	60
aug	16 : 20 : 25	400
dim	5 : 6 : 7	210
sus4	6 : 8 : 9	72

Experiment 2

Aim

To utilize the optimal frequency ratio for basic chords determined in Experiment 1, the intervals were adjusted to improve the sound of chords by using just intonation.

The ratio of the intervals in just intonation is as follows:

Table 5 Just intonation intervals

Notes	C	D	E	F	G	A	B
Ratio to C	1/1	9/8	5/4	4/3	3/2	5/3	15/8

Step 1: Diatonic Chords in C Major Scale

The diatonic chords in the C major scale are the following seven chords shown in Table 6 such as C major, D minor, E minor, F major, G minor, A minor, B diminished. Since these are the most important chords, these chords had to be able to be played at the optimal frequency ratio.

Table 6 Diatonic chords and frequency ratios in just intonation

Diatonic chord	Component notes	Chord type	Actual ratio	Optimal ratio
C major	C-E-G	maj	4:5:6	4:5:6
D minor	D-F-A	min	27:32:40	10:12:15
E minor	E-G-B	min	10:12:15	10:12:15
F major	F-A-C	maj	4:5:6	4:5:6
G major	G-B-D	maj	4:5:6	4:5:6
A minor	A-C-E	min	10:12:15	10:12:15
B diminished	B-D-F	dim	45:54:64	5:6:7

Table 6 shows that two chords, D minor and B diminished, are not optimized. Because the actual frequency ratio does not match the optimal frequency ratio.

Step 2: Adjust Intervals

Table 7 below lists the notes that compose each diatonic chord and their intervals. For D minor chord and B diminished chord, the original intervals were adjusted to obtain the optimal frequency ratio.

Table 7 Notes that compose diatonic chords

	C	D	E	F	G	A	B
C major	1/1		5/4		3/2		
D minor		**10/9**		4/3		5/3	
E minor			5/4		3/2		15/8
F major	1/1			4/3		5/3	
G major		9/8			3/2		15/8
A minor	1/1		5/4			5/3	
B diminished		9/8		**21/16**			15/8

When playing the D minor chord, the D note was adjusted from its original ratio of 9/8 to 10/9 to obtain the optimal frequency ratio of 10:12:15; when playing the B diminished chord, the F note was adjusted from 4/3 to 21/16 to get 5:6:7.

Conclusions / Future Plan

Conclusions

The optimal frequency ratio of basic chords was determined in terms of the least common multiple. This allowed me to adjust the intervals of the D minor chord and B diminished chord, which did not sound very good in just intonation, to the optimal frequency ratio.

Future Plan

The following two things are planned:

1. To find a more accurate method to calculate the frequency ratio because when the least common multiple of the frequency ratio was small but the number of the ratio was large, it could not be processed.
2. To create an instrument that automatically adjusts to the optimal interval when a chord is played, since it is difficult to use the optimal interval depending on the situation.

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動画解析による生徒の授業参加状態数値化システムの開発

要旨

日本は教員の過重労働が問題となっている国の一つである。本研究の目的は、二つのプロジェクトにより構成される第１プロジェクトでは教室における出欠を瞬時に取得することである。第２プロジェクトでは、教室における授業活動の状況を可視化することである。これらの研究の動機は、教員の負担を軽減するためである。この研究では、教室の動画を撮影し、動画処理の差分法を定期要することで必要な情報を抽出した。第１プロジェクトでは、出席をとるために、授業開始時に生徒に録画中のカメラに向かい手や頭などを振ってもらい、後に手動で ROI（Region Of Interest）を設定し人を抽出した。第２プロジェクトでは、授業は３時間、生徒の作った YouTube を見る授業、Ｂ４、Ｍ１、Ｍ２それぞれのプレゼンテーションを見る授業の４つのフェーズで構成し、これらの授業での生徒の活発度を動画解析により算出した値を用いて比較した。結果はビデオ撮影に１分間、動画の解析に２分間、合計３分かけて出席を取ることができた。次に、授業中の活発度と主観的アンケートを比較したが、一致しなかった。その理由は、生徒はただ動画を見ていただけの状態や質問を考えたり、プレゼンテーションの準備をしたりする他のアクティビティでは活発度のアンケート項目の興味関心を反映しなかったからだと考えられる。ただし、授業における活動、参加度合いである活発度を評価することはできた。今後、教員がその数値を見て、次の授業の準備に役立てることができる。次回は立命館高校の授業で実施する予定である

1. 背景

日本は教員の過重労働が問題になっている国のひとつである。2021 年、全国の公立小中学校教員を対象とした調査では、小学校教員の 68.2%、中学校教員の 63.3%が「過去２年間に教員を辞めたいと思ったことがある」と回答している。こうした教員の負担を少しでも減らすため、出欠を自動で確認し、授業の活性度を可視化するシステムを構築する。このシステムでは、授業開始時に教師があらかじめ用意したカメラで教室を撮影し、プログラムが自動的に画像を解析する。このシステムを利用することで、授業開始時の５分間の出席時間を短縮することができ、教員の業務負担を軽減することができる。また、授業時間を確保することができ、効率的な授業が可能となる。このシステムは、立命館中学校・高等学校をはじめ、さまざまな学校施設での活用が期待される。最終的には、スマートフォンやタブレット PC などのアプリケーションを通じて、手軽に情報を提供することを目指す。

2. 方法

この研究では差分法と呼ばれる画像処理技術を用いた（図 1)。動画は時間を表すものとしてフレームが、画像には画像情報を表すものとしてピクセルがある。この技術はあるフレームにある全ピクセルのフレームごとの輝度の違いから、動きを白ピクセルと黒ピクセルで画像に表すことができる（図 2)。もしその輝度の差の値があらかじめ決めておいたノイズとしての値より小さい場合カウントされない。授業の活発度が高いと、白ピクセルの割合は高くなり、逆も同様である（図 3)。実験の対象は大学生 25 人であった。実験は立命館大学琵琶湖草津キャンパス機械システム系第２演習室で行った。また iPhone13(version iOS

16.1.1)（図 4)、 PC(VAIO Windows 9)、プログラミング言語としての Python とともに差分法を用いた。iPhone は教室の前側の壁の天井付近に設置した．なぜなら全生徒の顔をカメラで映すためである。授業を撮影した動画に対して差分法を用いて動画解析し、白と黒のピクセルで構成されるデータとして結果を出力した。差分法によって検出された白色のピクセルは物体が動いているエリアを検出している。

Different image processing

$$I_d(x,y) = |I_n(x,y) - I_{n-1}(x,y)|$$

x, y：Position coordinates in image

I：Luminance in the image (0-255)

図 1. 差分法

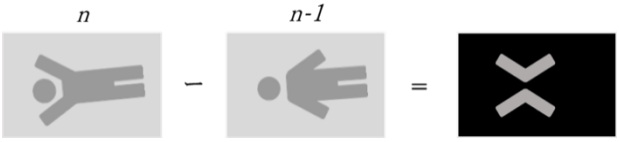

図 2. 差分法の概略

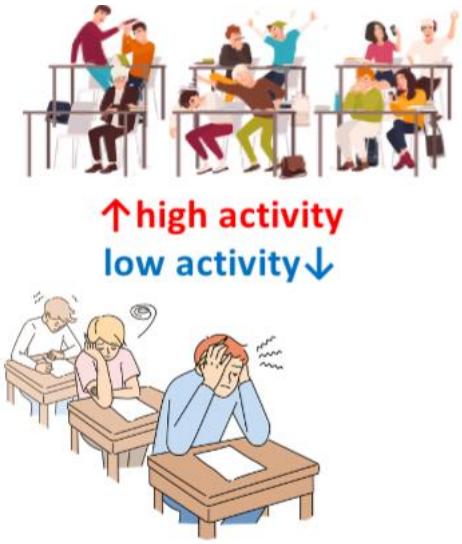

図 3. クラスの活発度の写真

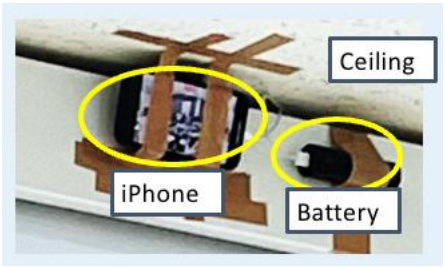

図 4. iPhone の設置方法

2−1. 第 1 プロジェクト

第 1 プロジェクトでは授業の始めに、動画を撮影しているカメラに対して手を振ったり、頭を振ったりしてもらった。そして、その様子の動画を教室の正面にあるカメラで 1 分程度撮影した。あらかじめ ROI を設定しておき（図 5)、その中で白ピクセルの割合が大きいと、出席と判断する。解析方法としては生徒が座席にいることを確認するために ROI を手動で画像上の各座席に設定し、それぞれの ROI の中での輝度の違いを計測した（式 1)。出席は、ROI での合計と平均が以下の方法で計算した閾値（式 2）を上まっていたらカウントとする。

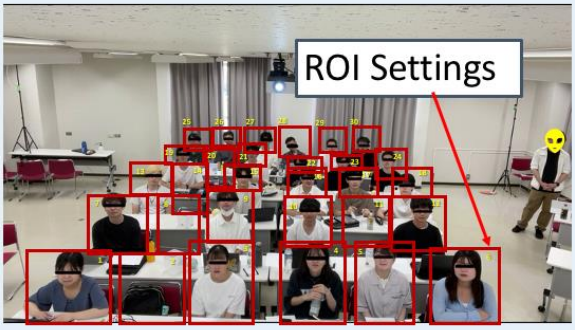

図 5. ROI を設定した写真

式（1）

$$White\ area = \frac{number\ of\ white\ pixels\ per\ one\ frame}{number\ of\ all\ pixels\ per\ one\ frame} \times 100\ [\%]$$

式（2）

$$Threshold = \bar{x} - \frac{\sum_{i=1}^{n}\sqrt{(x_i-\bar{x})^2}}{n}$$

$$x_i = \text{SUM,AVERAGE}$$

2－2. 第 2 プロジェクト

第 2 プロジェクトでは生徒は生徒が事前に作った Youtube を視聴する授業、B4、M1、M2 のそれぞれの生徒のプレゼンテーションを聞く授業の合計三時間程度、四つの授業を受けた（図 6）。
白ピクセルの数の合計がクラスの活発度とする。教室が積極的だと白ピクセルの数は増える。(図 7)
四つのクラスの白ピクセルの合計違いを比べた。

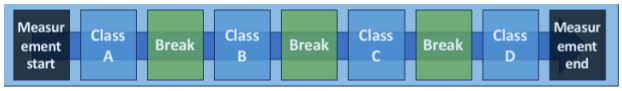

図 6. 授業の概要

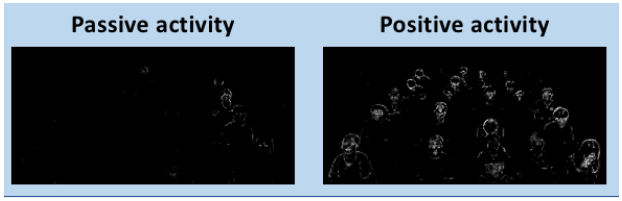

図 7. 白ピクセルのカウント

3. 結果と考察

3－1. 第 1 プロジェクト

第一プロジェクトでは、白ピクセルの合計と、平均両方で、出席を取れたと言える。座席番号 2 番、8 番、11 番、14 番、20 番は閾値を超えていないため欠席と判断された。図〇からもわかるように実際に彼らは欠席のため出席を取ることができたと言える。欠席している生徒の ROI の値が多少あるのは、出席している生徒がその ROI に入っているからだと考える。加えて、一つ問題がある。もし金髪の方がいると出席を取るのが難しい。以下の二つの図は、上の図が元の写真（図 8）、下の図は差分法を用いた後の写真（図 9）であるこれを見てもらうとわかるように、金髪の人のあたりで白ピクセルがほとんど現れていない。なぜならば、金のピクセルが持つ輝度は違いをほとんど持たないためであると考えられる。出席は動画の撮影時間とプログラミングの解析の時間合計 3 分で取ることができた。

図 8. 元の写真

図 9. 差分法を用いた写真

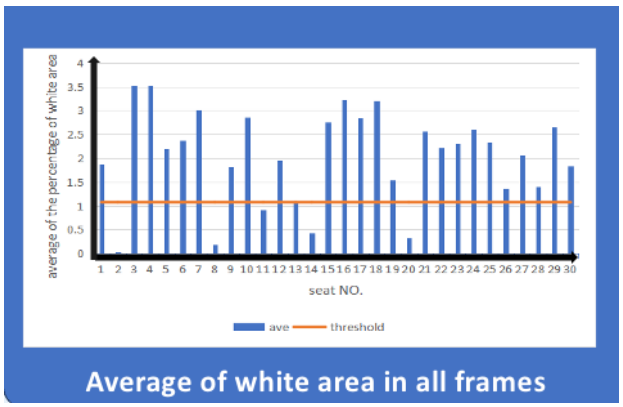

図 10. 各座席の ROI の白ピクセルの平均

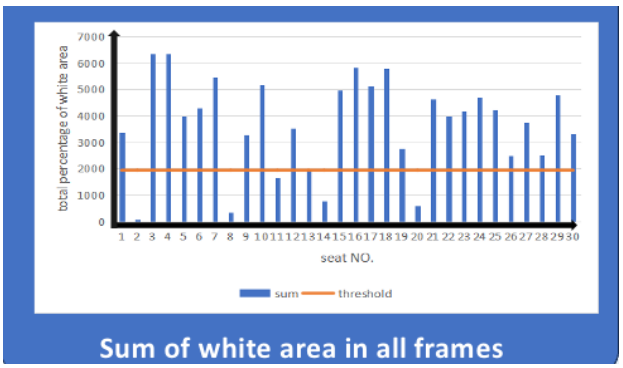

図 11. 各座席の ROI の白ピクセルの合計

図 12. 出席のカウント

3−2. 第 2 プロジェクト

第 2 プロジェクトではプログラミングによって出された結果と、授業後に生徒に書くように頼んだアンケートを比べた。生徒は YouTube を見る授業が一番興味を持って聞いていたと回答したが、結果によると、M4 のプレゼンテーションの授業が最も多くの白ピクセルの値を表示している。理由としては、YouTube は動画を見ているだけなので生徒はほとんど動くことはないが、プレゼンテーションでは生徒は質問を考えたり、プレゼンテーションの準備をする必要があったりしたためだと考える。また座席以外のところで生徒だけでなく、先生も動いていたためそれも結果に影響していた。先生はこれらの結果を用いて次の授業の計画を立てることができると考える。

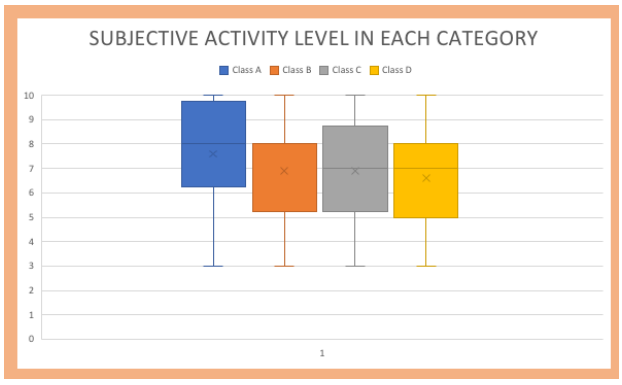

図 13. 主観アンケートの結果

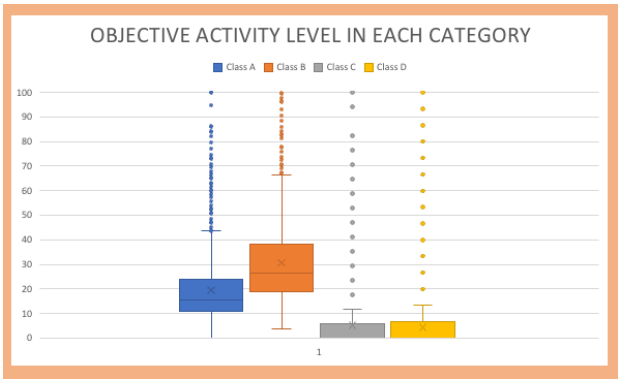

図 14. 各カテゴリーの白ピクセルの量

4. 展望

このシステムは小学校、中学校、そして高校で使われる、特に活発的な授業の多い小学校では必要とされるだろう。また、今回の出席は立命館大学で取ったので、次は立命館高校で取る必要がある。このシステムを使った後は、先生は生徒がどのように感じたかのフィードバックを得る必要がある。

5. 謝辞

ご指導していただいた立命館大学理工学部ロボティクス学科生体工学研究室の岡田志麻教授、文本要氏、山本一天氏、CHOU QIANXU 氏に、この場を借りて厚く御礼申し上げます。

6. 引用文献

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https://doi.org/10.3389/feduc.2021.681258

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- Development of a non-contact sleep monitoring system for children https://www.frontiersin.org/articles/10.3389/fdgth.2022.877234/full

Development of a Student Status Estimation System for High School Classrooms

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

Japan is one of the countries which has problems with teachers being overworked. This aims to reduce teachers' burden by instantly taking attendance and visualizing the activity level. In this research, Different Image Processing was used. It shows the difference between frames in a video. At the beginning of the class, students were asked to wave their hands, shake their heads, etc, and ROI, Region of Interest, was set to take attendance. The class consists of 4 phases for 3 hours. These were compared. Attendance could be taken within 3 minutes. It takes a video for 1 minute and analyzes it in 2 minutes. The class activity and subjective questionnaires were compared but didn't match. It is considered that the reason for this is because students were just watching movies for the YouTube activity, whereas the others, they were thinking about questions or preparing presentations. It was possible to help teachers because attendance could be taken, and teachers could compare the results and use them for the next class. The next planned test will be done in a class at Ritsumeikan High School.

Keywords: cars, tire grooves, splashed water, pedestrians, sidewalks

I. Introduction

Japan is one of the countries which have problems with professor's overwork. In 2021, 68.2% of elementary school and 63.3% of middle school teachers in a nationwide survey of public elementary and middle school teachers said they had wanted to quit teaching in the past two years. In order to reduce this burden on teachers as much as possible, we will build a system that automatically checks attendance with the first project and visualizes the level of class activity with the second project. In this system, teachers take images of the classroom with a camera previously prepared at the start of class, and the program automatically analyzes the images. Then, the attendance of students is taken, and the level of activity is visualized. This system can shorten the five-minute attendance time at the beginning of class, decreasing the teachers' business workload. In addition, class time can be secured, and classes can be taught more efficiently. In addition, by visualizing the level of class activity, it will be easier to improve classes throughout the class. This system will be used at Ritsumeikan Junior and Senior High Schools and various other school facilities. In the system, the final goal is to easily offer the information through applications such as smartphones and tablet PCs.

II. Materials and Method

This study used a technique called the Difference Image Processing (Figure 1). Video has frames and images have pixels. This technique can represent motion as white and black pixels (Figure 2) in an image based on the difference in luminance of all pixels from frame to frame. It is not counted if the difference in pixel-by-pixel luminance value is smaller than the difference in pixel-by-pixel luminance value in noise. The higher the activity level of the class, the higher the percentage of white pixels, and vice versa (Figure 3). The experimental subjects were 25 university students. The experiment was conducted in Seminar Room 2, School of Mechanical

Ritsumeikan University Biwako-Kusatsu Campus, Ritsumeikan University. The difference image processing was used with an iPhone13 (version iOS 16.1.1) (Figure 4), a PC (VAIO Windows 9), and Python as a programming language. The iPhone was set up near the ceiling on the front wall of the classroom. This is so that all students' faces can be seen on the camera. The video of the class was analyzed using the Difference Image Processing, and the results were presented as data consisting of black and white. White pixels detected by the difference image processing detect areas where objects are moving. In the first project, I asked students to wave their hands and shake their heads, etc. At the start of the class a-minute video was recorded. ROI was manually installed on the image previously to identify students in seats (Figure 5), and if the difference in pixel- by pixel luminance was large in predetermined ROI (Region Of Interest), it was determined that the student was in attendance. For the analysis method, ROI were set for each seat, and the difference in luminance within each ROI was calculated. Attendance was counted if the total percentage of white area was above the threshold value, or the average was above the threshold value calculated by the following method. (Figure 6).

Different image processing

$I_d(x,y) = |I_n(x,y) - I_{n-1}(x,y)|$

x, y : Position coordinates in image

I : Luminance in the image (0-255)

Fig.1 Different image processing

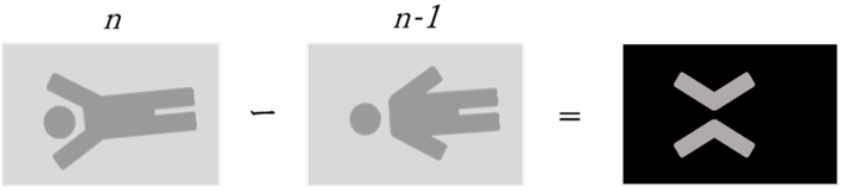

Fig.2 Visual summary of different image processing

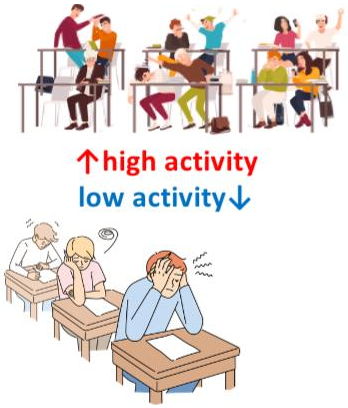

Fig.3 Image of class activity

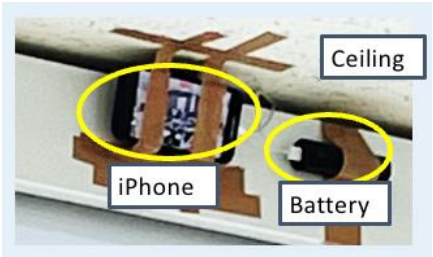

Fig.4 How the camera was set

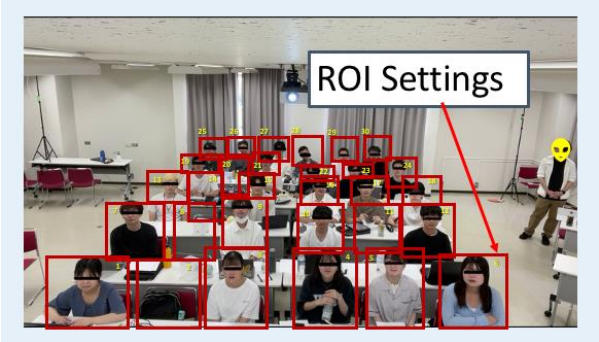

Fig.5 Image with set ROI

$$Threshold = \bar{x} - \frac{\sum_{i=1}^{n} \sqrt{(x_i - \bar{x})^2}}{n}$$

x_i=SUM,AVERAGE

Fig.6 How to set the threshold

In the second project, Students took part in a spontaneous class and were videotaped doing so for 3 hours. The amount of student activity varied by class content. There are 4 classes, (Figure 7) Class A, Class B, Class C and Class D. In class A, students watched a YouTube video they made. For the rest, Class B, C and D, they delivered presentations. Class B consisted of 4th year bachelor students. Class C consisted of 1st year master's students, and class D consisted of 2nd year master's students. The total number of white pixels was the activity amount. If the class was positive, the ratio of white pixel increases. (Figure 8) The 4 different classes were compared. Subjects answered the subjective questionnaire after all lectures. The method of questionnaire was 10 level answer style. The topic was "whether you joined classes subjectively and actively in each class." The validity of the class activity level was evaluated by comparing the subjective questionnaire and the results. The validity of the class activity level was evaluated.

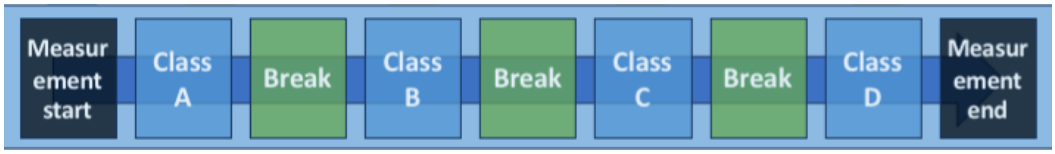

Fig.7 Overview of measurement flow

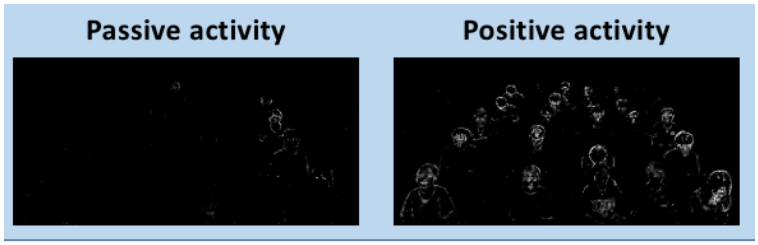

Fig.8 White count

III. Results and Discussion

In the first project, Figure 9 shows the attendance or non-attendance. There are 3 graphs in Figure 9. The top left graph shows the sum of white areas in all frames, and the top right graph shows the average of white areas in all frames. The orange line is the threshold. In addition, the bottom graph shows the attendance. If a student was determined as an absent, the value of the student was 0. If the student was present, it is 1. in both total and average, attendance could be taken. The student number 2, 8, 11, 14, 20 are determined to be absent because they didn't exceed the threshold. (Fig. 9) In the second project, the questionnaire that students answered and the results by the method were compared in Figure 10. Figure 10 shows the subjective activity level and the objective activity level. The left graph shows the subjective activity level in each category. On the other hand, the right graph is the objective activity level in each category. In both graphs, the blue one is from students watching YouTube videos. The orange one is from them listening to presentations by 4th year bachelor students. The grey one is from them listening to presentations by 1st year master's students. The yellow one is from them listening presentations by 2nd year master's students. Students answered that class A was the most

interesting. However, the result shows that class B showed the largest amount of white pixels. In classes C and D, they almost didn't move (Figure 10).

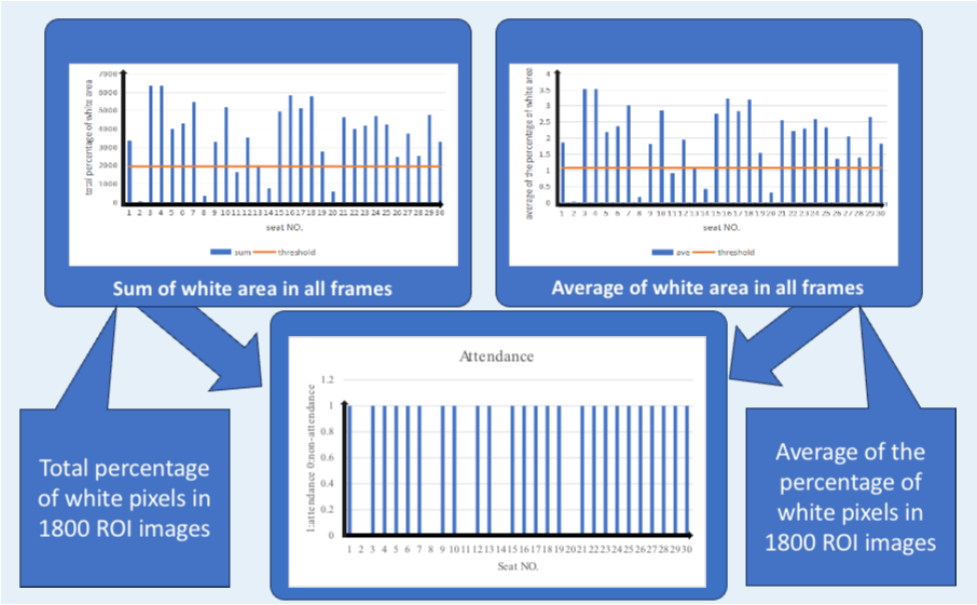

Fig.9 Attendance or non-attendance

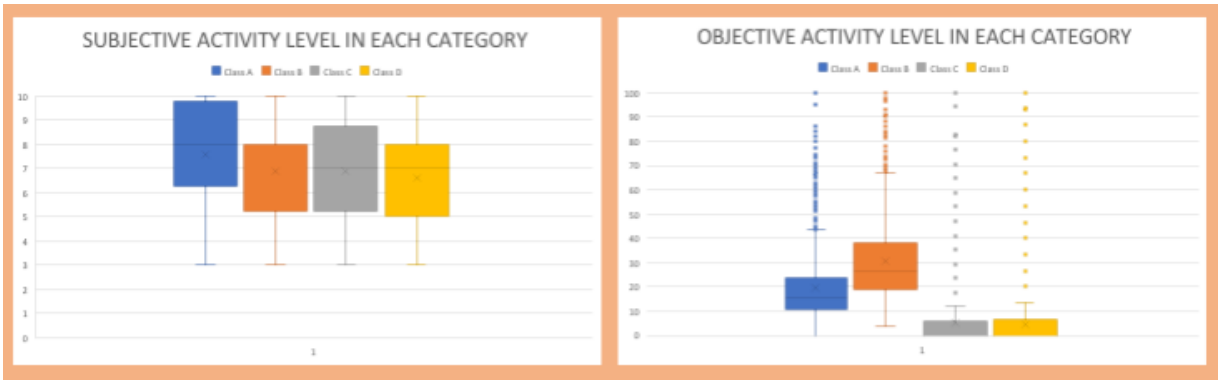

Fig.10 Subjective activity level and objective activity level

In the first project, the movement of present students shows up in the ROI of absent students. That's why the value of absents has a little bit. In addition, there is one problem. If there is a student with blond hair, it's hard to take attendance. The right image is the original image, and the left image is the image that uses Different Image Processing. (Figure 11) It doesn't show any white pixels. This is because the difference in blond doesn't have so much difference to that one in white. Attendance could be taken in a total of 3 minutes for the video

recording time and programming analysis time. In the second project, the results and the questionnaire were different. This is because, for the class A activity, students were just watching movies, whereas for the others, they were thinking about questions or preparing presentations. Furthermore, not only students, but also teachers were moving. In addition, presenters were moving forward to do presentations. These affected the results. Students answered the same value as class B in classes C and D, but the results didn't show the value.

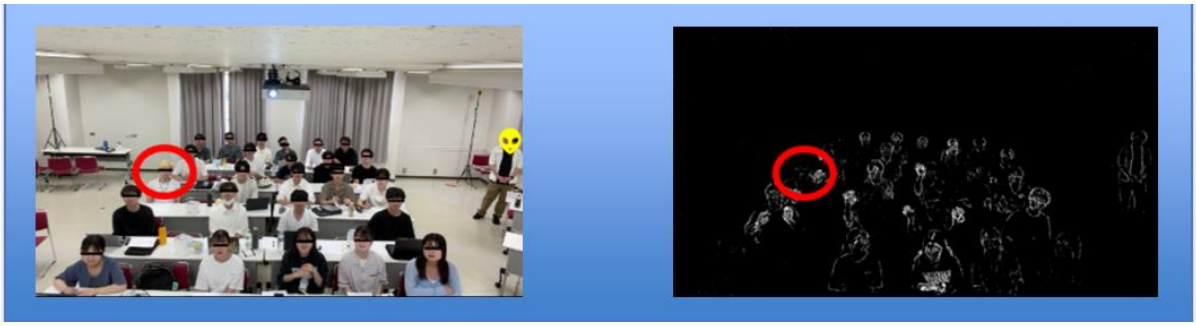

Fig.11 Original image (L) and difference image processing image (R)

IV. Conclusion

In the first project, attendance could be taken by taking video and ROI for each seat within 3 minutes, so it was done instantly. Based on both total and average calculations, five people in seat numbers 2, 8, 11, 14, and 20 were determined to be absent because they did not exceed the threshold. This system could help teachers. In the second project, the activity level across different categories were compared by applying Difference Image Processing to the entire classroom. After each class, teachers can simply look at the results and use them to plan for the next class.

V. Future Research

In the first project, this system needs to be improved in how to set the camera so that everyone's face can be seen in it. This system will be tested in all elementary, middle, and high schools in the future. Increased motion and activity, especially from elementary students, is

expected and will need to be accounted for. To begin with, the next planned test will be done in a class at Ritsumeikan High School. In the second project, after using the system, teachers will be asked to complete a survey asking them how they feel its use has affected their classes and for any other feedback that could be used to improve it. The class activity level was measured for each category, but it is planned to make a graph chronological order. In this research, students answered how they concentrated on lectures and how they get interested in them after all of it. There is a time-lag, so it's hard to comprehend how students feel. The next plan is going to be to get data related to the direction of students' faces and heart rate.

VI. Acknowledgements

The project would not have been possible without the help of my advisors: Professor Shima Okada, Kanaru Fumimoto, Kazutaka Yamamoto, and Chou Qianxu from the Biophysical Engineering Lab at Ritsumeikan University contained within the Department of Robotics, Faculty of Science and Engineering.

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Development of a non-contact sleep monitoring system for children https://www.frontiersin.org/articles/10.3389/fdgth.2022.877234/full

Development of a Student Status Estimation System for High School Classrooms

Ritsumeikan High School

JAPAN SUPER SCIENCE FAIR 2023

ABSTRACT

Japan is one of the countries which has problems with teacher's being overworked. This aims to reduce teachers' burden by instantly taking attendance and visualizing the activity level. In this research, Different Image Processing was used. It shows the difference between frames in a video. At the beginning of the class, students were asked to wave their hands, shake their heads, etc, and ROI, Region Of Interest, was set to take attendance. The class consists of 4 phases for 3 hours. These were compared. Attendance could be taken within 3 minutes. The class activity and the subjective questionnaires were compared, but they did not match. It is considered that the reason for this is because students were just watching movies for the YouTube activity, whereas for the others, they were thinking about questions or preparing presentations. It was possible to help teachers because attendance could be taken, and teachers can compare the results and use them for the next class. The next planned test will be done in a class at Ritsumeikan High School.

INTRODUCTION

Background Japan is one of the countries which has problems with teachers being overworked. In 2021, 68.2% of elementary school and 63.3% of middle school teachers in a nationwide survey of public elementary and middle school teachers said they wanted to quit teaching during the past two years.

Purpose The purpose of this study is to reduce the burden on teachers by instantly taking attendance (① ***Student Attendance***) and visualizing the activity level (② ***Class Activity Level***). The goal is to make it easy to improve the class by getting feedback and protect the privacy of the students by not having to use facial recognition.

METHOD

Theory

Fig. 1 Image of class activity

Different image processing

$$I_d(x,y) = |I_n(x,y) - I_{n-1}(x,y)|$$

x, y : Position coordinates in image
I : Luminance in the image (0-255)

If the difference in pixel-by-pixel luminance value is smaller than the difference in pixel-by-pixel luminance value in noise, it is not counted.

Fig. 2 Summary of different image processing

Measurement Method

Subjects : 25 university students
Location : Seminar Room 2, School of Mechanical Ritsumeikan University Biwako-Kusatsu Campus
Measurement device : One iPhone12 (Fig. 3)
Measurement objects : Subjective questionnaire(Visual Analogue Scale), Video of the classroom (1920 × 1080 pixels, 30 FPS)
Experimental conditions : Given the predetermined seating arrangement in the high school the region of interest (ROI) in the images was set accordingly.

Fig. 3 How to fix the camera

① Student Attendance

Students were asked to wave their hands, shake their heads, etc. at the start of class and a 1-minute video was recorded.

② Class Activity Level

Students took part in a spontaneous class and were video-taped doing so for 3 hours.
The amount of student activity varied by class content.

Class A : The reaction of watching YouTube video
Class B, C, D : The reaction of watching $B4^{*1}$, $M1^{*1}$, $M2^{*1}$'s presentation

*1 : 4th year bachelor students
*2 : 1st year master's students
*3 : 2nd year master's students

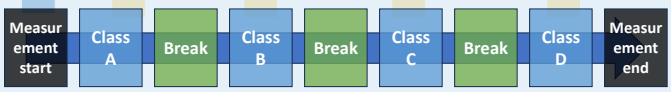

Fig. 4 Overview of measurement flow

Settings

① Student Attendance

The difference in pixel-by-pixel luminance was large in predetermined ROI (Region Of Interest).
→ Counting attendance

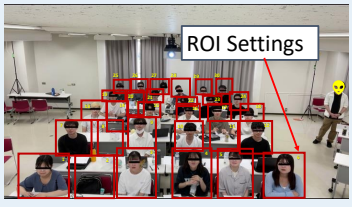

Fig. 5 Image with set ROI

② Class Activity Level

The total number of white pixels was the activity amount.

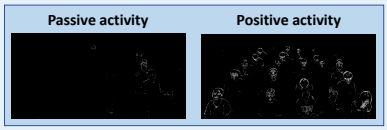

Fig. 6 White count

ANALYSIS METHOD

① Student Attendance

Set ROI for each seat (Fig. 5) and calculated the difference in luminance within each region.
Attendance was counted if the total percentage of white area was above the threshold value or the average was above the threshold value.

$$White\ area = \frac{number\ of\ white\ pixels\ per\ one\ frame}{number\ of\ all\ pixels\ per\ one\ frame} \times 100\ [\%]$$

$$Threshold = \overline{x} - \frac{\sum_{i=1}^{n}\sqrt{(x_i-\overline{x})^2}}{n}$$

x_i=SUM,AVERAGE

② Class Activity Level

Compared the difference in pixel-by-pixel luminance values in each of the four time periods for the entire classroom.

RESULTS AND DISCUSSIONS

① Student Attendance

Result ①

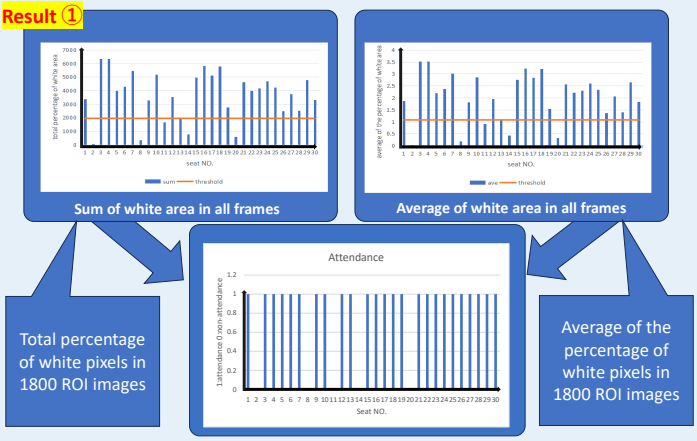

Fig. 7 Attendance or non-attendance

Discussion ①

- The movement of present students shows up in the ROI of absent students.
- If there is a person with blond hair, it is hard to take their attendance.

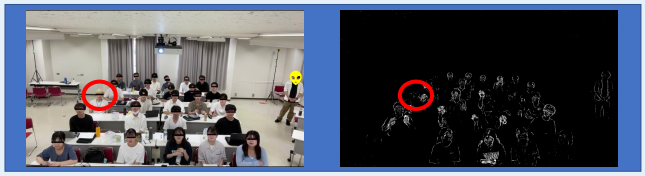

Fig. 8 Image and difference image

② Class Activity Level

Result ②

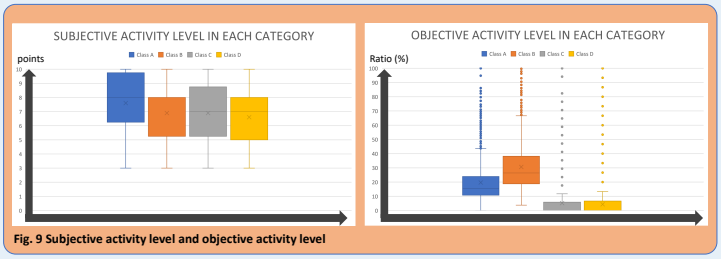

Fig. 9 Subjective activity level and objective activity level

Discussion ②

- For the class A activity, students were just watching movies, whereas for the others, they were thinking about questions or preparing presentations.
- Not only students, but also teachers were moving. In addition, presenters were moving forward to do presentations. These affected the results.

CONCLUSION

① **Student Attendance** : Attendance could be taken by taking video and ROI for each seat.
- In both the total and average, five persons in seat numbers 2, 8, 11, 14, and 20 were determined to be absent because they did not exceed the threshold.

② **Class Activity Level** : The activity level could be compared by category by calculating difference image processing the entire classroom.
- After every class, teachers can simply look at the results and use them to plan for the next class.

FUTURE PLAN

① **Student Attendance** : This system will be tested in all elementary, middle, and high schools in the future. Increased motion and activity, especially from elementary students is expected and will need to be accounted for. To begin with, the next planned test will be done in a class at Ritsumeikan High School.

② **Class Activity Level** : After using the system, teachers will be asked to complete a survey asking them how they feel its use has affected their classes and for any other feedback that could be used to improve it.

REFERENCES

- National Institute for Educational Policy Research. 2018. *The Work Environment of Teachers in Japan* https://www.nier.go.jp/English/educationjapan/pdf/20180816WEJT.pdf
- Alexander Wettstein. Sandra Schneider. Martin grosse Holtforth. Roberto La Marca. 2021. *Teacher Stress: A Psychobiological Approach to Stressful Interactions in the Classroom https://doi.org/10.3389/feduc.2021.681258*
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ACKNOWLEDGEMENTS

The project would not have been possible without the help of my advisors: Professor Shima Okada, Kanaru Fumimoto, Kazutaka Yamamoto, and Chou Qianxu from the Biophysical Engineering Lab at Ritsumeikan University contained within the Department of Robotics, Faculty of Science and Engineering.

フルートの音色の物理的解析方法

要旨

この研究は、フルートの音色を物理的に解析するものである。演奏する際に用いられる主要な技術を数値として抽出し分析した。主要な技術を「楽器がどれだけ鳴っているか」、「感情の音楽的表現」の 2 つに分類し、それぞれ実験を行って分析した。実験においては、WaveSpectra（PC ソフトウェア）でフルートの音を分析することで波形・倍音のデータを得た。１つ目の実験では、初心者と熟練者の音の違いは、「楽器がどれだけ鳴っているか」の違いであり、何らかの物理的な要素に現れると仮定して実験を行った。その結果、倍音のバランスと音の強度に違いがみられ、いずれも低音を演奏した際に顕著にあらわれた。初心者のデータでは、鳴っている倍音のうち高い音域のものが雑音(ノイズ)に埋もれていたことに対し、経験者のデータでははっきりと倍音を確認することができた。また、高い倍音になる程強度が小さくなっていくが、その強度の変化が熟練者のデータの方が滑らかだった。２つ目の実験では、表現による音色の違いに着目した。感情を歓喜、激怒、嘆き、愉快の 4 つに分類し、それぞれをイメージした音を出して実験を行った。この実験では、ポジティブな感情同士とネガティブな感情同士を比較すると、感情の方向性によって波形に違いが生まれるのではないかと仮定し、分析を行った。その結果、倍音のバランスと大きさが感情によって違うことがわかった。

1. 背景

楽器の演奏において、私たちは１つの音を聞いただけでもプロ奏者のような熟練者と初心者の音を聞き分けることができる。この違いはどこから生まれているのか疑問に思い、研究を始めることにした。本研究では、フルートの音色を「楽器がどのように鳴っているか」と「感情の音楽的表現」という２つの観点に分け、倍音に焦点を当てて物理的解析をおこなった。熟練者と初心者の音の違いのような、感覚的に捉えられることが多い音楽の事象を、データを分析することで、より理論的に解明することを目的としている。また本研究結果を踏まえて、特に初心者にとっての、優れた奏者になるための練習方法の開発や、演奏技術の習得の一助となることを目指したい。

2. 方法

2－1. 熟練者と初心者の違い

熟練者（桐山、フルート歴 7 年）と初心者（中西、フルート歴 1 週間）の違いがどのようにデータとして現れるのか実験した。まず、WaveSpectra で各奏者の高音（E、1324 Hz）と低音（E、662 Hz）を測定・強度と周波数をデータ化した。その後、鳴っている倍音の数と強度のバランスに焦点を当て、各奏者に見られる特徴を分析・比較した。

2－2. 感情表現

歓喜、激怒、嘆き、愉快の 4 つの感情（喜怒哀楽に基づくもの）について、それらを表現したときにデータ上でどのような違いが生じるのか分析した。まず、それぞれの感情と比較のための”ノーマル(感情表現をしない状態)”の 5 種類をラ(A、884 Hz）の単音で表現し、WaveSpectra で測定・強度と周波数をデータ化した。その後、倍音に焦点を当て、各感情表現に見られる特徴を分析・比較した。

3. 結果と考察

3－1. 熟練者と初心者の違い

図１、図２は、高音(E 1324Hz)を鳴らした際のWaveSpectra の画面である。縦軸が音の強度であり、横軸が周波数である。

熟練者、初心者に共通して、画面上の特定の周波数でピークが複数見られた。このピークがフルートの発する音波の中で強度が特に高く、私たちの耳に聞こえてくる音であると考えられる。

楽譜に示される音を基音といい、図１、図２を分析した結果、最も強度の高い左端のピークの周波数は 1324Hz であったことから、基音が最も強度が高く、同時に鳴る倍音は、周波数が基音から離れるほどに強度が下がる傾向が見て取れる。

図 3、図 4 は低音(E 662Hz)を鳴らした際の画面である。図 1、図 2 との比較をすると、高音よりも低音を鳴らした際の倍音の数が多いことが分かる。基音が最も強度が大きく、そこから周波数が離れるにつれて倍音の強度が小さくなる傾向は共通のものであることが分かった。

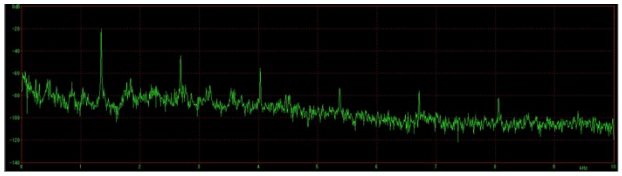

図 1. 高音（熟練者）　※縦軸：dB、横軸：kHz

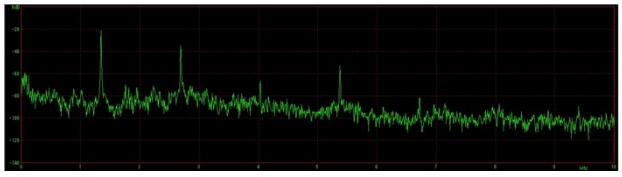

図 2. 高音（初心者）

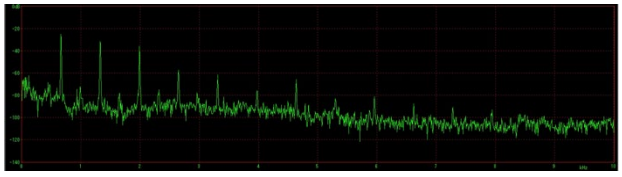

図 3. 低音（熟練者）

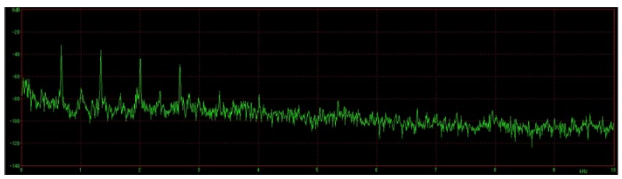

図 4. 低音（初心者）

(1) 倍音の数について

ここでは図１と図 2、図 3 と図 4 のように熟練者と初心者のデータの比較を行った。倍音のピークが鮮明にできていることを、倍音が鳴っていることの基準とした。熟練者のデータでは、高音、低音のどちらにおいても初心者のものよりたくさんの倍音が確認できた。

基音からより離れた、高い(周波数の大きい)倍音が、初心者のデータでは周りの雑音に含まれて見分けられないことに対し、経験者のデータではピークがはっきりと確認できた。この傾向は高音よりも低音の方が顕著に確認できた。

考察として、高音に比べ、低音の方が多くの倍音を鳴らすために、音を出す際の息のコントロールが難しく、明確な違いがみられたのではないかと考える。

(2) 倍音の強度について

倍音の強度に関しては、先述の通り、基音から周波数が離れるにつれて小さくなっていくという傾向が見られたが、私たちは、この強度の減衰傾向に着目した。

基音の強度(dB)を最大の 100 として、他の倍音の強度を基音と比較して 100 分率で表すことで初心者と経験者を比較した。つまり基音に対する他の倍音の強度のバランスを数値化し図５、図６に示した。それぞれの図において、熟練者は青色のマーカー(skilled)、初心者は橙色のマーカー(beginner)と示してある。近似曲線は熟練者のデータのものである。

図５(基音が高音の場合)を見ると、熟練者のデータは 1 次関数的に強度が変化していることが分かるが、初心者は 4000Hz 以降の倍音の強度が不規則であり、明らかな差を見て取ることができる。

図６(基音が低音の場合)では、多くの倍音があったためか、初心者のデータのばらつきが大きく、各倍音の強度が不規則に分布していた。それに対

して熟練者のデータは、基音を最大として他の倍音の強度が対数的に近似できることが分かった。

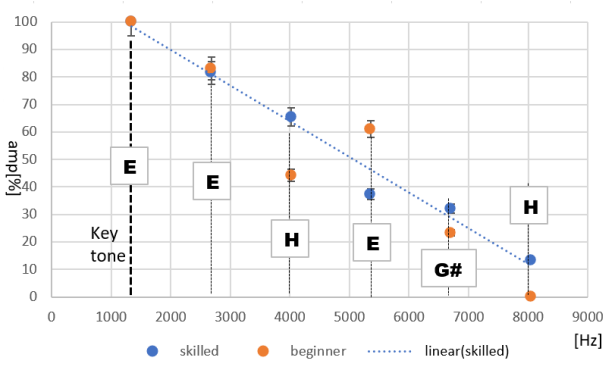

図 5. 各奏者の基音に対する他の倍音の強度比較

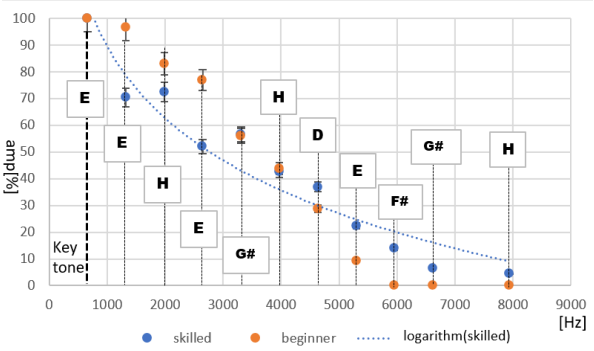

図 6. 各奏者の基音に対する他の倍音の強度比較

これらのことから、熟練者ひいてはプロの演奏する音は、基音を最大として低音域から高音域にかけて倍音の強度がより滑らかに変化していくことが特徴で、私たちが 1 音だけでも初心者との違いを聞き分けられるのはこれが原因ではないだろうか。この実験結果はサンプル数が少ないため、初心者と熟練者の双方のデータを増やしていくことが望ましい。そうすれば初心者や練習者は、自己の演奏の倍音の強度を観察する等、より客観的な要素を用いて練習を工夫できるようになるだろう。

3－2．感情表現

図 7～１１は、A（８８４Hz）を鳴らした際の WaveSpectra の画面である。それぞれ、ノーマル（感情表現をしない状態）、歓喜、激怒、嘆き、愉快を表現した。実験 1 と同様に、倍音の数と強度に違いがみられた。

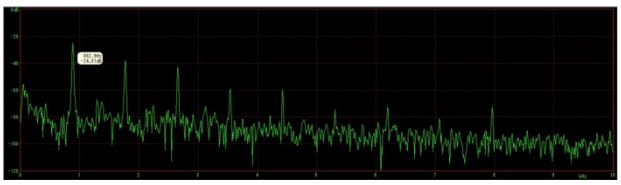

図 7. ノーマル

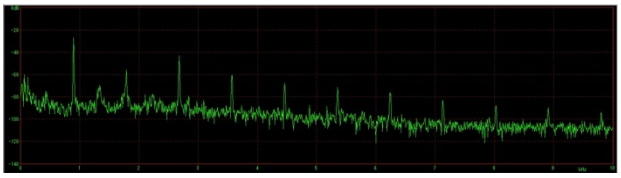

図 8. 歓喜

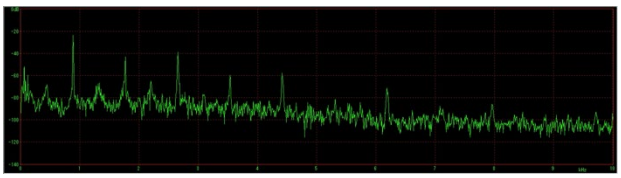

図 9. 激怒

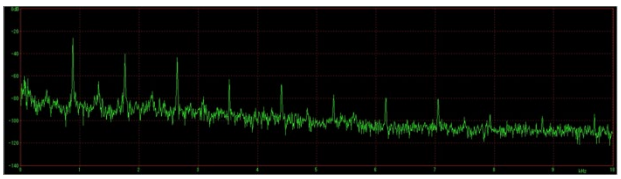

図 10. 嘆き

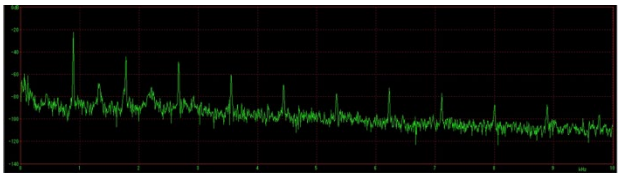

図 11. 愉快

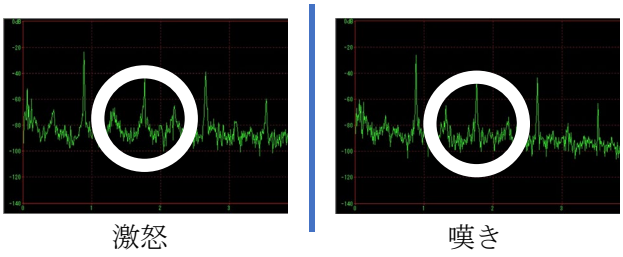

図 12. 激怒と嘆きの比較

(1)　ポジティブな感情について

ポジティブな感情として、歓喜と愉快を比較した。しかし、今回の実験結果からは大きな違いは見られなかった。言葉の定義やイメージが明確でなかったことによるものだと考えられる。また、いくつか見られた違いについては、瞬間ではなく

少し長い時間で見た際の変化であった。時間による倍音の変化の比較については、これからの課題としたい。

(2)　ネガティブな感情

ネガティブな感情として、激怒と嘆き比較を比較した。激怒のデータでは、倍音だけでなくその周りの音も大きいことが確認できた。一方、嘆きのデータでは、倍音のみが細い線で表示されている。この点について、激怒の場合は倍音の線が太いことに加えて円で示した倍音の前後の音が大きく（図 12)、嘆きと比較して倍音のピークを頂点とした三角形が大きいことが分かる。これらの倍音ではない音は、私たちの耳には雑音として認識される。雑音があることにより音に厚みが生まれ、激怒という感情の荒々しさが表現されていると考察した。

また、嘆きのデータでは高い倍音が非常にはっきりと確認できる。一方、激怒のデータではこれらの高い倍音が雑音に含まれており、見分けることができない。これは、奏者が嘆きという繊細な感情を表現するために、息を鋭く吐いてより綿密にコントロールをしようとしたことによるものではないかと考えられる。鋭い息とは、口を小さくすぼめて出すスピードの速い息という意味であり、高い音を出そうとする際に使う。細かなコントロールがしやすいのが特徴である。逆に、激怒では口の中の空間を大きく開けて温かい息を吐くようなイメージでゆっくりと息を吐いた。そのため、コントロールがあまりされず雑音の多い音になったとも考えられる。加えて、雑音が多いために高い倍音がはっきりみられないことは、実験 1 の初心者の音にもみられた特徴である。

考察として、演奏技術が上がるにつれて、激怒のような雑音を多く含む音や嘆きのような倍音がクリアな音をコントロールできるようになっていくのではないかと考える。

また、これらの倍音の特徴は、感情の方向性による違いから生じるのものなのではないだろうか。激怒は非常に外交的な感情で、嘆きは内省的な感情である。このイメージが息のコントロールに影響しているという仮説を立てた。先述の実験結果でも同様の特徴が見られる。この仮説が正しければ、音楽による感情表現を客観的に判断し練習する一助となるだろう。

演奏者の練習に役立てるためには、他の感情や今回あまり芳しい結果が得られなかったポジティブな感情についてのより詳しい実験も必要となる。また、実際に音を聞いた観客の感じ方とその音のデータを比較し分析することにより、観客に効果的に感情を伝える演奏方法が明らかになるのではないかと考える。

倍音以外の観点からもデータを分析するなど、よりたくさんの結果を得て考察を進めることが望ましい。

4. 展望

まずは多くの奏者のデータを集め、研究結果をより客観性のあるものにする必要がある。本研究では、フルートの音の違いについて倍音のみに焦点を当てて分析した。しかし、音を作る要素は他にもあるため、何が違いを生む要因となっているのかの詳しい研究が必要である。時間的要素による変化の評価が目下の課題と考えている。また、感情についての知識が不足しているため、よりたくさんの先行研究から情報を得て更なる実験を行っていきたい。加えて、フルート以外の楽器でも同様の実験を行い、どのような違いが出るのか調べていきたい。

5. 謝辞

2 年間の課題研究を通して、実験方法から考察まで終始的確な助言をくださった辻本先生に厚く御礼を申し上げます。また、実験に協力してくださった同級生の皆さんに心から感謝します。本当にありがとうございました。

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Method to Analyze Main Techniques of Flute Playing

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

This science project analyzed the primary techniques of flute playing, motivated by curiosity about the recognizable differences between beginner and professional players. It was hypothesized that the key distinctions lie in the playing techniques and the expression conveyed. Techniques were categorized into sound production and expression, with the latter assessed by the emotional resonance of the melody. The study focused on the variation in sound corresponding to different imagined emotions by the player. By examining how these factors influence the sound and overall impression, the research aimed to guide beginners toward more efficient practice. Referencing previous research on the relationship between sound pitch and wave direction in violin playing, a preliminary experiment on the flute was conducted. It revealed optimal sound projection in the flute's middle section, with no significant variation in sound pitch direction. Experiment 1 investigated the sound differences between beginner and professional players, identifying the number and balance of overtones as key differentiators. Experiment 2 explored the relationship between sound characteristics and four emotions: Happiness, Violent Anger, Grief, and Enjoyment, noting differences in overtones. This research contributes to understanding how players can make flute playing more expressive.

Keywords: flute, technique, sound, expressive, pitch, overtone, emotion

I. Introduction

This research is about the sound of the flute. The purpose is to consider whether the difference of the sound data can be analyzed physically when we can recognize its difference. The motive is to understand why one can recognize the difference between professional players' sound and beginners' sound as a flute player. The main topic of this research is the difference between professional players and beginner players. Also, the difference in sound data depending on emotional expression is considered, too. If we could analyze them physically, beginner players can get some information to be a better player from this research. If the sounds produced by beginner and professional players could be analyzed physically, valuable information could be obtained from this research, which could assist beginner players in improving their skills.

Previous research established a reference between the pitch of sound and the direction of the sound waves heard when a violin was played. A preliminary experiment of the flute was done, and the sound was heard best from the middle part of the flute. There was no difference in the direction of the sound pitch. In this experiment, the difference between a professional and a beginner player could not be revealed, but the result can be utilized for the recording method.

II. Methods

Experiment 1 ~ Difference Between Skilled and Beginner Players ~

This research is about the sound of the flute. The purpose is to consider whether the difference of the sound data can be analyzed physically when we can recognize its difference. The motive is to understand why one can recognize the difference between professional players' sound and beginners' sound as a flute player. The main topic of this research is the difference between professional players and beginner players. Also, the difference in sound data depending on emotional expression is considered, too. If we could analyze them physically, beginner

players can get some information to be a better player from this research. If the sounds produced by beginner and professional players could be analyzed physically, valuable information could be obtained from this research, which could assist beginner players in improving their skills.

Previous research shows the relationship between sound pitch and direction of the sound waves heard when a violin was played was a reference. A preliminary experiment of the flute was done, and the sound was heard best from the middle part of the flute. There was no difference in the direction of the sound pitch. The difference between a skilled and a beginner player could not be revealed in this experiment, but the result can be utilized and analyzed. This research enables players to play the flute more expressively.

Experiment 2 ~ Expressing Emotions ~

The analysis focused on understanding how the expression of emotions affects sound quality. Initially, the player conveyed four emotions: Happiness, Violent Anger, Grief, and Enjoyment, and these expressions were measured using WaveSpectra. The sound in a normal, unemotional state was also compared. Subsequently, the characteristics of each emotional expression were analyzed and compared, with particular attention to the overtones.

III. Results and Discussion

Experiment 1

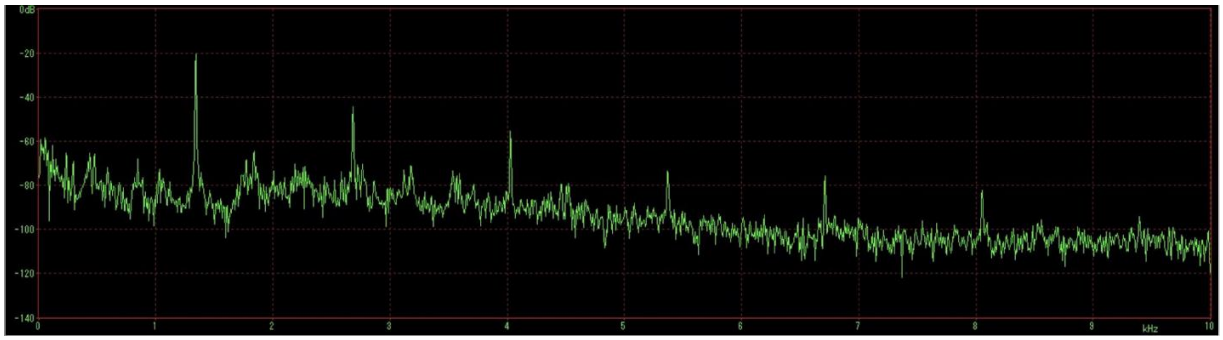

Fig.1 High tone of the skilled player

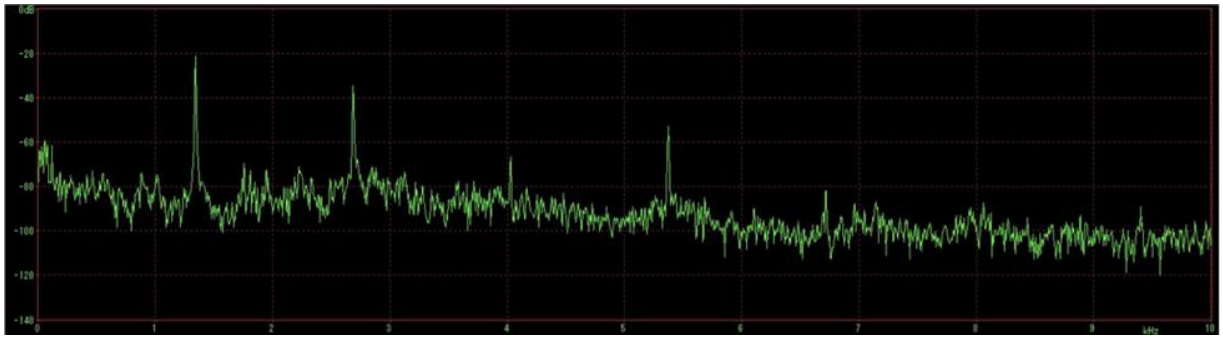

Fig.2 High tone of the beginner player

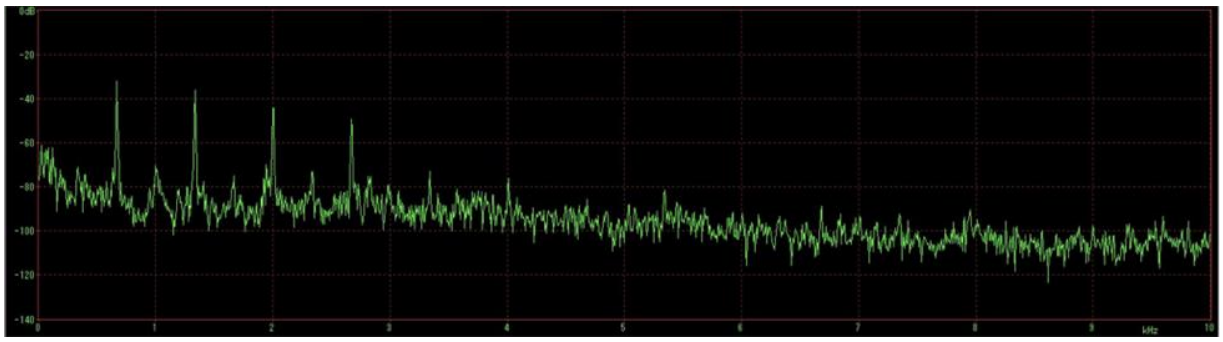

Fig.3 Low tone of the skilled player

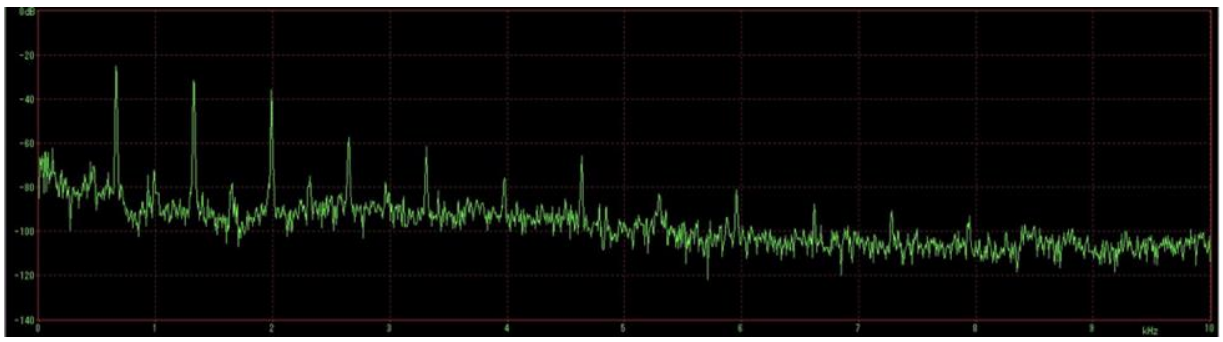

Fig.4 Low tone of the beginner player

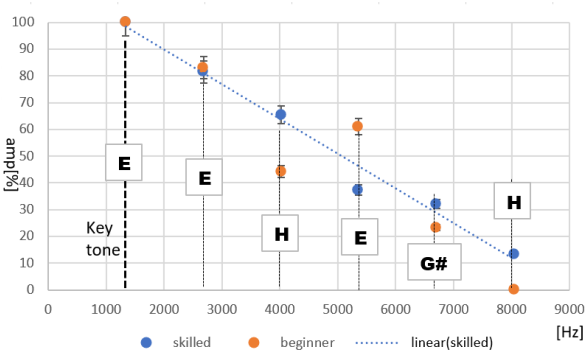

Fig.5 High tone

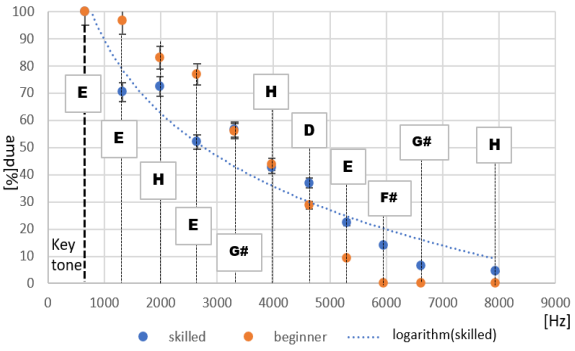

Fig.6 Low tone

Two features were identified as the key differences between the skilled player and the beginner player: the number and the balance of overtones.

The number of overtones was larger in the data of the skilled player. In the data of the high tone of the skilled player (Fig. 1), the higher overtones are much clearer than in the data of the beginner player. In the data of the beginner player, the tone that should be an overtone is included in the noise. This feature is more remarkable in the data of low tone (Fig. 3, Fig. 4). The data of the beginner player has many lower overtones, but the number of higher overtones was very small. These tones were hard to recognize because they are similar to noises. It can be thought that these tones made the original sound unclear.

The second feature concerned the balance of overtones. In the skilled player's data, the volume of overtones decreased as they got higher. For high tones, the skilled player's data approximated a linear curve, while for low tones, with more overtones present, the curve resembled a logarithmic line. In contrast, the beginner's data (represented by orange dots) showed fluctuating patterns, suggesting a smoother line for the skilled player's data.

This finding could be instrumental in guiding beginners to improve their playing. However, this study was limited to just two players. Further data collection from additional players is necessary to substantiate these results.

Additionally, it's generally believed that low tones are more challenging for beginners to play beautifully, which this research supports by showing that low tones have more overtones. Conversely, for skilled players, high tones are more challenging. This is evident in the data, where the volume gap between the keynote and its next overtone is larger, particularly in high tones, suggesting that skilled players can better emphasize the keynote, which is more challenging in high tones.

Experiment 2

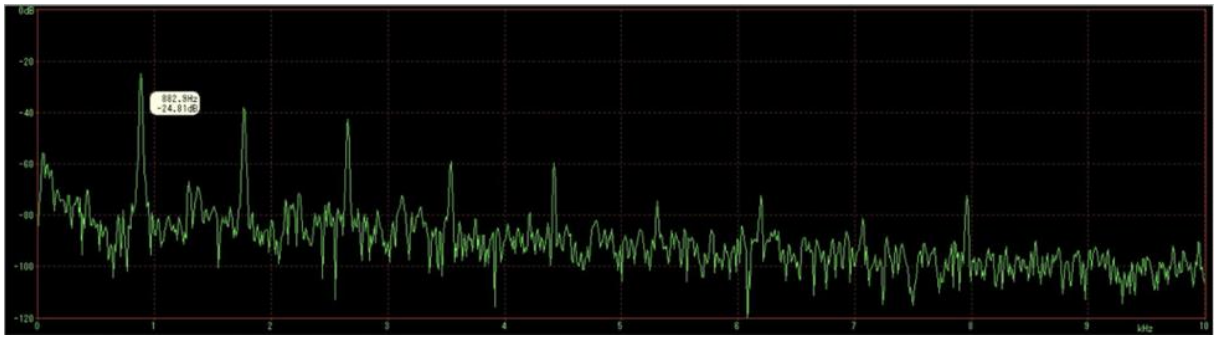

Fig.7 Normal

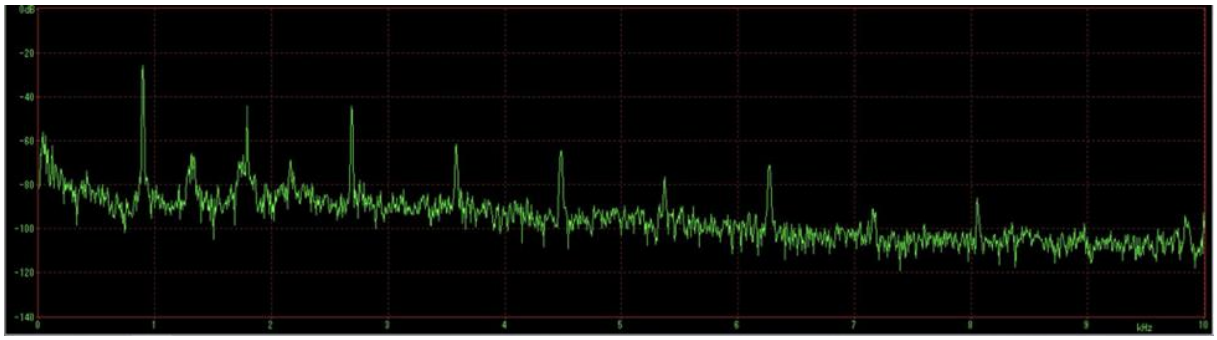

Fig.8 Happiness

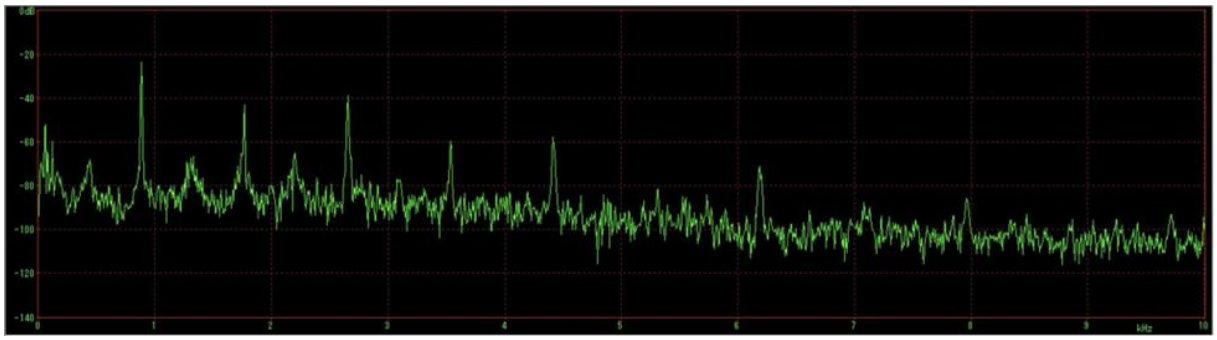

Fig.9 Violent anger

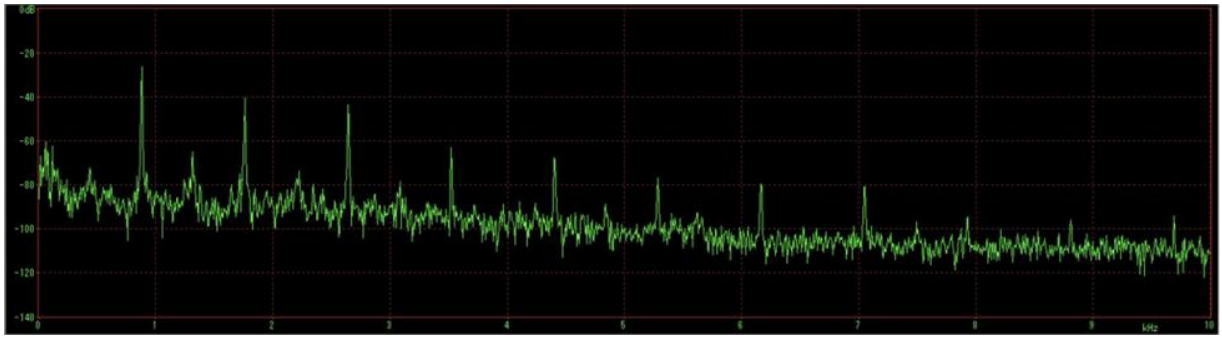

Fig.10 Grief

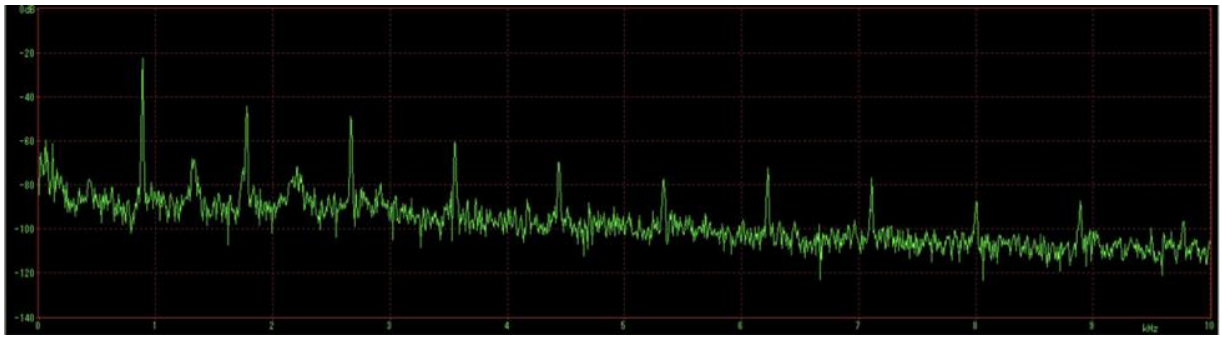

Fig.11 Enjoyment

The second experiment measured the sound for four emotions: Happiness, Violent Anger, Grief, and Enjoyment. To facilitate comparison, the sound in a normal state was also measured. The overtones for each emotion were compared, but no significant differences were found. This might be because more than expressing different emotions through only one tone is required, given the importance of melody.

The emotions were classified into positive and negative categories. Happiness and Enjoyment are positive, while Violent Anger and Grief are negative. Although Happiness and Enjoyment were compared, no significant differences were found, indicating a need for further research into positive emotions. It was hypothesized that the definitions of these emotions were not clear enough.

However, some differences were observed in the comparison of negative emotions. In the Violent Anger data, the overtones around the larger ones were pronounced, and the line was

thick, indicating some noise. This noise could be interpreted as expressing the roughness of the emotion. Generally, wind instrument players express anger by exhaling forcefully, and this result is consistent with that technique. In contrast, the higher overtones were much clearer in the Grief data than in Violent Anger. This might indicate that the player controlled their breath more delicately to express Grief, possibly because Violent Anger is extroverted while Grief is introverted. The study concluded that the data for each emotion depends on the emotional direction.

IV. Conclusion

From this research, it can be concluded that physical analysis of flute sound is indeed possible. A key finding is that the balance and number of overtones vary significantly based on the player's skill level and emotional expression.

In Experiment 1, two primary differences between skilled and beginner players were identified: the balance and the number of overtones. The skilled player's graph displayed a smoother approximate curve than the beginner's. Additionally, the sound produced by the skilled player contained more overtones.

Experiment 2 revealed variations in sound related to emotional expression. Differences were noted in the amount of noise and the clarity of overtones. It is inferred that the direction of the expressed emotion influences these variations.

V. Future Research

First and foremost, further experiments should involve more players. Since this research was conducted with only two players, obtaining more varied data is essential to validate our hypothesis. Additionally, other factors influencing sound differences need to be explored. While this study focused on overtones, other elements likely contribute to sound variation. In particular,

the balance of overtones may reveal additional characteristics. For instance, the approximate curve of high tones for the skilled player was a simple linear line in this study, but it might be logarithmic in the data of more skilled players. Creating a good approximate curve is more challenging in high tones, possibly following a logarithmic pattern, which should be investigated.

Furthermore, studying the sound of other musical instruments would be beneficial for a broader understanding. Research on emotional expression in music is a complex and somewhat vague field, necessitating a deeper dive into existing literature. This study did not discern a clear difference between Happiness and Enjoyment, indicating a need for more profound knowledge better to understand the relationship between emotional expression and sound data.

VI. References

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Method to Analyze Main Techniques of Flute Playing

Ritsumeikan High School

Abstract

This science project analyzed the main techniques of playing the flute. The motive was that we wondered why we can recognize the difference between beginner and professional players. It is hypothesized that the main techniques of how the flute is played and the expression make us recognize the difference. The main techniques of flute playing were categorized by making sound and expression. Expression is determined by how the emotion is felt from the melody. We decided to research about the difference of the sound that the player imagined about each emotion. Also, vibrato is very important to express. By revealing how these factors change the sound and impression, beginners can be more efficient player.Previous research shows the relationship between sound pitch and direction of the soundwaves heard when a violin was played was a reference. A preliminary experiment of the flute was done, and the sound was heard the best from the middle part of the flute. There was no difference in the direction of sound pitch. In experiment 1, we researched about the relationship between sound data and emotions. Emotions were divided to four emotions:Happiness, Violent anger, Grief and Enjoyment. There were some differences in overtone. In experiment 2, the difference between beginner and professional player sound was researched. The number of overtones was the difference. This research enables players to play the flute more expressively.

Introduction

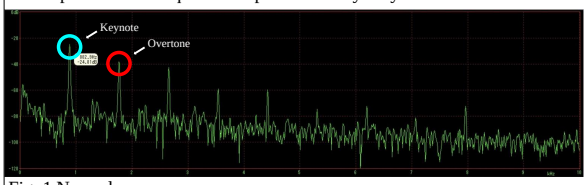
This research is about sound of flute. The difference of data of sound depends on the emotional expression played by the musician. This research looks at the logical reason why we can feel the emotion from music. Also, we can find ways to play the music more expressively.

Previous research shows the relationship between sound pitch and direction of the soundwaves heard when a violin was played was reference. A preliminary experiment of the flute was done, and the sound was heard best from the middle part of the flute. There was no difference in the direction of sound pitch. In this experiment, the difference between a professional and beginner player could not be revealed, but the result can be utilized and analyzed. This research enables players to play the flute more expressively.

Experiment 1

Results

The expression technique was experimented by only one tone.



※Vertical axis: dB
Horizontal axis: kHz

Fig. 1 Normal

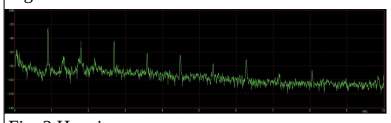


Fig. 2 Happiness

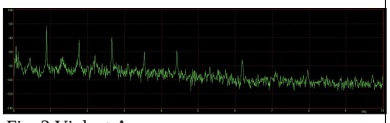


Fig. 3 Violent Anger

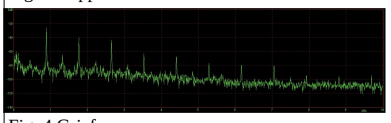


Fig. 4 Grief

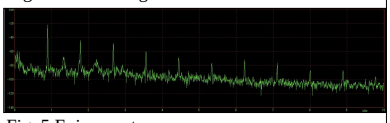


Fig. 5 Enjoyment

Fig. 2 ~ 5 are the data of sound: Normal, Happiness, Violent Anger, Grief, and Enjoyment.
We can see many overtones when the sound is expressed with emotion.
In Table 1, the overtones were compared only in each emotion. Table 2 is the information from a previous research. Table 3 and Table 4 are the comparison of the data on each side, negative and positive.

Table 1. Relationship between each emotion and overtones

	A (884Hz)	C# (1112)	E (1322)	A (1768)	C# (2225)	E (2645)	A (3536)	C# (4450)	E (5290)	A (7056)
Normal	-		△	◎	△	◎	○	○	△	
Happiness	-		△	○	△	◎	○	△	△	△
Violent Anger	-		△	◎	△	◎	○	○		
Grief	-		△	◎	△	◎	○	△	△	△
Enjoyment	-		△	◎	△	◎	○	△	△	△

◎ : −20~40 dB
○ : −40~60 dB
△ : −60~80 dB

Table 2. Characteristic of each overtone

A (1768 Hz)	Brightness
E (2645)	Thickness
A (3536)	Hardness
C# (4450)	Fullness
E (5290)	Sharpness

Table 3. Comparison of positive emotion

	Brightness	Thickness	Hardness	Fullness	Sharpness
Happiness		○	○		○
Enjoyment	○			○	

Table 4. Comparison of negative emotion

	Brightness	Thickness	Hardness	Fullness	Sharpness
Violent Anger		○		○	
Grief	○		○		○

Discussion

First, we compared the overtones in each emotion. However, we could not find any big difference from the data (Table 1). Since the melody is very important, only one tone is not enough to express different emotions. We classified the emotions into negative and positive to find the difference in more detail. We compared the two emotions on each side, negative and positive. In the previous research, it is said that each overtone has a certain characteristic (Table 2). The relative result is Table 3 and Table 4. Happiness and Enjoyment were compared. However, this is not a big difference, so we have to research more about the positive emotions. We hypothesized that the definitions of the words were not clear. Violent anger and Grief were also compared. The characteristics of negative emotions were clear. In the data of Violent Anger, the tones around big overtones were big and the line was thick. This means that there was some noise. This can be thought that the noises express its roughness. The noises made the sound complicated and heavy. On the other hand, in the data of Grief, higher overtones were much clearer than those of Violent Anger. This result can be thought the player tried to control the breath by exhaling sharply to express Grief. We thought that is because Violent anger is extroverted and Grief is introverted.

Methods

1. Measured the sound A (884 Hz) of the flute with WaveSpectra. The waveform and overtone was recorded.
   - Experiment 1
     Measured the sound with four emotions: Happiness, Violent Anger, Grief, Enjoyment.
   - Experiment 2
     Measured the sound with two people: a skilled player (7 years) and a beginner player (one week).
2. Analyzed the relationship of data.

Experiment 2

Results

Fig. 6 High tone of skilled player

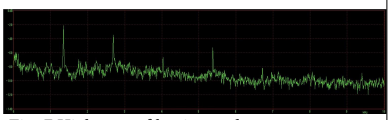


Fig. 7 High tone of beginner player

Fig. 8 Low tone of skilled player

Fig. 9 Low tone of beginner player

Table 5. The biggest overtones of high tone

	E	B	E	G	H	E	G#	H	D
Skilled	100		81.51		65.42	37.31	32.07	13.18	23.74
Beginner	100		83.01		44.11	60.99	23.28		12.96

Table 6. The biggest overtones of low tone

	E	E	H	E	G#	H	D	E	G#	H	D	E	F#	G#	H
Skilled		100		70.43		72.55		52.08	56.6	42.66	36.96	22.38	14.02	6.637	4.442
Beginner	53.75	100	49.88	96.68	37.26	83.07	43.69	76.99	56.04	43.75	28.84	9.392			

Number : % (dB)

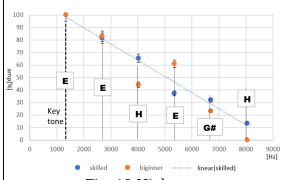


Fig. 10 High tone

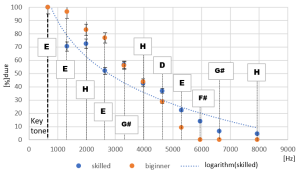


Fig. 11 Low tone

In Table 5, 6, Fig. 10 and 11, the volume of the overtones is displayed as the percentage when we let the volume of the keynote be 100.

Discussion

We found two features, the number and the balance of the overtones in the data of the skilled player.
The number of overtones were larger in the data of the skilled player. As you can see from Fig. 6~9, the higher overtones are much clearer in the data of the skilled player. In the data of the beginner player, the tones that should be an overtone are included in noise. In the data of low tone, these features are more remarkable. The data of the beginner player has many lower overtones, but the number of higher overtones were very small. The lower tones are hard to recognize because they are similar to noises. Also, so many tones other than overtones can be seen in the data. We thought that these tones made the original sound unclear.
The second feature is the balance. In the data of the skilled player, the higher the overtones become, the smaller its volume gets. However, the volume of overtones of the beginner player fluctuated. Fig. 10, 11 shows the result intelligibly. In Fig.10 (high tone), the approximate curve of the skilled player was linear. In Fig. 11 (low tone), there were more overtones so the approximate curve does not become simple linear. It became a logarithm. There is a possibility that the skilled player's overtones are on a smoother logarithm. The data of low tone also shows clearer results about this feature. This is a new discovery. By using this feature, the beginner player can get information to become a better player. However, we did an experiment with only two players this time. So we have to collect other player's data to support this result.

Conclusions / Future Plan

In conclusion, the balance and number of overtones were the biggest difference depending on emotions and skills. We learned the fact that tone color and expression is affected by overtone. As our future plan, we have to find other factors. We researched only about overtones this time, but there must be other factors. Also, the research about the sound of other instruments should be done. Moreover, the research about emotions is very deep and the topic is vague, so we have to learn more about previous research.

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太陽放射と近くの天体の反射スペクトルの比較

要旨

この研究はKorea Science Academy of KAIST (KSA)との共同研究である。今年度から新たなKSAの生徒と一緒に研究を始めた。昨年まで行っていた研究で得た知識、能力を活かして行うことのできる新たな研究テーマを実際にKSAの生徒と対面し、決定した。KSAと立命館でそれぞれ観測し、結果を分析して共有しあうという方法で進めた。同じ研究テーマの中でKSAチームと立命チームで比べる天体が違い、そして実験内容や実験結果も異なった。私たちは太陽と月のスペクトルをそれぞれ立命館の天体望遠鏡で観測し、比較した。またその比較結果からなぜそのような結果になったのか考察をした。結果からは、太陽と月のスペクトルは形状が異なるということが分かった。また、いくつかの吸収点が同じであった。そして月のスペクトルは太陽のスペクトルより小さいことが分かった。

1. 背景

光のスペクトル分析は、光源に関する多くの情報を提供することができる。特に、吸収スペクトルを分析することで、光源やその周辺の元素に関する情報を得ることができる。本研究の目的は、太陽光と、太陽反射である惑星や衛星からの光のスペクトルを比較・分析することで、天体表面の組成を分析することである。天体からの光は太陽光の反射であるが、地表や大気の組成などの原因によって、異なる太陽光とはスペクトルが現れると予想される。今回の研究を通して、宇宙空間にある天体から直接岩石を採取して分析しなくても、望遠鏡と分光器だけで宇宙空間の天体の表面成分を分析できる可能性のある結果が出ると期待している。本研究では、まず、月や太陽系惑星のスペクトルを取得した後、既知のベガのスペクトルと分光器から得たスペクトルを用いて、本来の太陽のスペクトル以外の物質や地球大気などの影響を除去したスペクトルを取得する。そして、このスペクトルと太陽のスペクトルの比較分析を通じて、天体表面の成分を予測するプロセスを行う。

スペクトルとは、分光器に光を通し、電磁波の波長ごとの強度分布を記録したものである。物理学では、プリズムなどの分光器に光を通すと虹のような色帯ができる（光成分の波長によって屈折率が異なるためである）。スペクトルを見れば、それぞれの光がどのような波長を持っているかが一目でわかる。

吸収スペクトルとは、ある物質が各波長の光をどれだけ吸収するかを表したグラフである。連続スペクトルを構成する光が冷たくて密度の低い気体を通過すると、吸収スペクトルになる。

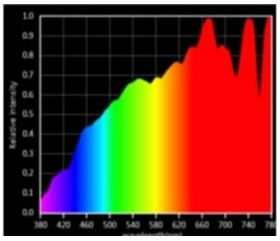

図1.スペクトルの例

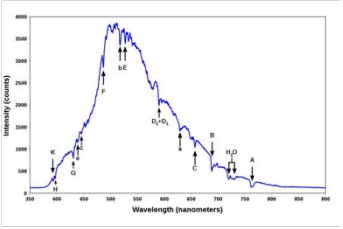

図2.吸収スペクトルの例

最後にこの研究はKorea Science Academy of KAIST (KSA)との共同研究である。今年度から新たなKSAの生徒と一緒に研究を始めた。昨年まで行っていた研究で得た知識、能力を活かして行うことのできる新たな研究テーマを実際にKSAの生徒と対面し、決定した。KSAと立命館でそれぞれ観測し、結果を分析して共有しあうという方法で進めた。

2. 先行研究

2-1. 背景

私たちのチームは本テーマである太陽光と太陽光が反射された月からの比較をする前に、先行研究として積分球の効用性について研究した。積分球の中で光を乱反射させることでより均一な光を入手することができ、分光器の校正ができる。

先行研究として私たちは昨年度に直径 2m の積分球を作った（図 3)。積分球は内面が球形で，内壁が硫酸バリウムなどの反射率の高い光散乱素材で作られている。私たちは硫酸バリウムスプレーを積分球の内壁に塗った。これは取り込んだ光(測定光)を散乱させ均一にする効果がある。そこで私たちは、この作った積分球の正確性を確かめるために、実験を行った。

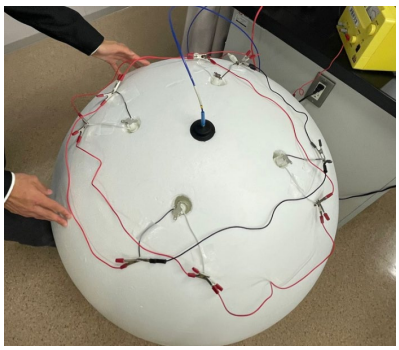

図 3. 積分球

2-2. 実験方法

積分球に光源を配置し、光ファイバーを積分球の中に付けることで積分球のなかを乱反射した均一な光は光ファイバーを通じ、コンピュータとデータを数値化する FLAME-S により数値としてコンピュータの中に得ることができる。まず初めに、実験室内の電気をつけた状態で実験を行い、次に実験室内の電気をオフにしてデータを得た。本研究の 1 番の狙いは、積分球として効用性を確かめられるかであるため。メインの実験として、LED ライトや白熱電球を使用し、コンピュータ内の Excel を用いてグラフ化し可視化できるようにした。直径 2m の発泡スチロールからできた半球を繋ぎ合わせ、積分球を作成した。また、電球を通す穴をくり抜いた。しかし最初のこの実験では積分球の内壁にカラースプレーは塗っていない。次に、くり抜いた穴に電球を入れてスペクトルを測った。今回の実験では LED とハロゲンの 2 種類のスペクトルを取り、部屋が明るい場合と暗い場合の 2 パターン試した。次にやすりを使って積分球の内壁を擦ってから、カラースプレー（白色）を使って塗装した。その後、先ほどと同じように LED とハロゲンを点灯した時のスペクトルを得た。そして積分球の内壁の塗装前と塗装後の二つの電球のスペクトルを比較した。

2-3. 実験結果

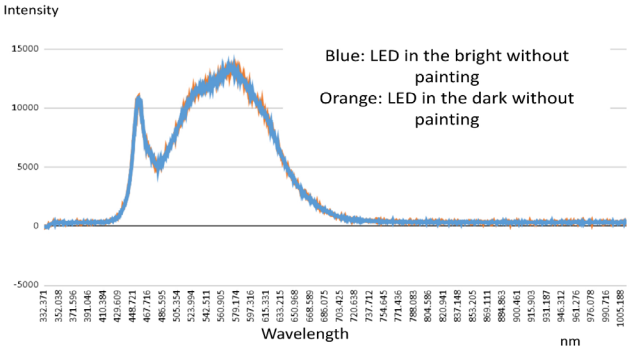

図 4.　LED 部屋の明るさの違いのグラフ
青：LED（塗装なし、明るい部屋）
オレンジ：LED（塗装なし、暗い部屋）

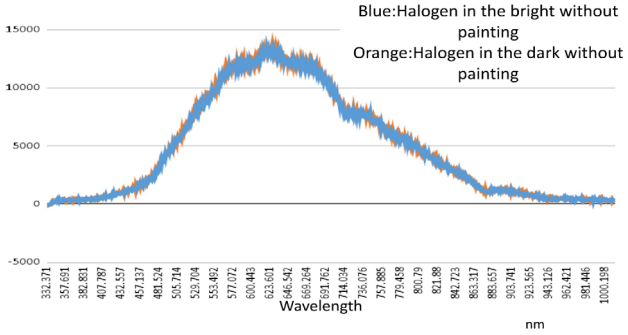

図 5.　ハロゲン　部屋の明るさの違いのグラフ
青：ハロゲン（塗装なし、明るい部屋）
オレンジ：ハロゲン（塗装なし、暗い部屋）

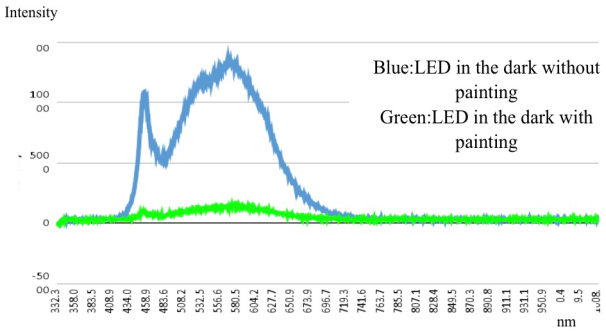

図 6. LED 塗装有無　比較のグラフ
青：LED（塗装なし、暗い部屋）
緑：LED（塗装あり、暗い部屋）

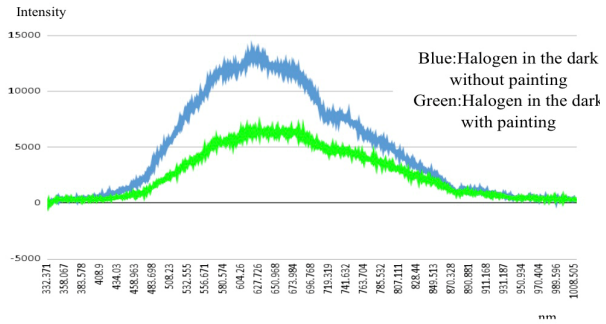

図 7. ハロゲン　塗装有無　比較のグラフ
青：ハロゲン（塗装なし、暗い部屋）
緑：ハロゲン（塗装あり、暗い部屋）

2-4. 考察

オレンジ色のグラフは LED とハロゲンを点灯し、明るい部屋で実験を行ったものである。この結果から LED からの光を取り込むには部屋を暗くしなければならないことがわかった。また、カラースプレーは波長を滑らかにし、積分球にとってより適したものであることがわかった。これはこのカラースプレーがより多くの光を乱反射させるためである。今回の実験により、作成した積分球をフラットフィールド補正に使用していきたい。

3. 観測方法

3－1. 天体のスペクトルの獲得

天体観測には天体望遠鏡　(NISHIMURA FACTORY、カセグレン式、口径 3000 mm）を使用した。光ファイバー（図 8）とオーシャンビュー社の分光器 Flame-S（図 9）を使用し、得られた光を定量化した。

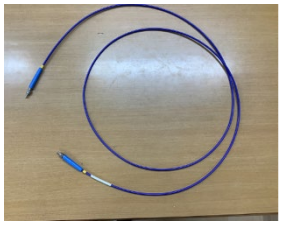

図 8. 光ファイバー

図 9. 分光器　FLAME-S

今回は 10 回ずつ測ったため Excel の機能を使用し、10 回の平均のグラフを作成した。

3－2. 太陽と月のスペクトルの獲得と比較

まず、天気予報で観測に適した日を探す。その日は湿度が適切で、曇り空でなければならない。なぜなら、データは周囲の環境からノイズを吸収してしまうからだ。次に、適切な日に太陽と月のスペクトルを観測した。そして、データをエクセルにまとめ、異なるスペクトルのグラフを作成した。最後に、太陽と月の 2 つのスペクトルを重ね、違いを比較し、分析した。

4. 実験結果

4－1. 太陽のスペクトル

図 10. 太陽のスペクトル

グラフから、440 nm ,515 nm, 590 nm, 650 nm ,690 nm, 720 nm, 760 nm で吸収されていることが分かる。

4−2. 月のスペクトル

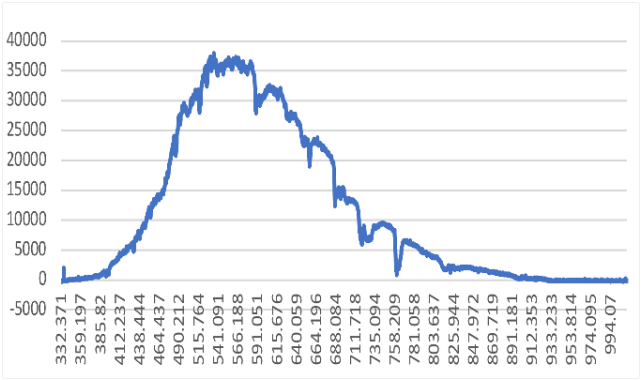

図 11. 月のスペクトル

グラフから、530 nm, 590 nm, 660 nm , 680 nm, 710 nm, 760 nm で吸収されていることが分かる。

4−3. 太陽と月の比較スペクトル

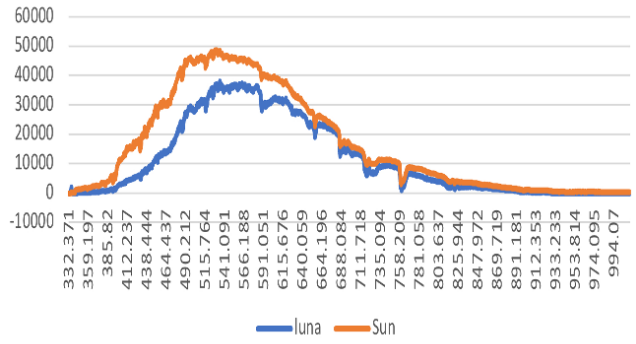

図 12. 太陽と月の比較スペクトル

この結果から、月のスペクトルは太陽のスペクトルより小さい。これらは特に短い波長においては強度が変わることがわかる。また、750 nm で大きく吸収していることがわかる。いくつかの吸収点が同じである箇所がある。

5. 考察

使用した分光器では、1000 nm あたりの波長の詳細を詳しく得ることができないため、可視光範囲の波長について注目することとした。

5−1. 考察 1

400〜500 nm で月が光を吸収している。月の成分として多い斜長岩の色は暗灰色からは灰青色の色をしている。この青色は波長でいうと 430 nm 〜490 nm の波長を示すため、太陽からの光が月を通過することでこの部分の波長が減衰して、太陽に比べて凹んでいるのではないかと考えた。

5−2. 考察 2

グラフより、月のスペクトルが 600 nm 付近で大きく凹んでおり、月の影響であると考えられる。月には斜長岩同様に玄武岩も存在する。新鮮な玄武岩は黒色を示すが、酸化すると赤茶色を示す。赤色というのは波長の 640 nm〜770 nm を吸収する性質を持つ。月には地球ほどではないが、酸素が存在している。これらのことより、長年の月日を重ねることで酸化したことがこの結果に影響しているのではと考えた。

5−3. 考察 3

考察 2 のように玄武岩は酸化している可能性があるが、完全に酸化しているわけではなく、黒色を示す玄武岩と酸化した赤茶色の玄武岩が共存していると考えた。それに加えて、スペクトルは別日に取得していることもあるため、完全に同じ条件下ではないことや、近年の大気汚染などに少なからず影響を受けて細かなノイズが含まれていることが考えられる。

6. 展望

今回の実験では太陽と月のスペクトルを比べなぜその波長で吸収されているのか、理由を考えた。しかしこの考察は私たちの考察なので正確ではないかもしれない。だから、今回の実験では納得のいく考察を得ることができなかったため、今後さらに天体について知識を深め、さらに正確な考察をしていきたいと考えている。また、太陽と月だけではなく他の天体でスペクトルを比較し考察をしたい。月の光は太陽の光を反射しているため同じスペクトルになるように思えるが、今回の実験で違うと分かった。なぜ異なる形状になったのか最終的な理由を考えたい。

7. 謝辞

本研究を進めるにあたり、お忙しい中ご指導いただいた笠巻奈月先生、市川美恵先先生、国際共同研究でお世話になった Korea Science Academy of KAIST の Dr. In- ok Song に心より深く感謝申し上げます。また、積分球の作成にあたり助言をくださった立命館大学の佐伯和人教授に熱く感謝致します。昨年度、今年度と共に研究をして来た Korea Science Academy of KAIST の 6 人の仲間 Dong Hyeok Kim, Min Soo Kim, Minhyuk Jeong, Minchan Kim, Yoonhong Park, Seonghyeok Choi、執筆のご指導をいただいた先生方にも熱くお礼を申し上げます。みなさまのご指導があったからこそ私たちは本研究を進めることができ、知識を深めることができました。

8. 参考文献

1. スペクトルとは
   https://www.klv.co.jp/corner/what-is-spectrum.html
2. Fraunhofer lines
   https://en.wikipedia.org/wiki/Fraunhofer_lines

Comparison between Solar Radiation and Reflectance Spectrum of Nearby Astronomical Objects

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

Spectral analysis of light can provide much information about the light source. In particular, by analyzing the absorption spectrum, it is possible to obtain information about the elements of the light source or its surroundings. The purpose of this study is to analyze the composition of the surface of an astronomical object by comparing and analyzing the spectrum of sunlight and light from planets or satellites, which are solar reflections. Since the light from astronomical objects is a reflection of sunlight, it can be thought that the spectrum will not differ from that of the sun. However, the initial prediction was that different spectra would emerge due to factors such as the composition of the surface or the atmospheric conditions. Through this research, there is anticipation of obtaining results that could potentially be employed to analyze the surface composition of celestial objects using only a telescope and spectrometer, eliminating and analysis for direct collection and analysis of rock samples from these objects. In this study, first, after obtaining the spectrum of the moon and the planets of the solar system, the known spectrum of Vega and the quantum efficiency information of the spectrometer will not be used to obtain the real spectrum with the influence of substances other than the original sun spectrum and the of the astronomical objects such as earth's atmosphere removed. Then, through a comparative analysis of this spectrum and the real spectrum of the sun, a process of predicting the components of the surface of the astronomical object can be conducted.

Keywords: spectral analysis, absorption spectrum, astronomical objects, Vega, atmosphere

I. Introduction

This collaborative research project with the Korea Science Academy of KAIST (KSA) compares the spectrum of the Sun and the Luna and analyzes the differences. The KSA team used Vega's spectrum to obtain and analyze Saturn's spectrum. A spectrum is a record of the intensity distribution for each wavelength of electromagnetic waves obtained by passing light through a spectroscope. In physics, a rainbow-like color band is created when light is passed through a spectroscope such as a prism, because the refractive index differs depending on the wavelength of the light component – arranged in order of wavelength.

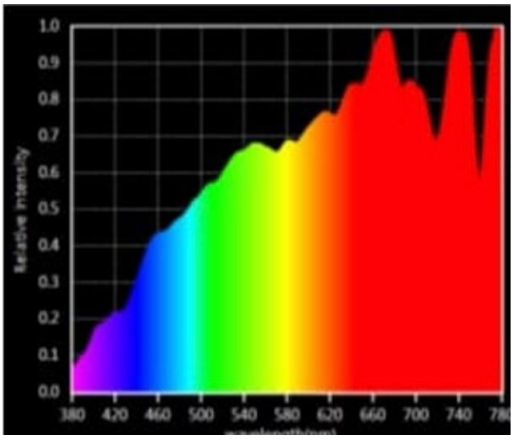

Fig.1 Spectrum of sunlight (Ref.1)

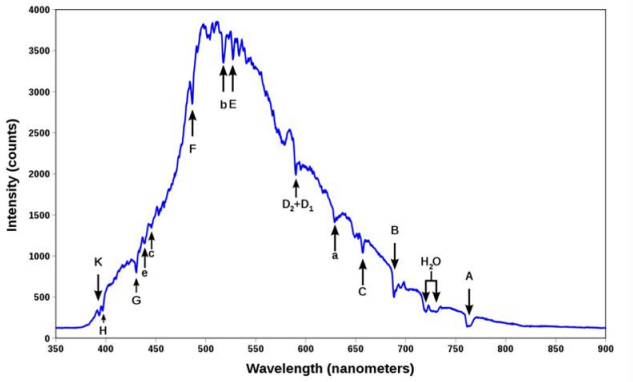

Fig.2 Absorption spectrum

Broadly speaking, it is the decomposition of a certain composition, and the components are arranged by size. By looking at the spectrum, it can see briefly what kind of wavelength each light has. The absorption spectrum is a graph showing how much light of each wavelength is absorbed by a substance. If light comprising a continuous spectrum passes through a cool, low-density gas, the result will be an absorption spectrum.

II. Materials and Method

An Astronomical telescope (NISHIMURA FACTORY, Cassegrain type, Caliber 3000mm) was used to observe astronomical objects. Optic fibers and the spectrometer Flame-S of Ocean View were used to quantify the obtained light. A computer was used to make the graph of collected data in Excel.

Fig.3 FLAME-S

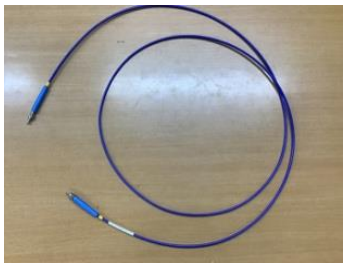
Fig.4 Optic fibers

Fig.5 OtO spectrometer

First, weather forecasts were used to find days with suitable conditions. The day used for observation needed to have proper humidity and be cloudless. That's because collected data will absorb some noises from the surrounding environment.

Second, the spectrum of the sun and Luna were observed on suitable days. Third, data was compiled in Excel, and graphs were created for the different spectrums. Finally, the differences between the two spectrums of the Sun and Luna were analyzed.

III. Data Analysis

In our experiment, the spectrometer couldn't get the wavelength range of more than 1000 nm in detail. So, we tried to get the feature in the range of visible light and focused on the color.

The sun and luna spectrums were viewed on different days. Figure 6 shows spectrum of the sun, while Figure 7 shows spectrum of Luna. From these results, we can see different shapes. Some absorption points are the same in places. As shown in Figure 8, Luna's spectrum is smaller than the sun's spectrum.

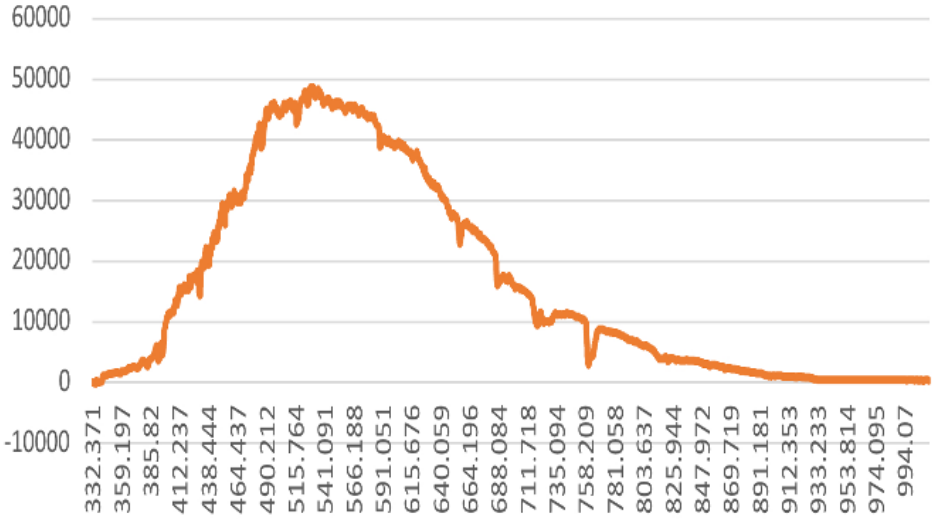

Fig.6 Sun spectrum data acquired on October 23, 2023, around 13:00 at Ritsumeikan High School (no clouds, good humidity)

Fig.7 Luna spectrum data acquired on September 29, 2023, around 19:00 at Ritsumeikan High School (no clouds, good humidity)

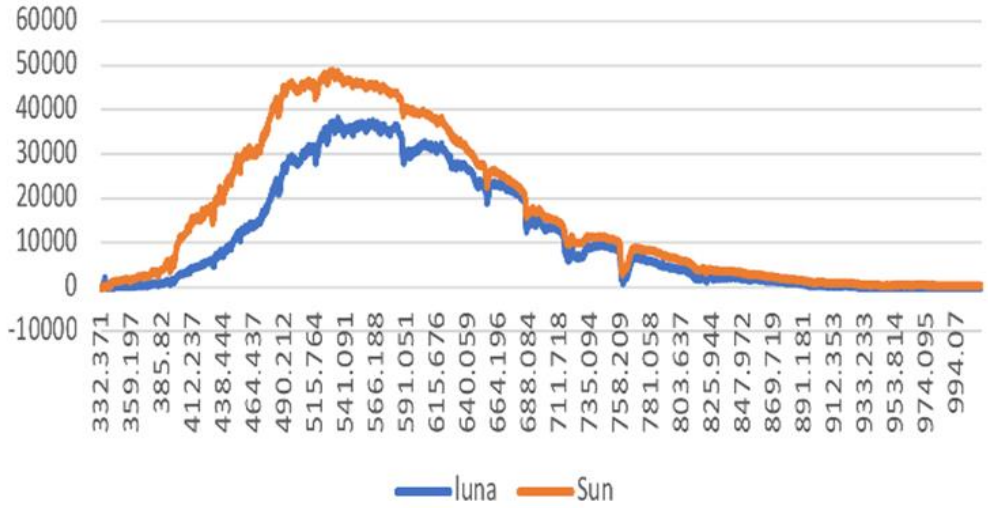

Fig.8 Graph showing the spectrum data from the sun and Luna

IV. Discussion

Wavelengths of 400 nm to 500 nm

It is thought the lights that come from Luna to the earth absorbed the wavelengths in the range of 400 nm to 500 nm due to the plagioclase that exists on the surface of Luna. That's because the original color of Plagioclase is dark gray to grayish blue. (The blue color is absorbed around the wavelength in the range of 430 nm to 490 nm.)

Fig.9 Wavelengths of 400 nm to 500 nm

Wavelengths of Around 600 nm

This part of the spectrum data is thought to have been influenced by the presence of basalt on the surface of Luna. Pure basalt is black in color. However, when basalt is oxidized, it

changes from black to reddish brown. The reddish-brown color is similar to orange, which absorbs wavelengths between 590 nm and 640 nm. This demonstrates oxygen is present on Luna, although not as much as on Earth. It is thought that the basalt has been oxidized for a long time.

Fig.10 Wavelengths of around 600 nm

Although it is thought that there is oxidized basalt as an explanation for Figure 10, it seems that both oxidized and non-oxidized basalt are present on the Lunar surface. Also, the spectra were not observed on the same day, so the two experiments were not performed under the same conditions. This result may have also been affected by air pollution and other factors.

V. Conclusion

This research has shown that it is possible to analyze the composition of the atmosphere and surface by comparing the spectra of the sun and moon taken with telescopes and spectrographs. It was found that that the absorption line between 400 nm and 500 nm was because of plagioclase, and the 600 nm absorption line was due to oxidized basalt. In conclusion, we tried to use school equipment to study the atmosphere's composition on the Moon's surface. This experiment showed that using spectroscopy makes it possible to recognize the components that make up extraterrestrial bodies with simple equipment.

VI. References

スペクトルとは [What is the spectrum?] https://www.klv.co.jp/corner/what-is-spectrum.html

Comparison Between Solar Radiation and Reflectance Spectrum of Nearby Astronomical Objects

Ritsumeikan High School[1], Korea Science Academy of KAIST[2]

Abstract

Spectral analysis of light can provide a lot of information about the light source. In particular, by analyzing the absorption spectrum, it is possible to obtain information about the elements of the light source or its surroundings. The purpose of this study is to analyze the composition of the surface of an astronomical object by comparing and analyzing the spectrum of sunlight and light from planets or satellites, which are solar reflections. Since the light from an astronomical object is a reflection of sunlight, it can be thought that the spectrum will not be different from that of the sun. However, our prediction was that different spectra would appear due to causes such as the composition of the surface or the atmosphere. Through this research, we are looking forward to getting a result that can possibly be used to analyze the surface components of objects in outer space using only a telescope and a spectrometer without directly collecting and analyzing rocks from them. In this study, first, after obtaining the spectrum of the moon and the planets of the solar system, the known spectrum of Vega and the quantum efficiency information of the spectrometer will be used to obtain the real spectrum with the influence of substances other than the original sun spectrum and the surface of the astronomical object such as the earth's atmosphere removed. Then, through a comparative analysis of this spectrum and the real spectrum of the sun, a process of predicting the components of the surface of the astronomical object can be conducted.

Introduction

Spectrum is a record of the intensity distribution for each wavelength of electromagnetic waves obtained by passing light through a spectroscope. In physics, a rainbow-like color band is created when light is passed through a spectroscope such as a prism (because the refractive index differs depending on the wavelength of the light component). Arranged in order of wavelength. Broadly speaking, it is the decomposition of a certain composition, and the components are arranged by size. By looking at the spectrum, it can see at a glance what kind of wavelength each light has.

Absorption spectrum is a graph showing how much light of each wavelength is absorbed by a substance. If light comprising a continuous spectrum passes through a cool, low-density gas, the result will be an absorption spectrum.

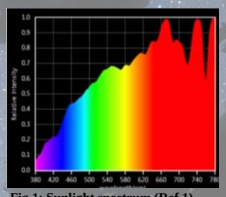

Fig.1: Sunlight spectrum (Ref.1)

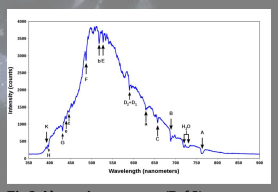

Fig.2:Absorption spectrum (Ref.2)

Experimental tools

Rits

-Astronomical telescope(NISHIMURA FACTURY, Cassegrain type, Caliber 3000 mm)
-Optic fibers
-The spectrometer Flame-S of Ocean View
-Computer(Dynabook)
-iPhone

Fig.3:FLAME-S

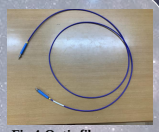

Fig.4:Optic fibers

KSA

-Astronomical telescope (TAKAHASHI 8-inch refractor, FCT-200)
-OtO spectrometer & Optic fibers
-Computer
-RSpec / Real-time Spectroscopy

Fig.5:OtO Spectrometer

Experiment 1 (Rits)

Method

1.Weather forecasts were used to find days with suitable conditions.

2.The spectrum of the Sun and Luna were observed on suitable days.

3.Data was compiled in Excel and graphs were created for the different spectrums.

4.The differences between the two spectrums of the Sun and Luna were analyzed.

Results

Exposure time = 100μs

Sun

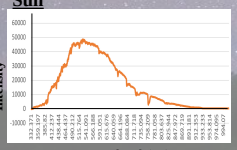

Fig.6: Sun spectrum
Day : October 23rd
Time : Around 1 pm
Place : Ritsumeikan High School
Condition : No clouds,Good humidity

Luna

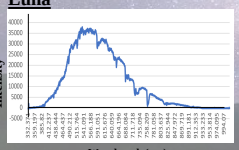

Fig.7: Luna spectrum
Day : September 29th
Time : Around 7 pm
Place : Ritsumeikan High School
Condition : No clouds, Good humidity

Sun and Luna

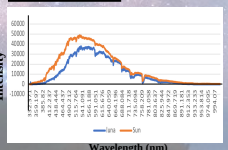

Fig.8: Sun and Luna spectrums
These are different shapes.
The absorption points are same.
The luna's spectrum is smaller than the sun spectrum.

Discussion

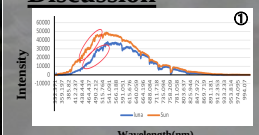

Fig.9: wavelength that is range of 400 nm to 500 nm

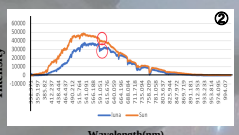

Fig.10: wavelength that is range of around 600 nm

Fig.11: Sun and Luna spectrum

In our experiment, spectrometer can not get the data that is range of more than 1000 nm in detail. Our experiment tried to get the features in the range of Visible light and focused on the color .

Fig.12:Around condition (when we took Luna and Sun spectrum)

Chart ①

The wavelength that is between the range of 400 nm to 500 nm was absorbed.
→ The effect by the plagioclase of Luna's surface.
- The original color is dark gray to grayish-blue.

(The blue color is absorbed around the wavelength in the range of 430 nm to 490 nm)

Chart ②

The wavelength that is in the range of around 600 nm.
→ The basalt oxidized for a long time.
- Basalt exists on the surface of Luna.
- Pure basalt is represented by a black color. But the basalt that is oxidized changes to a reddish brown from the black.

(The orange absorbs the wavelength that is range between the of 590 nm to 640 nm)
→ Oxygen is present on Luna

Chart ③

It is mentioned that there is oxidized basalt in the explanation of Fig.10, but it seems that both oxidized and non-oxidized basalt are present on Luna surface. Also, the spectra were not observed on the same day. This result is also affected by air pollution and other factors.

Experiment 2 (KSA)

Method

1. The spectrum of Vega and Saturn was observed.
2. Using Rspec, a calibration factor was obtained according to the wavelength with the known Vega spectrum and the Vega obtained in step1.
3. The Saturn spectrum was calibrated with the obtained calibration factor.
4. The absorption band of Saturn's spectrum was analyzed and were determined the atmospheric compositions.

Results

Exposure time=10s

Vega

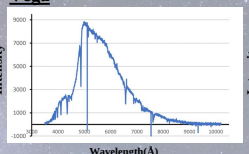

Fig.13:Vega spectrum

Reference Vega

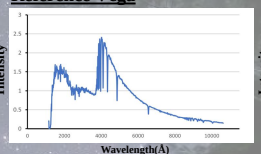

Fig.14:Reference Vega

Calibration Factor

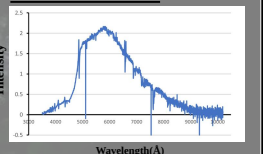

Fig.15:Calibration Factor

Saturn

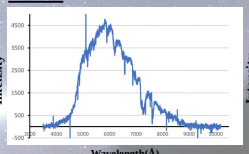

Fig.16:Saturn spectrum

Calibrated

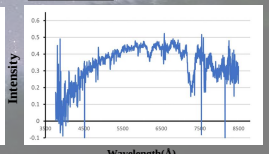

Fig.17:Calibrated Saturn

Day : September 18th
Time: Around 20:30
Place: KSA Observatory
Condition: No clouds, Good humidity

Discussion

Fraunhofer Absorption Line

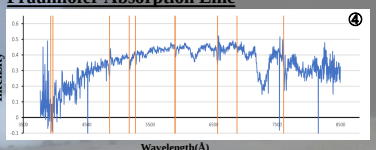

Fig.18:Fraunhofer Absorption Line

Methane Absorption Line

Fig.19:Methane Absorption Line

Chart ④

Fraunhofer lines (orange) appeared in the calibrated Saturn spectrum (blue).
→ This implies that the light originated from the Sun.

Chart ⑤

The calibrated Saturn spectrum (blue) had absorption lines that are not identified as Fraunhofer lines (e.g. around 620 nm).
These lines fit well with methane's absorption lines (yellow).
→ Saturn's atmosphere contains methane.

Conclusions

This research has shown that it is possible to analyze the atmosphere or the surface composition by comparing the spectrum of the Sun, Moon, and Saturn, taken by using telescopes and spectroscopes. For the moon we found out that the absorption line of 400 - 500 nm is shown because of plagioclase and the 600 nm absorption line was due to oxidized basalt. Analyzing the calibrated Saturn spectrum using Vega showed additional absorption lines other than the Fraunhofer absorption line, which was Methane. However, because the school's equipment could only obtain the spectrum in the visible light region, the spectrum in the IR region could not be compared. If it becomes possible to compare IR spectra, it will be possible to compare more diverse elements.

In conclusion, we tried to find out the compostion of the moon's surface and Saturn's atmosphere with school equipment. Through this experiment found we use spectroscopy, it is possible to recongnize the components that make up the celestial bodies outside of Earth with simple instruments.

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効果的かつ海の生態系を守る人工リーフの実用化について

要旨

昨年度の実験から,私たちが考案した新型人工リーフが旧型人工リーフよりも波による砂浜の侵食の低減に効果的であることが示唆された。しかし,未だ実用化に向けた様々な課題が残っているため,海の生態系や制作コストなど、より実用的な観点を考慮して研究を行うことにした。まず、人工リーフ上に着生した水草による砂浜の侵食の低減効果を調査するため、3D プリンターで作成したプラスチック製の人工リーフに水草のモデルを取り付け、人工リーフ表面に占める水草モデルの面積と波による砂の侵食面積の関係を測定した。その結果,水草の表面積が大きいほど浸食面積が小さくなることがわかった。次に、人工リーフを通る水面波の波高を変化させ、人工リーフの天端水深、表面の突起物の個数と配置パターンがそれぞれ、各波高の水面波にどのような影響を与えるかを測定し、エネルギーの増減を示す減衰率を算出した。天端水深と波高に関しては、水面波の波高が人工リーフに干渉する場合に特にエネルギーの減衰が確認されたが、一部の条件下ではエネルギーの増幅が見られた。表面の突起物の個数や配置パターンと波高に関しては、個数に応じて減衰率に影響があり、今のところどのような条件下でもその上限が約 7 割であることがわかった。さらなる改善には、突起物を加工しエネルギーを逃すような工夫が必要である。今回、水草が波の減衰に効果的であることがわかったが、人工リーフの素材であるコンクリート上に生育できるのかを確認する必要がある。また今回は、人工リーフを通過前後する水面波の波高を比較しエネルギーを算出したが、それに加えて一定時間におけるエネルギーの総和という形で、人工リーフの効果を評価する必要がある。

1. 背景

過去 15 年で日本列島の砂浜は全体の面積の約 13%を海岸浸食によって失っている。政府はそれに対する対抗策として,防波堤の建設を進めている。防波堤には,水面上よりも高い離岸堤と呼ばれるものや,テトラポット,人工リーフなどの種類があり,私たちはその中でも人工リーフに焦点をあてて研究を行うことにした。人工リーフとは,水面下に造成する構造物で,珊瑚礁の波を打ち消す機能を模したものであるため,海岸浸食の軽減が期待される,さらに,防波堤などと違い水面下にあることによって景観が保たれることや,潮の流れを遮らないというメリット有しており,ほかの防波堤よりもメリットがはっきりとしている。しかし,人工リーフに関する論文を調べても,天端水深や天端距離に関することばかりで形状に関する記載が少ないと感じた。そこで私たちは,新たな形状を考案するために人工リーフの研究を始めた。

昨年度の研究では,一般的な形状の旧型モデル(図 1)と吸音材の形状を模して考案された新型モデル(図 2)の海岸浸食への軽減率を比較し,新型モデルの方が効果的であることが示唆された。しかし,人工リ

ーフを設置すること自体がそもそも海の生態系に悪影響を与えてしまうことや,製造コストが高いことなどの問題点がある。それらの問題点を解決することができれば,考案した新型モデルの人工リーフの実用化により近づき,海岸侵食の問題に対して効果的な対策ができると見込まれる。

図 1. 旧型モデルの人工リーフ

図 2. 新型モデルの人工リーフ

2. 方法

2－1. 水草の着生による侵食への影響

3D プリンターで作成した旧型と新型の人工リーフに，それぞれ等間隔に 108 個の穴を開け，図 3 に示すようにその穴にスズランテープで作成した水草のモデルを取り付け，水草を着生させた場合と見立てて，波による浸食面積の測定実験を行った。

水草の有無だけでなく，個数による違いも比較したかったため，私たちは水草のモデルを 108 個(100%)，54 個(50%)，0 個(0%)の 3 パターンに分けて取り付け，それを旧型と新型の両方で実験をしたため，計 6 パターンの人工リーフで砂の侵食面積を測定し，効果を比較した。

実験方法は，水槽に砂を安息角に揃えて設置し，次に一定の量の水を入れ，LEGO Mindstorms を用いて造波装置から波を発生させ，侵食の様子を 35 秒間撮影した。その工程をそれぞれ 6 回行い，0 秒の時点と 35 秒の時点の静止画を ImageJ というソフトウェアを用いて解析し，浸食面積を測定した。

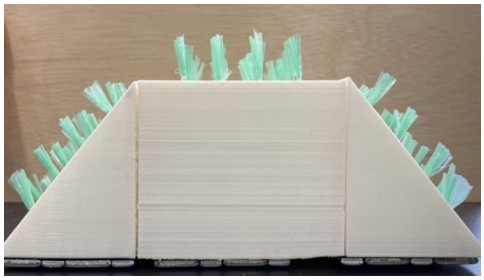


図 3. 旧型人工リーフ　水草付き

2－2. 波のエネルギーの減衰率

この実験は，立命館大学理工学部の実験施設を使用させていただき，施設内の規則波を発生できる造波装置を使用して波高を測定した。水の密度と重力加速度を定数とみなすと，図 4 を参考に，波の単位面積あたりのエネルギーは波高の 2 乗に比例することがわかる。

この式を用いて,人工リーフを通過する前の波のエネルギーが通過後に何%減少するかを求め，これを減衰率と定義してデータを比較した。

この実験では，3D プリンターでの新型人工リーフのモデル作成が困難であったため，コンクリート製のものを使用した。この人工リーフモデルは土台部分と突起部分に分けて自作し，突起部分については，クリア

ファイルを漏斗型に成形して型を用意し，その型にコンクリートを流し込んで作成した。

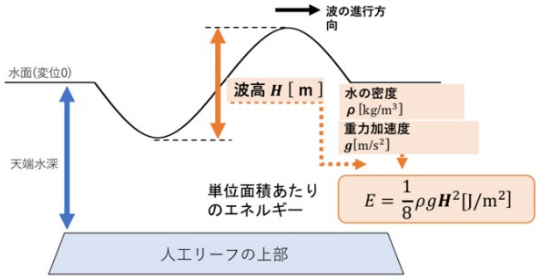


図 4．単位面積あたりのエネルギーの公式

図 5．コンクリート製新型人工リーフ

2－2－1．天端水深による波高の変化と減衰率の算出

図 6 に示す水深を天端水深と定義し,これを 1.0cm, 2.0 cm, 3.0 cm, 5.0 cm, 7.0 cm に設定し，造波装置から波高 2.0 cm, 3.0 cm, 4.0 cm の波を発生させ，人工リーフ通過前と通過後の波高を測定した。

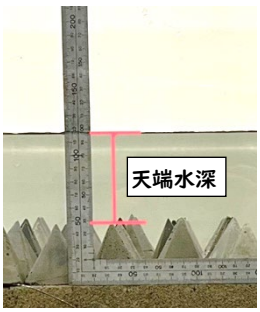


図 6．天端水深

2－2－2．突起物の個数と配置による波高の変化と減衰率の算出

新型人工リーフの突起物の個数・配置を以下の 4 パターンに設定し，造波装置から波高 2.0 cm, 3.0 cm, 4.0 cm の波を発生させ，人工リーフ通過前と通過後の波高を測定した。

突起物のパターンは個数 176 個(100%), 個数 104 個(59%)のジグザグ配列と縦配列，そして個数 88 個(50%)のジグザグ配列の計 4 パターンである。

3．結果と考察

3－1．水草の着生による侵食への影響

人工リーフに着生した水草の被度割合が大きいほど侵食面積が小さくなっていることがわかった。また，6 回の実験による浸食面積の平均値をグラフ化し，T 検定を用いて比較したところ，新型モデルの場合は，水草 100%と水草 50%・水草 100%と水草 0%を比較したときに大きく差があることがわかった。旧型モデルの場合は，水草 100%と水草 0%を比較したときに差があることがわかった。

人工リーフに着生した水草の被度割合が大きいほど浸食面積が小さくなっていることから,水草が着生することで新型人工リーフの本来の効果が損なわれることはないと言えるだろう。水草を単体で見たときのメリットとして水質がきれいになったり，魚の新たな住みかになったりもすることがあるので水草が着生することでそのような効果をあるかもしれないと考察することができる。

3－2．天端水深と減衰率の関係

天端水深を変化させた結果，表 1 のようになった。赤色が減衰，青色が増幅を表し

ている。この表から新型人工リーフは波高と干渉する水深のときに最も減衰率への影響があることがわかった。しかし，波高に干渉しない一定の範囲においては逆にエネルギーが増えていることがわかった。

エネルギーが増えてしまった原因として,人工リーフの形と天端水深と波の波高の関係性が大切なのではないかと考えることができる。とくに,形状については台形の形のため波が人工リーフに干渉した際に波のエネルギーを波の進行方向の反対がわではなく,上側に一部逃げてしまっているのではないかと考察をした。

表 1. 天端水深の変化による減衰率

天端水深（cm） / 波高（cm）	7.0	5.0	3.0	2.0	1.0
2.0	9.8%	0%	－44%	－56%	44%
3.0	0%	－21%	－78%	0%	56%
4.0	－5.1%	－27%	－10%	64%	70%

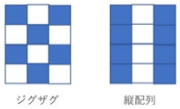
3－3. 突起物の個数と配置と減衰率の関係

新型人工リーフの突起物の個数と配置を変えて実験を行った結果，配置による大きな変化は見られず，基本的に突起物の個数によって減衰率が大きく変化することがわかった。しかし，突起物の個数が 176 個(100%)のときと 104 個(59%)を比較したときに，個数に大きな差があるにも関わらず，いずれも減衰率が最大 7 割近くで止まっていることがわかった。

最大の減衰率が 7 割であるとしたら,水草が十分育つことのできる面積を確保したうえで突起物の個数を減らした形状があるかもしれない,もしある場合突起物 100%の時よりも建設コストなども減らすことを視野に入れてさらに実用化に向けての案をだすことができると考えた。

表 2. 突起物の個数と配置の変化による減衰率

個数（個） 配置 / 波高（cm）	176（100%）	104（59%） ジグザグ	104（59%） 縦配列	88（50%） ジグザグ
2.0	44%	－10%	0%	－21%
3.0	56%	41%	36%	19%
4.0	70%	72%	67%	58%



ジグザグ　縦配列

4. 展望

人工リーフへの水草の着生によって人工リーフのエネルギーの減衰に影響がないことがわかった。しかし,人工リーフの素材であるコンクリート上で水草が生育可能か確認できていない。そのため,できる限り実際の環境を再現したうえでコンクリートに水草を植えて育つが確認する必要がある。また,今回波のエネルギーを求める公式的に習慣的な波のエネルギーを求めて比較したため,次は継続的な波のエネルギーを求める公式を使ってそれを求めて比較を行ってみたい。また,津波が発生する地域に置くことも考慮して津波に対しての効果があるのかないのか,ある場合どれくらいあるのかを調べたい。最後に,新型人工リーフによる減衰率の上限が 7 割あるということを利用して,最適な配置と個数を見つけてなおかつ水草の生育条件や建設コストなどの実用化の際のことも考慮したうえで最も効果的である人工リーフの形状を考案し,実際の海に置いて実験を行ってみたいと考えている。

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中西敬教授
和歌山工業高等専門学校生物応用科学科
楠部真崇教授
立命館高校　辻本遼二郎先生
には，この場をかりて厚く御礼申し上げます。

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The Effect of Auditory Stimulus on the Olfactory Sensory Artificial Reef with Effective Shape and Protection of Marine Ecosystems

G12 SSG Course

Ritsumeikan High School

JSSF 2023

January 19, 2024

Abstract

Last year's experiments suggested that the new type of artificial reef that was devised was more effective than the old type. However, since problems for practical application remained, it was decided to conduct the study considering the marine ecosystem, production cost, etc. 108 holes were drilled in a plastic artificial reef created by a 3D printer and attached water plant models created with lily tape in three patterns: 100%, 50%, and 0% of the number of holes. The model water plants were attached to the reef in three patterns: 100%, 50%, and 0% of the holes. Six patterns of the old and new models were made and submerged in a 90 cm tank, and the area of sand erosion by waves was measured. The results showed that the larger the surface area of the water plants, the more the erosion area was affected. Next, we measured the increase or decrease in energy from waveforms before and after waves passed through the concrete artificial reef by varying the top water depth, wave height, number of protrusions, and wave height. When top water depth and wave height were varied, wave waveform interference with the artificial reef was greatly reduced, but energy amplification was observed at some wave heights. When the number and placement of protrusions and wave height were varied, the effect depended on the number of protrusions, and the upper limit of attenuation was found to be about 70% under all conditions. It is necessary to devise a way to create depressions in the protrusions to release the energy. Finally, water plants were found to be effective in attenuating waves, but it is necessary to confirm whether they can grow on concrete, the material of the artificial reef. Also, since we measured the instantaneous energy in this study, we need to measure the continuous wave energy.

Keywords: artificial reef, marine ecosystem, water plants, erosion area, wave height

I. Introduction

In the past 15 years, sandy beaches in the Japanese archipelago have lost about 13% of their area to coastal erosion. The government has been promoting the construction of breakwaters as a countermeasure. There are several types of breakwaters, including detached breakwaters higher than the water surface, tetrapods, and artificial reefs. An artificial reef is a structure built under the water's surface that mimics the wave-canceling function of a coral reef and is expected to reduce coastal erosion. The advantages of artificial reefs over other breakwaters are clear. However, when we looked up articles on artificial reefs, we found that there were few descriptions of the shape of artificial reefs, only those related to the depth and distance of the top edge. Therefore, we began research on artificial reefs to devise a new shape.

In the previous year's research, we had studied the general shape of the previous model. The new model was designed to mimic the shape of sound-absorbing material, and the results suggested that the new model was more effective. However, installing an artificial reef itself harms the marine ecosystem, and the manufacturing cost is high. If these problems can be solved, the new model of artificial reefs will be closer to practical application and will be a more effective solution to the problem of beach erosion.

Fig.1 Model of conventional type of artificial reef

Fig.2 Model of new type of artificial reef

II. Materials and Method

2.1 Influence of Water Plant Attachment on Erosion

We measured the area of erosion caused by waves by making 108 holes at equal intervals in the old and new types of artificial reefs made by a 3D printer and attaching a model of water plants made by tinned tape to each hole, as if the reefs were covered with water plants.

Because we wanted to compare the difference not only by the presence of water plants but also by the number of water plants, we installed 108 (100%), 54 (50%), and 0 (0%) water plants models in three different patterns, and conducted the experiment using both the old and new models, thus measuring the erosion area of sand in a total of six artificial reef patterns and comparing their effects. The experimental method was to place sand in an aquarium tank.

Fig.3 New type artificial reef with water plants models attached

2.2 Attenuation Rate of Wave Energy

For this experiment, we were allowed to use the experimental facilities of the Faculty of Science and Engineering, Ritsumeikan University, and measured wave heights using a wave generator that can generate regular waves in the facility. If the density of water and the acceleration of gravity are regarded as constants, the energy per unit area of the wave is proportional to the square of the wave height.

Using this equation, we determined what percentage the energy of the wave before passing through the artificial reef decreased after passing through, which we defined as the attenuation rate, and compared the data.

In this experiment, a concrete model of the new artificial reef was used because it was difficult to create a model of the new artificial reef using a 3D printer. The model of the artificial reef was made by dividing it into a base part and a projection part. For the projection part, a mold was prepared by molding a clear file into a funnel shape, and concrete was poured into the mold.

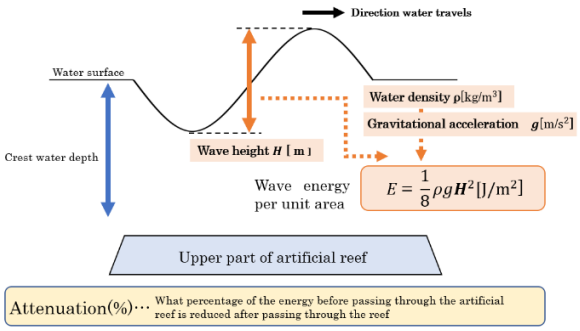


Fig.4 Formula for finding the energy of a wave

Fig.5 Overall view of artificial reef

2.2.1 Variation of Wave Height and Attenuation Rate with Depth of Water at Top Edge

The distance between the top of the artificial reef and the bottom of the water surface is defined as the top water depth, which is defined as 1.0 cm, 2.0 cm, and waves with heights of 2.0 cm, 3.0 cm, and 4.0 cm were generated by the wave generator, and the wave heights before and after passing through the artificial reef were measured.

2.2.2 Calculation of Wave Height Variation and Attenuation Rate by the Number and Arrangement of Protrusions

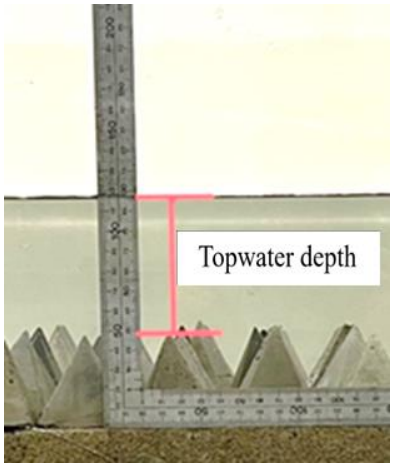


Fig.6 Topwater depth

Waves of 2.0 cm, 3.0 cm, and 4.0 cm in height were generated by the wave generator, and the wave heights before and after passing through the artificial reef were measured.

The patterns of protrusions were 176 in number (100%), 104 in number (59%) in zigzag and vertical arrangement, and 88 in number (50%) in zigzag arrangement, for a total of 4 patterns.

III. Data Analysis

3.1 Effect of Water Plant Cover on Erosion

It was found that the larger the percentage cover of water plants attached to the artificial reef, the smaller the erosion area. The mean erosion area from six experiments was graphed and compared using the T-test, and it was found that in the case of the new model, there was a large difference when comparing 100% water plants to 50% water plants and 100% water plants to 0% water plants. In the case of the old model, it was found that there was a difference when 100% water plants and 0% water plants were compared.

3.2 Relationship Between Topwater Depth and Attenuation Rate

Table 1 shows the results of varying the top water depth. Red indicates attenuation, and blue indicates amplification. This table shows that the new artificial reef has the greatest effect on the attenuation rate at depths that interfere with wave height. However, it was found that the

energy of the new artificial reef increased within a certain range where it did not interfere with wave height.

As the cause of the energy increase, we can consider that the relationship between the shape of the artificial reef, the top water depth, and the wave height may be important. In particular, the trapezoidal shape of the artificial reef may have allowed some of the wave energy to escape to the upper side of the reef when waves interfered with it, rather than to the opposite side of the direction of wave travel.

Table.1 Function of topwater depth

天端水深 (cm) / 波高 (cm)	7.0	5.0	3.0	2.0	1.0
2.0	9.8%	0%	−44%	−56%	44%
3.0	0%	−21%	−78%	0%	56%
4.0	−5.1%	−27%	−10%	64%	70%

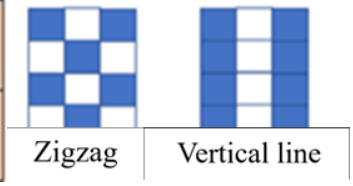
3.3 Relationship between the Number and Arrangement of Protrusions and Attenuation Rate

Experiments were conducted by changing the number and arrangement of protrusions on the new artificial reef. The results showed no significant change depending on the arrangement; basically, the attenuation rate changed significantly depending on the number of protrusions. However, when the number of protrusions was 176 (100%) and 104 (59%), it was found that the attenuation rate stopped at a maximum of nearly 70% in both cases, despite the large difference in the number of protrusions.

If the maximum attenuation rate is 70%, we thought that there might be a shape in which the number of protrusions is reduced after securing an area in which water plants can grow sufficiently. If so, construction costs and other costs might be reduced compared to when the number of protrusions is 100%.

Table.2 Change in placement

個数（個） 配置 波高（cm）	176（100%）	104（59%） ジグザグ	104（59%） 縦配列	88（50%） ジグザグ
2.0	44%	－10%	0%	－21%
3.0	56%	41%	36%	19%
4.0	70%	72%	67%	58%



IV. Discussion

Since the erosion area decreases with the percentage cover of water plants attached to the artificial reef, it can be said that the attachment does not impair the effect of the new type of artificial reef. The fact that the wave energy increases within a certain range without interfering with wave height suggests that the shape of the new artificial reef is not effective under all conditions but that the direction of the wave force may be lifted upward. The energy may be amplified depending on the depth at the top edge of the reef. Furthermore, the fact that the attenuation rate of the new artificial reef is only about 70% despite the large difference in the number and arrangement of the protrusions suggests that the upper limit of the attenuation rate by the new artificial reef may be about 70% and that the most effective arrangement of the protrusions may exist.

V. Conclusion

Although it was found that the growth of water plants on the artificial reef is effective in attenuating wave energy, it has not been confirmed whether water plants can grow on concrete, the material used for the artificial reef. Therefore, it is necessary to try growing water plants on concrete in an aquarium with frequent water changes, assuming the actual circulation of ocean currents, given the hard and alkaline nature of concrete water. In addition, since we obtained

instantaneous wave energy this time, we would like to measure the period to obtain the continuous wave energy next time. Then, considering the possibility that the upper limit of the attenuation rate by the new artificial reef is about 70%, we would like to experiment to find the optimal arrangement and number of reefs.

VI. Future Research

Although it has been found that the energy attenuation of the artificial reef is not affected by the attachment of water plants to the artificial reef, it has not been confirmed whether water plants can grow on concrete, which is the material of the artificial reef. Therefore, it is necessary to confirm whether water weeds can grow on concrete by planting them in the actual environment as much as possible. In addition, since we compared the energy of habitual waves using the formula for determining the energy of waves this time, we would like to use the formula for determining the energy of continuous waves next time and compare the results. In addition, we would like to investigate whether or not the reef is effective against tsunamis, and if so, how much effect it has, taking into consideration the fact that it is placed in an area where tsunamis occur. Finally, we would like to find the optimal arrangement and number of artificial reefs, taking into account the conditions for growing water plants and the cost of construction, and devise the most effective shape of artificial reefs, and conduct experiments by placing them in the actual sea.

VII. Acknowledgements

We wish to thank Leave a Nest for their generous financial assistance. Also, thank Professor Masataka Kusube of Wakayama National College of Technology, Professor Masamitsu Fujimoto of Ritsumeikan University, and Professor Takashi Nakayama of Kinki University for their helpful discussions and advice.

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Artificial reef with effective shape and protection of marine ecosystems

Ritsumeikan High School

Abstract

We are investigating artificial reefs that can effectively shape and protect marine ecosystems. An artificial reef is a type of breakwater; a measure designed to control coastal erosion. Breakwaters that are constructed under the surface of the water and have the effect of dissipating waves are called artificial reefs. Prior research suggested that artificial reefs with new shapes were effective in controlling beach erosion. Our current efforts are concentrated on two aspects. Firstly, creating new underwater habitats for organisms by growing waterweeds on artificial reefs, studying the influence of the presence of waterweeds on wave dissipation and reducing the burden on the marine ecosystem from the installation of artificial reefs. Secondly, dividing the wave amplitude into stages using a wave generator device, and examining the rate of reduction in wave energy passing over the artificial reef. The performance of the invented artificial reef will be evaluated by comparing the difference between the invented artificial reef and a conventional artificial reef to confirm whether the effect is superior in all locations, including areas where high waves caused by typhoons are less likely to occur and areas where waves are calm. The final goal is to optimize the newly designed artificial reef for various coasts.

Introduction

In the last 15 years, Japan's sandy beaches have lost about 13% of their total area to coastal erosion. The government has been promoting the construction of breakwaters as a countermeasure. We are conducting research on artificial reefs, which are structures built under the surface of the water that mimic the function of coral reefs to dissipate waves.

Pre-Experiment

In a pre-experiment, the performance of an older artificial reef with a common shape and a new type artificial reef that mimics the shape of sound-absorbing material were compared looking at how much each controlled beach erosion.

Fig. 1 Model of the conventional type

Fig. 2 Model of the new type

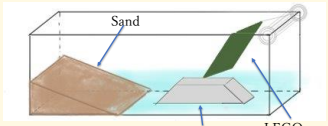

Fig. 3 Experimental conditions

Method

1. Sand was placed in the tank's angle of repose.
2. Water was put into the water tank.
3. A wave-making machine made from LEGO Mindstroms, was placed above the water tank.
4. 35 seconds of video was taken.
5. The area was measured using ImageJ.
6. Steps 1~5 were repeated 6 times.

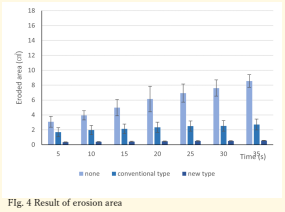

FIg. 4 Result of erosion area

Results suggest that the new type artificial reef was the most effective.

New type > conventional type > none

Experiment 1

Aim

To study the change in the effect on shoreline erosion when models of water plants are attached to an artificial reef.

Materials

water, water tank (900 mm × 250 mm × 300 mm), LEGO Mindstorms, Sand, Model of water plants

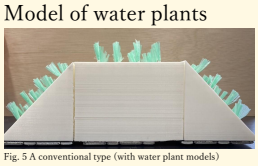

Fig. 5 A conventional type (with water plant models)

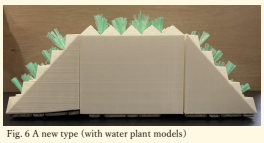

Fig. 6 A new type (with water plant models)

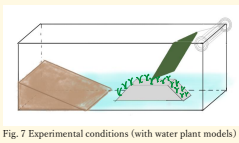

Fig. 7 Experimental conditions (with water plant models)

Method

108 holes were drilled in each of the two artificial reefs. Holes were 2 cm apart. Three tests were conducted with the new type and convention type artificial reef models. In the first test, water plant models were placed in 100% of the holes (108 holes). In the second test, water plant models were placed evenly in 50% of the holes (54 holes). And in the last test, no plant models were placed. The results were measured in the same way as in the pre-experiment.

Result

The results showed that the greater the number of water plants attached to the artificial reef, the smaller the eroded area. Attaching water plants was not found to effect of the efficiency of the new type of artificial reef.

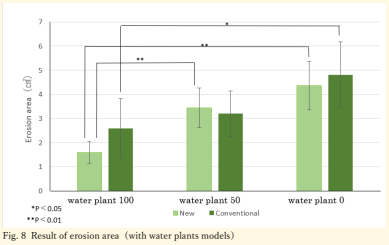

Fig. 8 Result of erosion area (with water plants models)

Acknowledgements

We wish to thank Leave a Nest for their generous financial assistance. Also, Professor Masataka Kusube of Wakayama National College of Technology, Professor Masamitsu Fujimoto of Ritsumeikan University, and Professor Takashi Nakayama of Kinki University for helpful discussions and advice.

Experiment 2

Aim

To compare the change in wave height when changes are made to the:
(1) depth of the water above the artificial reef
(2) number and placement of protrusions

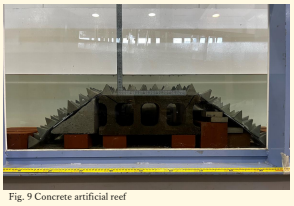

Fig. 9 Concrete artificial reef

Materials

water, wave tank, concrete artificial reef, brick

Method

1. The concrete artificial reef was placed in the tank
2. Wave heights were adjusted to 2 cm, 3 cm, and 4 cm before passing through the artificial reef.
3. The heights of the waves were measured after they passed through the artificial reef.

Experiment 2-1

- Steps 1 to 3 were performed as above, setting the depth at the top of the reef to 7 cm, 5 cm, 3 cm, 2 cm, and 1 cm.

Experiment 2-2

- Steps 1 to 3 were performed as above with 4 different patterns of the number and arrangement of protrusions on the artificial reef.

The comparison method applies this formula for energy per unit area.

Result

$$E = \frac{1}{8}\rho g H^2 [\mathrm{J/m^2}]$$

ρ [kg/m³] : water density
g [m/s²] : gravitational acceleration
H [m] : wave height

Table 1 Attenuation rate with change in top water depth

Wave height (cm) \ Cost water depth (cm)	7.0	5.0	3.0	2.0	1.0
2.0	9.8%	0%	−44%	−56%	44%
3.0	0%	−21%	−78%	0%	56%
4.0	−5.1%	−27%	−10%	64%	70%

Table 2 Attenuation rate with change in number and arrangement

Wave height (cm) \ Number and arrangement	176(100%)	104(59%) Zigzag	104(59%) Vertical line	88(50%) Zigzag
2.0	44%	−10%	0%	−21%
3.0	56%	41%	36%	19%
4.0	70%	72%	67%	58%

Zigzag

Vertical line

Experiment 2-1

Attenuation rates increased when the artificial reef interfered with wave heights. In addition, wave energy was amplified under certain conditions.

$$(1-\frac{E'}{E_0}) \times 100 = \varepsilon \qquad \varepsilon\ [\%] : \text{attenuation rate}$$

Experiment 2-2

The attenuation rate was highly dependent on the number of protrusions. If the number of protrusions is the same, there is no change due to the different placement of the protrusions. Furthermore, the attenuation rate of the new model's artificial reef may be limited to 70%.

Conclusions / Future Plan

Future experiments will first verify whether water plants can grow on concrete in this experiment. In addition, future experiments will elucidate why the energy of waves passing through the artificial reef increase in certain case due to changes in top and water depth. Then, the number and placement of the most suitable number of pieces for cost reduction will be verified.

Fig.10 Concrete with water plants attached

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