THE IMPROVEMENT OF THAI SUNG-YOD RICE'S GERMINATION USING ATMOSPHERIC PLASMA

BY

PATCHAREE WONGPANOM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (ENGINEERING TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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A Thesis Present

By

PATCHAREE WONGPANOM

Submitted to

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Approved as to style and content by

Advisor and Chairperson of Thesis Committee ______________________
(Assoc. Prof. Dr. Alice Sharp)

Co-Advisor ______________________
(Assoc. Prof. Dr. Thawatchai Onjun)

Committee Member and
Chairperson of Examination Committee ______________________
(Asst. Prof. Dr. Paiboon Sreearunothai)

Committee Member ______________________
(Prof.Hidetoshi Sekiguchi)

Committee Member ______________________
(Dr. Udom Sae-Ueng)

Committee Member ______________________
(Assoc. Prof. Dr. Pakorn Oppaprakasit)

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Abstract

[THE IMPROVEMENT OF THAI SUNG-YOD RICE'GERMINATION BY USING ATMOSPHERIC PLASMA]

by

PATCHAREE WONGPANOM

Bachelor of Science, Huachiew Chalermprakiet University, 2014
Master of Engineering, Sirindhorn International Institute of Technology Thammasat University, 2016

The aim of this research is to improve the germination of Thai Sung-yod rice using atmospheric plasma. Several aspects of the germination are considered, including the moldy rate, the length of sprouts and roots, the weight of sprouts and roots, the moisture content, wettability, the quantity of gamma-aminobutyric acid (GABA) content and surface area. Paddy and brown rice of sung-yod rice were exposed by plasma, which is generated by dielectric barrier discharge (DBD) with a high frequency electric field over a parallel copper plate. Paddy and brown rice were exposed with varied times of exposure. All data from the experiments were analyzed by using ANOVA software at the confidential 95%. It is found that atmospheric plasma treatment can significantly increase the germination rate. The quantity of GABA content both of paddy and brown rice also increase up to 50% and 43%, respectively. Moreover for paddy, atmospheric plasma can significantly reduced the moldy rate, moisture content, contact angle and surface area significantly up to 67%, 10%, 31% and 86% respectively. For brown rice, atmospheric plasma can significantly reduce moldy rate, contact angle and surface area up to 22%, 22% and 94% respectively.

Keywords: Sung-yod rice, Germination rate, Contact angle, Gamma-aminobutyric acid (GABA), Water absorption, Atmospheric plasma, Plasma, Dielectric barrier discharge

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Patcharee Wongpanom

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Introduction

1.1 Introduction

Rice is one of the most important foods for the human, which is widely consumed in many countries around the world, especially Asia. In the past decades, it is the one of the main exports in Thailand. In 2014, Thai export of rice was estimated at 8.77 million tons. However, the export of Thai rice is not so consistent. For example, the years 2010-2013, export of Thai rice decreased due to the global warming and climate. This caused some impact on Thai economy. As a result new technology is strongly needed to enhance the rice production.

In addition, the current trends of consumers move toward a healthy food with more nutritional value. Many people prefer to eat brown rice because brown rice has more nutrient and good for digestion than white rice. It is known that the outer coating of brown rice contains high proteins and minerals. In fact, rice with dark red and black contains more nutrients and anti-oxidants.

Recently Sung-yod rice, a local rice from Phatthalung province, becomes popular due to its softness and delicious taste with higher nutritional values, such as high in protein and vitamins, especially niacin. It is known that niacin can prevent Alzheimer’s disease witch becomes a big issue for human nowadays.

Figure 1.1 Paddy(A) and brown rice(B) of Sung-yod rice [4]

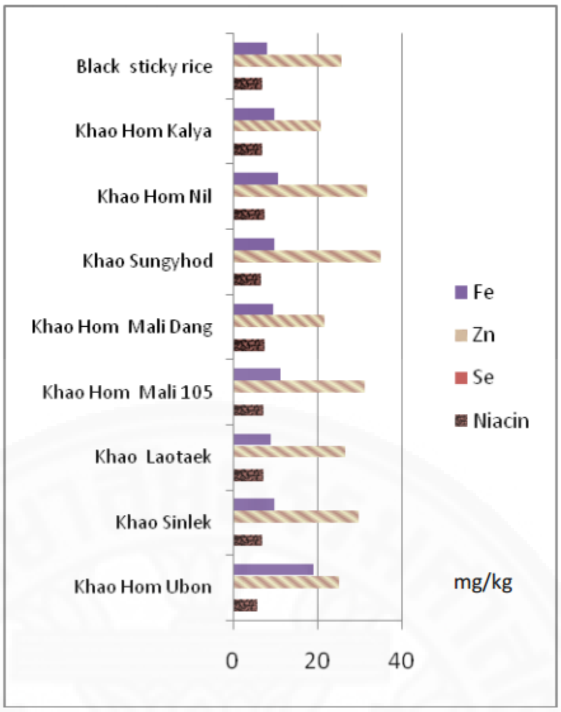

Figure 1.2 Iron, zinc, selenium, niacin of 9 rice cultivars of 9 rice cultivars[4]

In 2000, Her Majesty Queen Sirikit visited the Phatthalung Rice Research Center and advised the government officer about the transplanting of Sung-Yod rice. In 2003, Her Majesty Queen Sirikit re-visited to Phatthalung Rice Research Center and the researchers offered Sung-yod rice to Her Majesty Queen Sirikit. Her Majesty Queen Sirikit suggested to promote and preserve the of Sung-yod rice. Normally, Sung-yod rice is difficult to plant. It is also sensitive to light that mean germination rate is better during short daylight than at night, which is just a few months per year.

Plasma technology have been well developed and become a widely used for many processing and applications such as printed circuit board (PCB) hole etching, surface modification of polymers, air purification and sterilization. Plasma is an effective, economical, and environmentally safe method. Current research is directly related to the surface modification of agricultural crops. A positive effect of plasma treatment on germination of a variety of agricultural crops has been found and presented in a number of previous studies. It is interesting to apply the plasma technology to enhance the Sung-yod rice germination and production.

1.2 Problem and significant of the study

Sung-yod rice is a local rice of Phatthalung province from the south of Thailand. It was developed as a pure breed by the breeder of Phatthalung Rice Research Center and being the first Thai rice variety obtaining GI(geographical indication) certification in 2006. Sung-yod rice is the rice with high nutrients. However, Sung-yod rice is sensitive to the length of the photoperiod or sensitive to the light that makes it is able to cultivate only once time per year. The enhancement of Sung-yod rice's the germination rate and properties of sung-yod rice by using atmospheric plasma is interesting. If the seeds have higher germination rate and early state properties, the production should increase.

1.3 Objective of the study

The aim of this research is to improve Thai Sung-yod rice's germination and early state properties by using atmospheric plasma generated from a dielectric barrier discharge (DBD).

1.4 Scopes of the study

To determine the changed in following parameters:

1.4.1. The germination rate of Sung-yod rice. The parameters considered are:

1.4.1.1 The length of sprouts and roots.

1.4.1.2 The weight of fresh and dry weight of sprouts and roots.

1.4.1.3 The mold rate.

1.4.2. The moisture content of Sung-yod rice

1.4.3. The wettability of Sung-yod rice.

1.4.4. The GABA content of Sung-yod rice.

1.4.5. The surface ares of Sung-yod rice.

Chapter2
Literature Review

2.1 Rice

Rice is an annual grass of biennial plant family, classified in the Oryza genus of the family Poaceae or Gramineae. Rice can growth well in the tropical zone and temperate zone, can be divided into 3 main groups,

1) Oryza sativa which originated in Asia and elsewhere in the world.
2) Oryza glaberrima which has its origins in Africa
3) Wild rice which occurs naturally in all countries of the continent, such as rice, Oryza perennis, Oryza officinalis, Oryza spontanea, Oryza nivara

Grains of rice called "caryopsis" or "brown rice", which was covered by the lemma and palea makes completely petals of paddy, shown in Figure 2.1

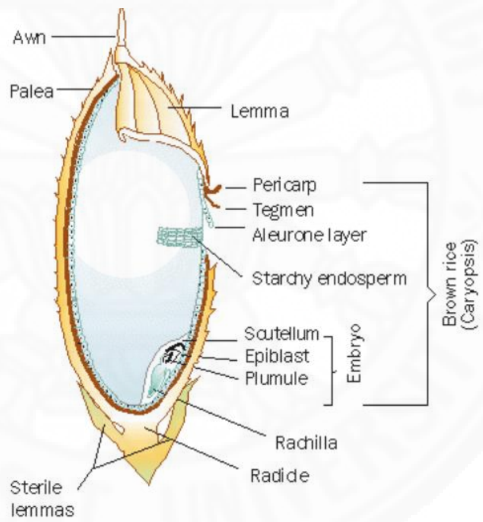

Figure 2.1 Rice structure[1]

2.1.1 Rice structure

Rice grain is the type of caryopsis that has testa near ovary wall. It consists of

2.1.1.1 Hull or husk is coating of the rice grain consist of lemma, palea, awn, rachilla, and sterile lemmae. Lemma is coating 2 of 3 parts of the rice grain with a structure that looks like a hook. That structure makes the hull or husk is closed tightly and encapsulated the seeds within it. The weight of hull is about 20 percent of the weight of rice.

2.1.1.2 Caryopsis coat composed of 3 layers of tissues include pericarp, tegment or seed coat and aleurone layer

(1) Pericarp is the outer part of the rice can divide into 3 layers which are epicarp, mesocarp and endocarp. Pericarp is rod cell wrapped around seeds.

(2) Tegmen or Seed coat is a thin cell wall, has long oval shapes and rich in fat. Because of that make it has the feature to prevent water entering to the grain texture. Hyaline layer or nucellus is adjacent to the tegmen or seed coat and have transparent manner. Hyaline layer or nucellus contains of Pigment As well as the tegmen or seed coat.

(3) Aleurone layer has the cube-shaped cells with nucleus in the middle. Aleurone layer located inside next to nucellus, it's the same tissue with endosperm. Cell of aleurone layer composed of protein, fat, hemicelluloses and cellulose.

2.1.1.3 Starchy endosperm is the inner part layer of seed. Starchy endosperm is mainly composed of starchy and protein. The starch of the grain is very small about 3-5 microns and it's a polygon shape stay together as compound granule. It is found in the top layer of the seed next to aleurone layer.

2.1.1.4 Embryo is a small section at the bottom of a grain. It's rich in protein and vitamins it is an important part for the germination. The rice germ in embryo is known as the location of the part of germinated rice to be a new beginning of rice. Embryo will grows into plumule and radicle both parts are hold together by a very short segment called mesocotyl. All parts of the embryo are inside aleurone layer and embryo also next to ventral side of starch. Ventral side is full of nutrients, minerals and vitamins for growth; protein (in the form of protein bodies), fat (in the form of lipid bodies), vitamin B (thiamine) and vitamin E (tocopheral).

2.1.2 Characteristics of growth of rice

2.1.2.1 Roots are used to hold sprouts with the soil to keep them not to falling down. Rice has no taproot but has rootlet scattered under the ground. The rice use roots for food absorption from the soil consist of minerals and water. All food will be transported to the leaves and turned it into flour by photosynthesis.

2.1.2.2 Stems is a hole in the middle and divided into segments by a partition between segments. The number of segment will be equal to the number of leaves, typically have about 20-25 segments. At the base of stems, segments have shorter and thicker than the end of stems. However, it is larger than segment at end of stems. Stems of rice are covered with a leaves. When rice is stretch tall to produce grains it can see stems or segment.

2.1.2.3 Leaves are contained sheath and blade. Sheath is duty to cover the stems at the base of sheath, which swelled convex called sheath pulvinus. Blade is next to sheath, it's has difference in length, width, shape, color and hair on the leaves based on species. Rice has leaves for the photosynthesis to transfrom nutrients, water and carbon dioxide into flour for use to generating growth rice.

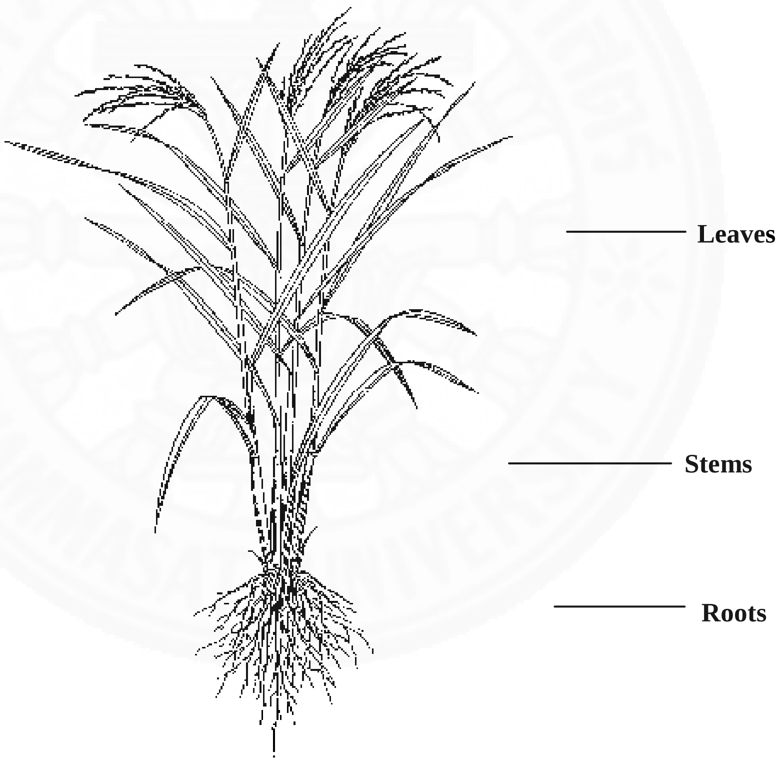

Figure 2.2 Characteristics of growth of rice[6]

2.1.3 Classification of rice

Cultivar of rice which planted for consumers has many different styles to meet the needs of consumers. The area characteristics and its surroundings of rice in Thailand can be classified follows

2.1.3.1 Classification of rice by ecosystem or environment

(1) Irrigated rice means is the rice that can grow in fields that are flooded. Irrigated rice has to catchment and get the water from the irrigation system to maintains the water level of 5-15 cm during growing season.

(2) Rainfed lowland rice is the rice that can grown in fields that are flooded, which use Khanna to retain water, relying on natural rainfall throughout the growing season. Water levels generally do not exceed 50 cm, but sometimes the water level may be dry or higher more than 50 cm based on the amount of rainfall.

(3) Deepwater rice or floating rice is the rice that can planted in water level no higher than one meter, if the water level is higher than one meter plant will be growing rapidly to escape water level within 1-3 mounts. The rice makes a long-winded along with the water level rises.

(4) Upland rice is the rice in the rainfed areas in their natural state or upland farms without a dyke to retain water or surface water. Plant by sowing or sprinkle seeds directly into the ground.

2.1.3.2 Classification of rice by characteristic of sensitive to the light

(1) Rice is sensitive to the length of the photoperiod (photoperiod sensitive rice variety). Usually rice is a short-day plant, which requires short of a day or photoperiod while growth in a reasonable period of time to stimulate the flowering or grain. Cultivars that are sensitive to light have probable date of flowering at the same time every year.

(2) Rice is not sensitive to the length of the photoperiod (photoperiod insensitive rice variety). It is a flowering on age times and can harvest after produce grains 30 days, which is usually age between 90-140 days. It can grow all year round and grow in the off-season paddy field with enough water to grow.

2.1.3.3. Classification by type of rice starch in the grain into meat

(1) Sticky rice (glutinous rice or waxy rice) contains the most of amylopectin and less amylose or none at all. When the rice is opaque color after steaming rice seed had been sticky together with a cohesive and transparent manner.

(2) Rice (non-glutinous rice) contains of amylose remaining 7-33 %, the remainder is amylopectin. After cooked, it is opaque and does not stick together.

2.1.4 Nutritious of rice

Rice has starch or carbohydrate around 70 %, and includes with another nutritious for example:

- **Protein** is found at the surface area of grain brown rice and embryo more than other parts. Typically, brown rice has a protein content ranging from 4.3% to 18.2%, or about 9.5%. Protein of Thai rice average is about 7.48% ± 1.65% and average of milled rice of Thai rice is about 6.5%.
- **Fat** is found at aleurone layer and embryo. If a brown rice changes into milled rice, it can cause a loss of fat over 80%.
- **Minerals** are found near the surface of the kernel including phosphorus, magnesium, and potassium.
- **Vitamins** are found in the aleurone layer and embryo. This can cause milled rice loss a lot of vitamins such as nicotinic acid, niacin, thiamine and riboflavin, which is found in brown rice.

2.2 Sung-Yod rice

Sung-yod rice (Oryza sativa L.) is a local rice of Phatthalung province with different characteristics from other rice. Its seed coat is white with a red light to dark red in the same seed. Sung-yod rice is lowland rice. It can grow in lowland areas where the water level is around 5-10 cm to 70-80 cm. It's also sensitive to light that makes the plantation to be only one time per year. For chemical properties, it has fiber content 4.81%, lowest in among local rice, which make the properties of cooked rice is soft rather sticky and easily digestible for the elderly.

The dark red and black colors are source of nutrition and disease prevention with more than white rice, about 2-3 times. Sung-yod rice has high protein, and vitamins, especially niacin**.** This is important for brain and nervous system, skin, tongue and tissues of the digestive system. It is also good for reducing cholesterol levels. Sung-yod rice also contains iron and phosphorus which are useful to nourish blood, nourish healthy body and prevent Alzheimer disease. It also contains anti-oxidant which is oryzanol and Gamma Amino Butyric Acid (GABA) that can reduces the risk of cancer.

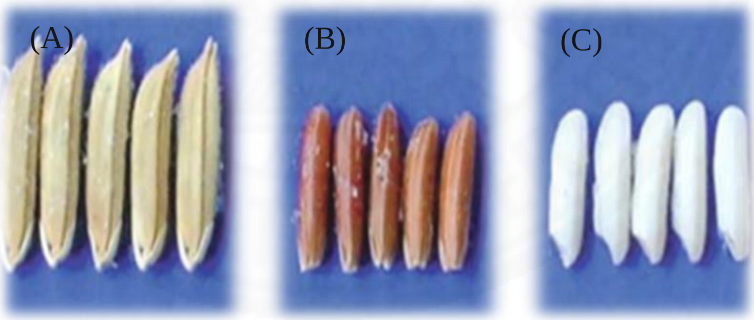

Figure 2.3 (A) Rice with husk, (B) Brown rice and (C) White rice of Sung-yod rice

Table 2.1 Nutritional of Sung-yod rice

Nutritional of Sung-yod rice (100 g)	Quantity
Fat (g)	2.42
Carbohydrate (g)	78.31
Fiber (g)	4.81
Ash (g)	1.26
Vitamin B1 (mg)	0.32
Niacin (mg)	6.46
Protein (g)	7.30
Moisture (g)	10.71
Energy (kilo calories)	364

Source from: Ministry of Agriculture and Cooperatives, Rice department of Thailand, Phatthalung Rice Research Center.

2.3 Plasma

If energy is supplied to gas, it will ionize and turns into the energy-rich plasma state. Plasma can be found in natural such as lightning, polar light, light (corona) around the sun or flame. Plasma generated in the laboratory can be divided into two groups: high temperature plasma and another group is low temperature plasma. When energy is applied exceeding a breakdown voltage, it makes atoms of the gas collision and the electrons out of the atoms that process is called “ionization”. Plasma can be generated by ions and electrons at an electrode by means of a radiofrequency (RF), microwave (MW) or dielectric barrier discharge (DBD). The production of plasma is limited (under vacuum conditions) due to this vacuum system costs and maintenance. For the production of plasma at atmospheric pressure, the vacuum it's no longer necessary.

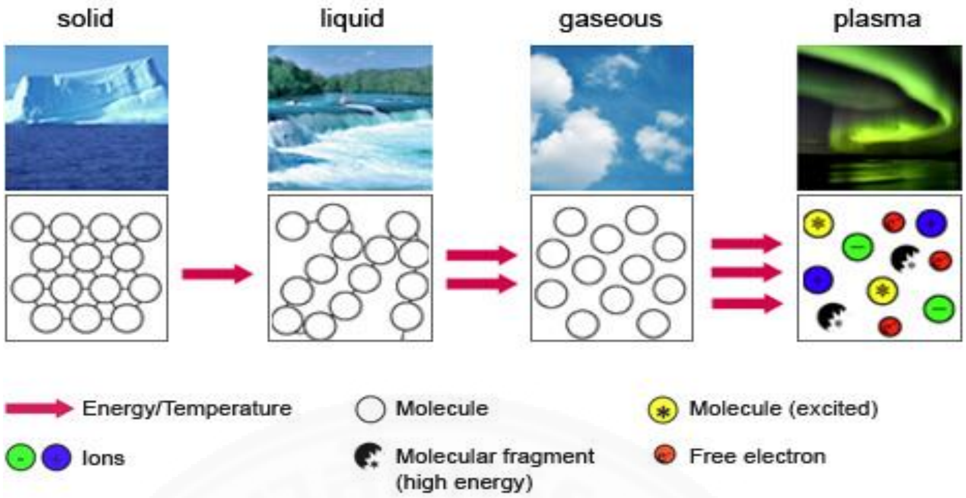

Figure 2.4 Plasma – The fourth state of matter[2]

2.3.1 Atmospheric plasma

Since plasma is defined as a ionized gas, atmospheric plasma refers to plasma that can generated at atmospheric pressure. The atmospheric plasmas are generated from electrical energy. The electric field transfer energy to the gas electrons then transmitted to the neutral by collisions. Atmospheric plasma has prominent technical significance because in contrast with low-pressure plasma or high-pressure plasma no reaction to maintenance of a pressure level differing from atmospheric pressure. Atmospheric plasma can be generated by Dielectric Barrier Discharge (DBD) technique and they are widely used nowadays in many applications. A schematic of a DBD is shown in Fig 2.5.

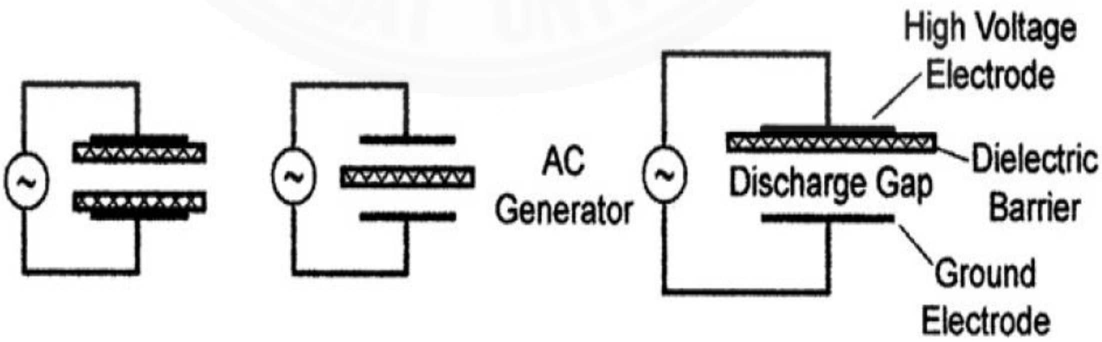

Figure 2.5 A few example schemes for Dielectric Barrier Discharge(DBD) set up[53]

2.3.2 Dielectric Barrier Discharge (DBD)

Dielectric Barrier Discharge (DBD) is also known as silence discharge, were invented by W. Siemens in 1857. This use a principle of charge and discharge to dielectric by applied high voltage. DBD is usually working at atmospheric pressure. DBD is the electrical discharge between two electrodes separated by an insulating dielectric barrier discharge. DBD consists of two electrodes, one uncoated and exposed to the air and the other encapsulated by a dielectric material. The dielectric material is non-conductive, the electrons of the atoms of matter that cannot break free electrons easily. The dielectrics electrodes materials can make from many types of materials such as glass, quartz, epoxy, or PTFE(TEFLON). The electrodes are supplied with an AC or DC voltage at high levels that can causes the air between two electrodes to weakly ionize. After applied power pass through top and bottom electrodes plasma will be occur between two electrodes.

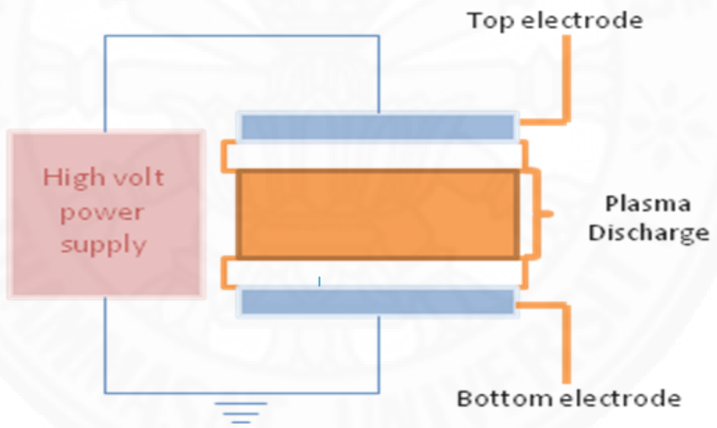

Figure 2.6 The simple schematic of Dielectric Barrier Discharge (DBD)

2.4 Moisture content

Moisture content (humidity) is a value that indicates the weight of water contained in food. It is one of the most important properties of for food.

2.4.1 The important of measuring moisture content

Moisture content is one of the most important features of the food lead to:

2.4.1.1 Moisture content affects to the food spoilage, especially deterioration due to microorganisms (microbial spoilage). Food with moisture content or high water content is a perishable food because it is a suitable condition for the growth of microorganisms that can cause food spoilage organisms such as bacteria, yeast and mold.

2.4.1.2 Moisture content can affect on food safety. Food that has high water can growth bacteria caused pathogenic and toxin lead to food poisoning. The creation of toxic fungi (mycotoxin), such as aflatoxin and patulin, is harmful to consumers.

2.4.1.3 Moisture content affects on physical and thermal properties such as melting point, boiling point, thermal conductivity and specific heat.

2.4.1.4 Moisture content to the sensory quality. It affects the taste of food such as texture: viscosity and caking.

2.5.1.5 Moisture content affect to the chemical reactions that has a negative impact on food during storage, such as browning reaction and lipid oxidation.

2.5.1.6 Moisture content affects to the pricing of goods such as rice and grains are purchase pricing variable moisture content.

2.5 Wetting properties

Wetting or Wettability can be defined as the ability of liquid to preferentially wet on a surface of solid. Wetting is an important parameter in directing the bonding or adherence between two materials. Wetting can measure by using the contact angle, which is the degree of interaction between liquid and solid.

2.5.1 Contact angle

The contact angle is the angle between a liquid and solid caused by a drop of liquid spreads on the surface of solid**.** It is defined as “the angle formed by the intersection of the liquid-solid interface and the liquid-vapor interface”[54]. The interface is called as the “three phase contact line” where solid, liquid, and vapor co-exist. As the tendency of a drop to spread out form a flat of liquid, solid surface increases, the contact angle will decreases. Thus, the contact angle provides an inverse measure of wettability**.** Adhesive forces between a liquid and solid cause a liquid drop to spread over the surface form a flat of liquid. Cohesive forces cause the drop to form a ball up and avoid contact with the surface.

Calculations of wetting properties based on measurement of contact angle values which are an important parameter—the solid surface tension, which evaluates the wetting properties of a solid material are depended on contact angle values.

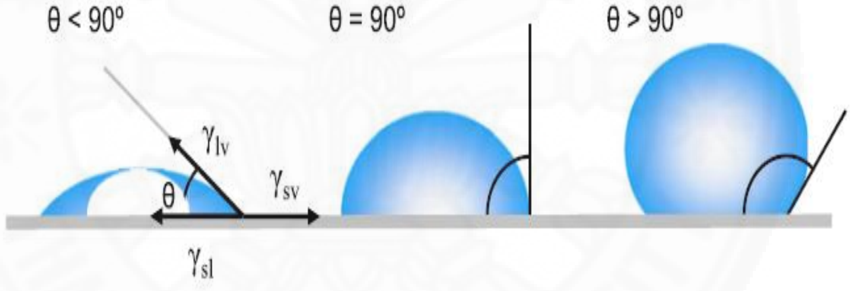

Figure 2.7 The contact angle formed by drop of liquid is shown [54]

The contact angle (θ), as seen from Figure 2.7 shows that a drop of liquid spreads out to cover a large area on the surface and has the contact angle less than 90° (low contact angle), indicatin that the wettability of the surface is favorable. If the droplet changes into a flat on the surface when the contact angle equal to 0°, it indicates that the wettability is perfect. Moreover, the liquid are form as a liquid droplet and the contact angle has the angle more than 90° means that the wettability of the surface is unfavorable.

Table 2.2 Degree of wetting of Contact angle [6]

Contact angle	Degree of wetting	Strength of:	
		Solid/liquid interactions	Liquid/liquid interactions
θ = 0	Perfect wetting	strong	weak
0 < θ < 90°	high wettability	strong	strong
		weak	weak
90° ≤ θ < 180°	low wettability	weak	strong
θ = 180°	perfectly non-wetting	weak	strong

2.6 Gamma Amino Butyric Acid (GABA)

Gamma Amino Butyric Acid or GABA is a substance formed by natural processes occurring while the rice is germinated the white root nodule of rice. GABA is caused by biochemical changes when water infiltrates into the grain and urging enzymes within the grain to operate. When the seeds start to germinate, the nutrients which stored in the grain are biodegradable by the biochemical processes causing carbohydrates in grains, smaller molecules call Oligosaccharide. Protein in the grain also digested causing amino acids, peptides and found the accumulation of important chemicals is gamma amino butyric acid also known as "GABA". GABA is an amino acid from the decarboxylation process of Glutamic acid.

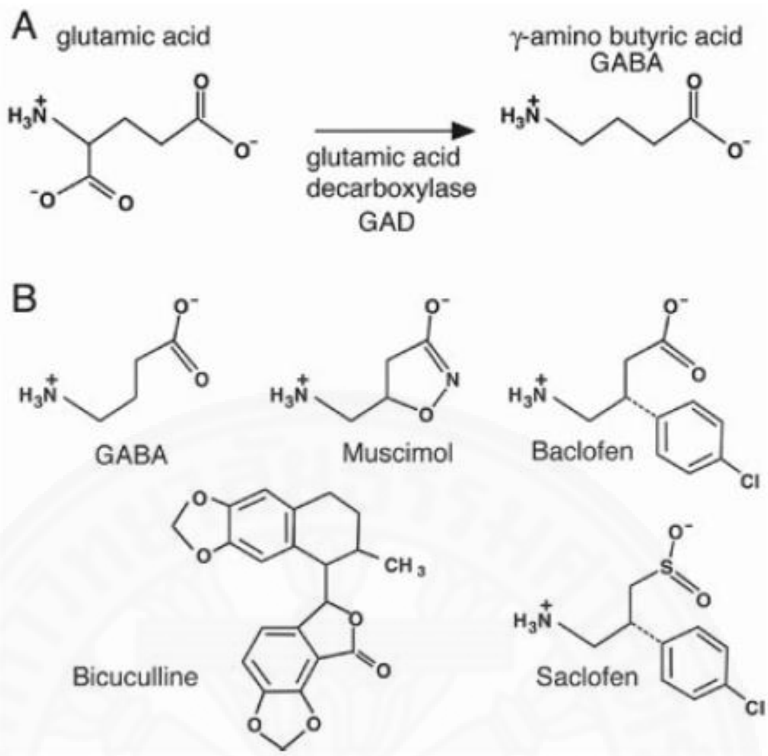

Figure 2.8 GABA structure[19]

The germination will create GABA while the rice is germinated and gone out when the leaves and roots are germinated. The decline of the amount of GABA caused by glutamate and GABA are transported into the Krebs cycle for generate energy to growth the seedlings.

2.6.1 The benefits of gamma amino butyric acid

Gamma amino butyric acid has functions as a neurotransmitter in the central nervous system, which acts as an inhibitor to maintain a balance in a brain. It can stimulate a brain to relaxation, sleep well, maintenance of the nervous system, maintenance of the nervous system, antihypertensive (reduce blood pressure), reduction of LDL (Low Density lipoprotein), and prevention of Alzheimer disease. Moreover, GABA helps to stimulate the anterior pituitary, which is responsible for producing hormones that help in the human growth hormone (HGH). Human growth hormone (HGH) causing the tissue that make the muscle firmness and substance lipotropic which is to prevent the accumulation of fat in the body that can lose weight.

2.7 Some literature reviews of plasma technology on agriculture

Recent researchers related on the plasma are listed as below:

Chaitanya Sarangapani and colleagues reported that low pressure plasma can increased the water absorption of parboiled rice and also reduce the cooking time up to 8 min. Textural properties were improved after treatment as hardness and stickiness decreased with increase in power and time. In addition, the surface morphological changes in parboiled rice were investigated using contact angle, surface energy measurements and SEM micro-graphs. After low pressure plasma treatment the surface energy of parboiled rice increased and contact angle was decreased. It could be concluded that low pressure plasma treatment improves cooking properties and quality of parboiled rice.

Hua Han Chen and colleagues reported that a textural property of cooked brown rice has been shown to determine its acceptance by consumers. The results showed that plasma treatment barely influenced the adhesiveness and hardness values of brown rice. However, cohesiveness was significantly increased in the treated samples. Plasma treatment revealed its influence on the textural properties of cooked japonica brown rice (Taikeng 9; TK9). This could have been caused by the different amylose content (~15.6 wt percent for Indica rice cultivar, TCS10; ~12.5 wt. for Japonica rice cultivar, TK9). Plasma treatment effectively improved the cooking properties of long-grain brown rice by reducing cooking time and cooking loss.

Hua Han Chen and colleagues reported that brown rice was exposed to low-pressure plasma ranging from 1 to 3 kV for 10 min. Treatment of brown rice in low-pressure plasma increases the germination percentage, seedling length, and water uptake in laboratory germination tests. All of the various treatments, 3 kV plasma exposure for 10 min yielded the best results. In germinating brown rice, a-amylase activity was significantly higher in treated groups than in controls. Low-pressure plasma also increased gamma-aminobutyric acid (GABA) levels from 19 to 28 mg/100 g. In addition, a marked increase in the antioxidant activity of brown rice was observed with plasma treatments compared to controls. The main finding of this study indicates that low-pressure plasma is effective in term of enhancing the growth and GABA accumulation of germinated brown rice, which can supply high nutrition to consumer.

Tipwimol Traikool and colleagues reported that dielectric barrier discharge (DBD) used to improve germination rate of Phathum Thani 80 (RD 31) rice seeds. Power discharge 30 W, frequency 5.5 kHz and gas gap 3 mm. The rice with plasma treatment for 30s effectively improved the germination rate result, 75.4 percent of germination rate by using copper electrodes. The length of trunk and root, and the fresh weight of trunk and root have increased. The physical properties by SEM showed that properties were improved after treatment the surface of the rice have roughness less than without plasma treatment.

Jai Hyuk Choi and colleagues reported that atmospheric pressure (AP) plasmas can sterilize against almost all kinds of bacteria because many ions and reactive species, such as oxygen atoms and ozone, etc., are generated during atmospheric pressure plasmas. Atmospheric pressure plasmas are proper processes for application to air cleaners and sterilizers. They also evaluate a germicidal effect caused by pulsed plasma system in air utilizing a dielectric barrier discharge (DBD) type reactor incorporating alumina, glass, etc. Escherichia coli, Bacillus subtilis and Pseudomonas aeruginosa bacteria were used for this sterilization experiment. For analysis of the relationship between sterilization results and chemical species generated in the discharge, they used optical emission spectroscopy and checked emission spectra by atomic oxygen (394.2 and 436.8 nm) and second positive system of nitrogen (337.1 nm). Experimental results showed that DBD treatment during 70 s sterilized E. coli with 99.99 percent effectively and ozone molecules were the dominant germicidal species. From these results can conclude that the pulsed DBD system is very effective for sterilization.

Steffen Emmert and colleagues reported that application of high voltages across small gas filled spaces results in ionization of the air. Generally, two types of cold plasma can be discerned: direct plasma (e.g. dielectric barrier discharge—DBD) and in direct plasma (plasma torch, plasma jet. Advantageous features of direct plasma treatment include the higher plasma density as well as the induced high frequency electric current onto the skin. In plasma treatment anti inflammatory, anti pruritic, antimicrobial, tissue stimulation, stimulation of microcirculation, and other therapeutic effects are achieved in a single treatment due to the combined action of ultraviolet radiation, reactive oxygen species (e.g. ozone), reactive nitrogen species, and electric fields. This should lead to norms for the technical devices to allow a standardized treatment of given diseases in the mid-term.

Daniela Bermúdez-Aguirre and colleagues reported that food borne outbreaks in the United States were often associated with fresh produce. Emerging pathogens are become more resistant to conventional disinfection methods, and thus consumers are looking for food that is free of chemicals. Atmospheric pressure cold plasma (APCP) appears to be an alternative for microbial inactivation without changes in the product. Vegetables were exposed to APCP discharges from a needle array from 3.95 kV up to 12.83 kV (60 Hz) in argon, from 30 s to 10 min. After processing, microbiological quality and Hunter's color parameters were assessed. Results showed that the inoculation level had an effect on the degree of inactivation; it was easier to inactivate the bacteria at lower counts. Tomatoes, followed by lettuce, were easier to disinfect than carrots, maybe because of the surface structure. Color parameters did not show significant changes after processing.

Noriko Komatsuzaki and colleagues report that a new method of processing germinated brown rice (GBR) were established. They processed grain of cultivars with a large germ by soaking and gaseous treatment. After soaking for 3 h and gaseous treatment for 21 h at 35˚C, the content of c-aminobutyric acid (GABA) in GBR (24.9 mg/100 g) was higher than that by the conventional soaking method (10.1 mg/100 g). Although the number of microorganisms on the surface of the GBR increased during soaking, steaming for 20 min and ethanol treatment for 3 min completely sterilized the GBR and did not reduce the amount of GABA.

Chapter 3
Materials and methods

3.1 Sample

Paddy and brown rice of Thai Sung-Yod rice cultivar from Phatthalung province were used. They are stored rice samples at room temperature throughout the experiment period during August 2015 to June 2016.

Figure 3.1 Thai Sung-Yod rice’s cultivar are obtained from Phatthalung province

3.2 The instruments and chemicals used in research

3.2.1 System model of Dielectric Barrier Discharge (DBD)

Figure 3.2 The power supply is shown

3.2.2 Instruments and equipment used in the laboratory

(1) 4 decimal point analytical balance

(2) Hot air oven

(3) Desicator

(4) Spectrophotometer

(5) Mortar and pestle

(6) Filter paper(no.1)

(7) Dropper

(8) Test tube

(9) Beaker

(10) Plastic boxes

(11) Tissue

Figure 3.3 Hot air oven is shown

Figure 3.4 Desicator is shown

Figure 3.5 Spectrophotometer is shown

3.2.3 Chemical

(1) Ethanol (C_2H_5OH)

(2) Phenol (C_6H_5O)

(3) Borate buffer

(4) Sodium hypochlorite (NaOCl)

3.3 Exposure of rice

Samples of paddy and brown rice of Thai Sung-Yod rice were placed distributed in dielectric barrier discharge between gas gaps 3 mm. High voltage supply was operated at 16 kV with frequency 5.5 kHz pass through top and bottom electrodes. Air was used as the discharge gas between both electrodes.

3.4 Experimental methods

3.4.1 Measurement of germination rate

(1) Treated 100 seeds of sung-yod rice for 15 second, 30 second, 45 second and 60 second.

(2) Planted 100 seeds of with plasma treatment and without plasma treatment seeds of sung-yod rice on tissue paper with 20 ml distilled water, which is counted and observed for 7 days.

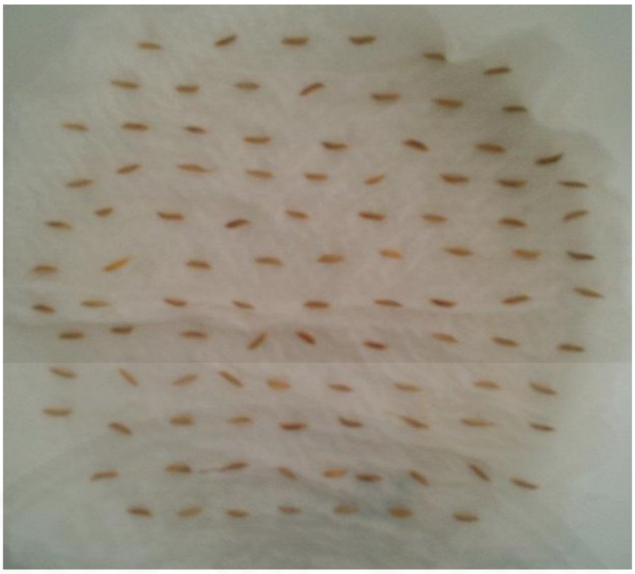

Figure 3.6 100 seeds of Sung-yod rice planted on tissue paper

(3) The germinated seeds and the mold of with plasma treatment and without plasma treatment were counted and observed for 7 days.

(4) After 7 days, the sprouts and roots were separated for measured the length and the weight of sprouts and roots.

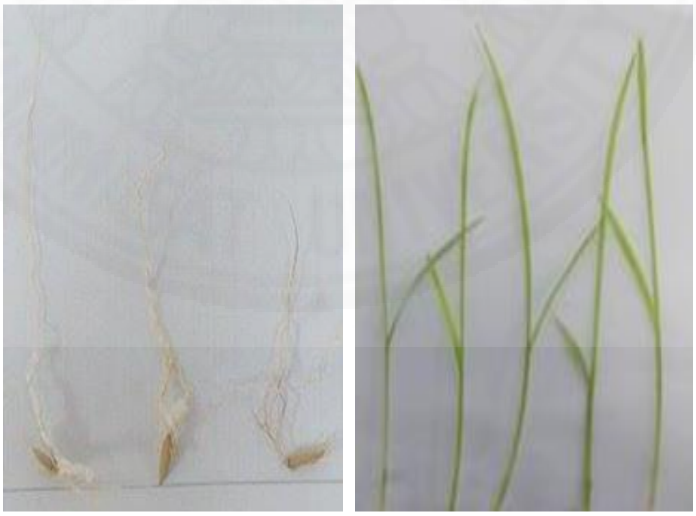

Figure 3.7 The sprouts and roots were separated

(5) The germination rate, the mold rate, the length of sprouts and roots and the weight of sprouts and roots were analyzed by ISTA (1976 : 3-49).

$$\%\text{Germination rate} = \frac{\text{The number of germinated seeds}}{\text{The number of seeds planted}} \times 100$$

$$\%\text{Mold rate} = \frac{\text{The number of mold (per seeds)}}{\text{The number of seeds planted}} \times 100$$

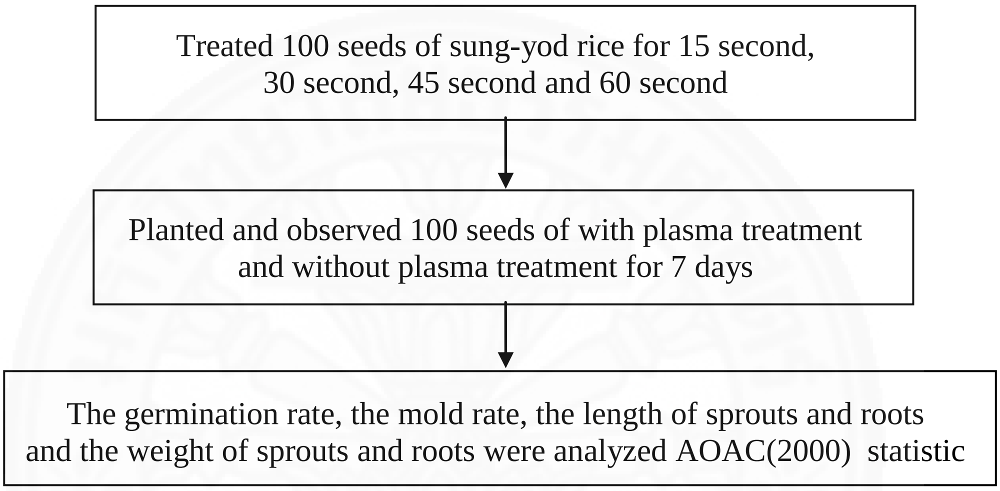

Figure 3.8 Diagram of measurement of germination rate

3.4.2 Measurement of moisture content

(1) Weighted and treated 100 seeds of sung-yod rice for 30 second, 1 minute, 2 minute, 4 minute, 6 minute and 8 minute.

(2) Covered the seeds of with plasma treatment and without plasma treatment of sung-yod rice with foil sheets then take it to the oven at 105℃ for 2 days.

(3) After 2 days, allowed to cool in the desicator, then weighted dry samples and calculated and analyzed by AOAC statistic.

Calculation

$$\%W = \frac{A-B}{A} \times 100$$

Where:

%W = Percentage of moisture in the sample

A = Weight of fresh sample (grams)

B = Weight of dry sample (grams)

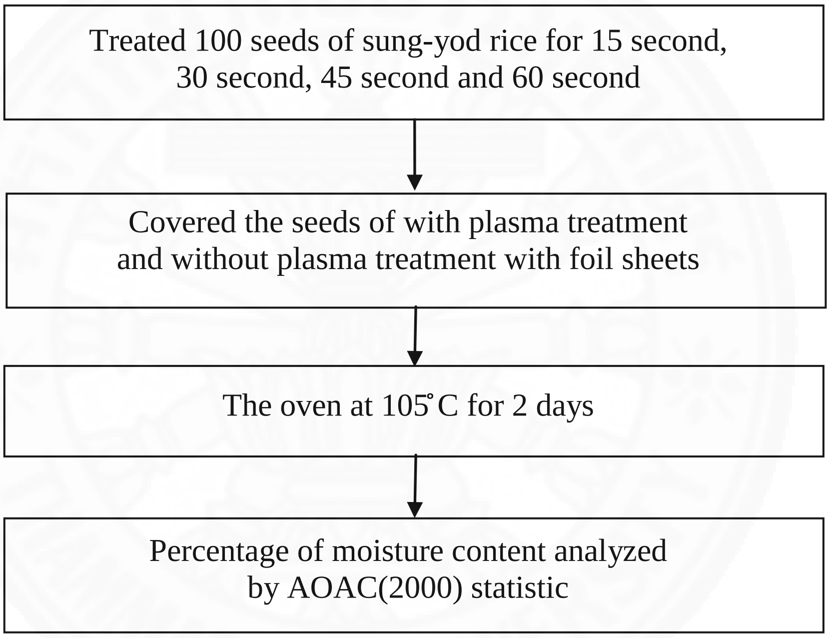

Figure 3.9 Diagram of measurement of moisture content

3.4.3 Measurement of contact angle

(1) Treated seed sample of sung-yod rice for 15 second, 30 second, 45 second and 60 second.

(2) Drops distilled water and take a photo on each seed of with plasma treatment and without plasma treatment.

(3) Upload the photos into computer.

(4) Used image J software to analyzed contact angle.

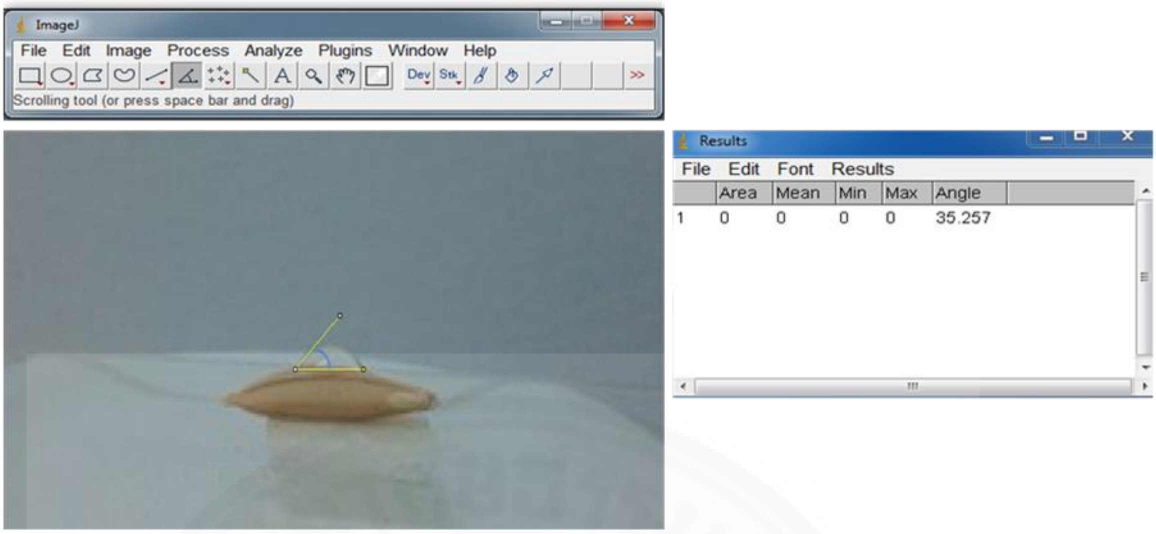

Figure 3.10 Measurement of contact angle

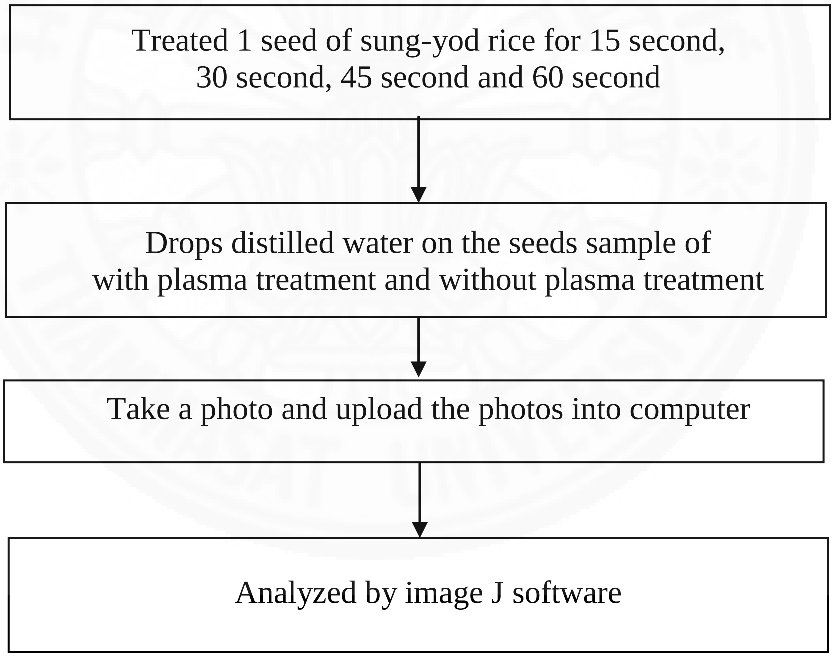

Figure 3.11 Diagram measurement of contact angle

3.4.4 Measurement of GABA

(1) Treated seed sample of sung-yod rice for 15 second, 30 second, 45 second and 60 second.

(2) Soaked the seeds of with plasma treatment and without plasma treatment of sung-yod rice for 4 hr in the oven at 40°C.

(3) After 4 hr rice seeds samples were soaked for 24 h at room temperature and let's rice seeds samples germinated for 7 days. After germinated rice seeds samples were threshed.

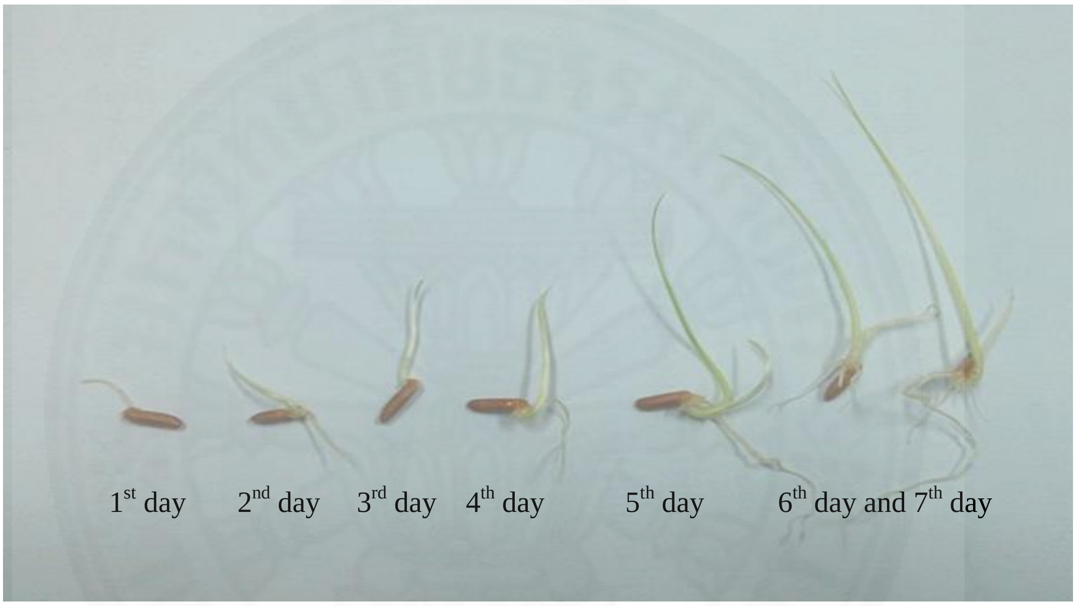

Figure 3.12 The Germination of Sung-yod rice during the first-seventh day is shown

(4) After germinated rice seeds samples were threshed and dissolved with 80% ethanol shaken thoroughly, and then filtered with filter paper (no.1).

Figure 3.13 The filtration of solution with filter paper

(5) The filtered solution was boiled in a water bath to evaporate the ethanol

(6) Added 3 ml distilled water, 0.2 ml of 0.2 M borate buffer and 1.0 ml of 6% phenol. The solutions were mixed thoroughly and cooled in a cooling bath for 5 min.

(7) Added 0.4 ml of 10–15% NaOCl, and the solution was shaken thoroughly.

(8) The solution was boiled in a water bath (100 °C) for 10 min, and allowed to cool

(9) Optical density was determined by spectrophotometer at a wavelength of 630 nm, with ethanol 2.0 ml as a blank

(10) GABA content was quantified by comparing the optical density reading with the standard GABA content curve (y = 0.049 + 10.14 x).

Table 3.1 Wavelength standards

Vision	Wavelength (nm)
Far ultra violet	10-200
Near ultra violet	200-380
Visible	380-780
Near infrared	780-3,000
Middle infrared	3,000-30,000
Far infrared	30,000-300,000
Microwave	300,000-1,000,000,000

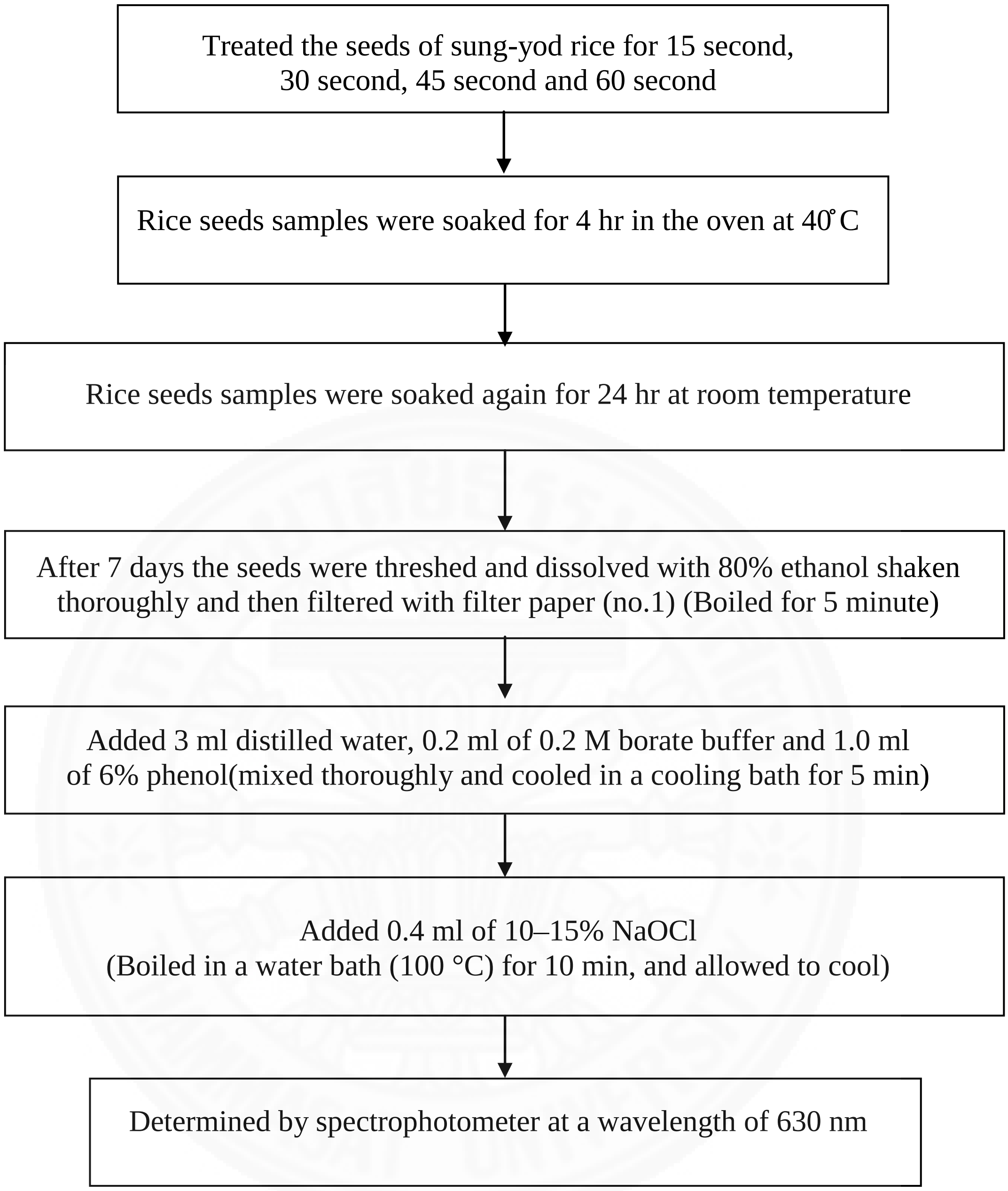

Figure 3.14 Diagram of measurement of GABA content

3.4.5 Measurement of surface area

To analyze the surface area by using BET (The Brunauer, Emmett and Teller) method with Autosorb IQC model of Quantrachome. BET is the common technique for determined the surface area of porous materials. The process is based on the replacing of materials' porous by adsorption and desorption of nitrogen gas. There are 2 functions of BET method (Degas sample and Analysis). Nitrogen adsorption - desorption isotherm was measured and then and the samples were degassed. The specific surface area was calculated by BET equation with the obtained adsorption data.

3.5 Statistical analysis

All data from experiments were analyzed and present as numeric unit as same as the table or linear graphs. Mean and standard deviation of data was calculated by ANOVA software.

Chapter 4
Experiment results and discussion

4.1 The study effect of atmospheric plasma on the germination rate with plasma treatment 30 second

Sung-yod rice are exposed with atmospheric plasma for 30 second and planted in the different times, which are long photoperiod (long-day) and short photoperiod (short-day). Without plasma treatment and with plasma treatment seeds at long photoperiod and short photoperiod are planted and observed for 7 days. The germinated rate, the moldy rate, the length of sprouts and roots, and the weight of sprouts and roots were analyzed by using statistic method and ANOVA software.

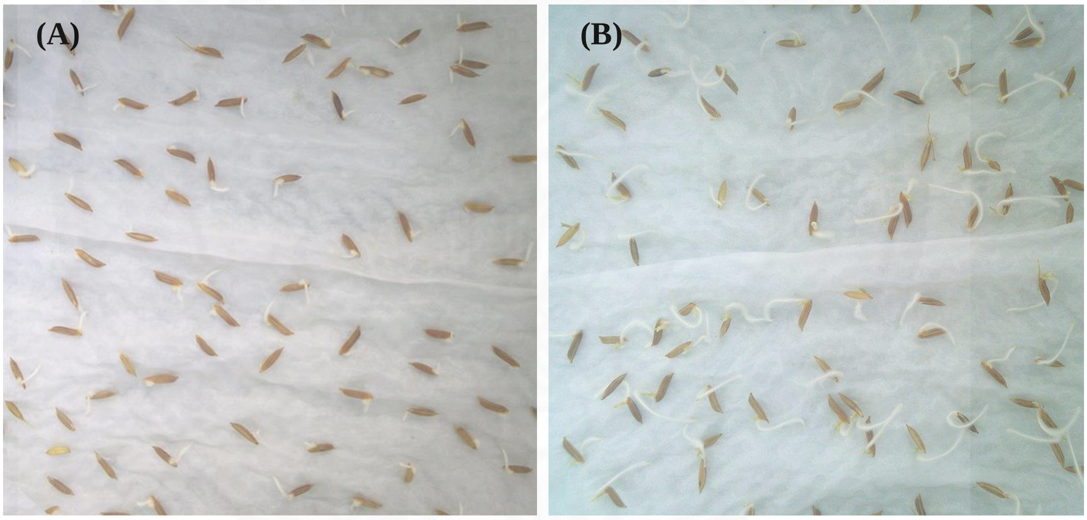

Figure 4.1 The comparison of the germinated seeds between (A) without plasma treatment and (B) with plasma treatment at 3nd days

4.1.1 With plasma treatment 30 second planted with long photoperiod

4.1.1.1 Effect on the germination rate

With plasma treatment can increased the germination rate of paddy and brown rice by 43.67% and 9.87% respectively, compared with without plasma treatment.

4.1.1.2 Effect on weight of sprouts and roots.

With plasma treatment has more weight of sprouts and roots than without plasma treatment. Weight of sprouts and roots increase by 18.48% and 11.91% respectively.

4.1.1.3 Effect on length of sprouts and roots

The lengths of sprouts and roots have no difference significantly between without plasma treatment and with plasma treatment.

4.1.1.4 Effects on moldy rate

Moldy is one type of fungi that often occur during germination state. Mold rate of with plasma treatment rice significantly reduce. Moldy rate of paddy with plasma treatment reduce by 67 %.

4.1.2 With plasma treatment 30 second planted with short photo period

4.1.2.1 Effect on the germination rate

With plasma treatment can increased the germination rate of paddy by 14.5% compared with without plasma treatment. It has no different significantly in brown rice between without plasma treatment and with plasma treatment.

4.1.2.2 Effect on weight of sprouts and roots.

With plasma treatment has more weight of sprouts than without plasma treatment. Sprouts weight increase by 2%. It has no different significantly in weight of roots.

4.1.2.3 Effect on length of sprouts and roots

The lengths of sprouts and roots have no difference significantly between without plasma treatment and with plasma treatment.

4.1.2.4Effects on moldy rate

The moldy rate has no difference significantly between without plasma treatment and with plasma treatment.

Table 4.1 The comparison of paddy with plasma treatment 30 second between planted at long photoperiod (long day) and short photoperiod (short day)

Paddy	Long photoperiod (Long day)	Short photoperiod (Short day)
Germination rate	43.67%	14.50%
Weight of sprouts	18.48%	2.40%
Weight of roots	11.91%	0%
Length of sprouts	0%	0%
Length of roots	0%	0%
Mold rate	1%	0%

From the table shown above, with plasma treatment planted at long photoperiod (long day) has a higher germination rate than planted at short photoperiod (short-day) compared with without plasma treatment of each period. Sung-yod rice is sensitive to light it can grow well at short photoperiod (short-day) that makes it has a lower germination rate than planted at long photoperiod (long day). Thus plasma treatment can improved the germination rate both of long photoperiod (long-day) and short photoperiod (short-day) but it can improve better when plant in worst condition that is long photoperiod.

4.2 The study effect of atmospheric plasma on the germination rate with plasma treatment 15 second, 30 second, 45 second and 60 second

4.2.1 Effect on the germination rate

With plasma treatment can increased the germination rate compared with without plasma treatment.

Plasma treatment can increase germination rate by

- 15 second by 7.65%
- 30 second by 14.50%
- 45 second by 19.44%
- 60 second by 17.98%

4. 2.2 Effect on weight of sprouts and roots

With plasma treatment has more weight of sprouts and roots than without plasma treatment. Sprouts weight increase by 20% and Roots weight increase by 10%

Plasma treatment can increase weight of sprouts by

- 15 second by 11.49%
- 30 second by 2.40%
- 45 second by 30.92%
- 60 second by 13.63%

Plasma treatment can increase weight of roots by

- 45 second by 2.79%
- 60 second by 1.40%

4. 2.3 Effect on length of sprouts and roots

The lengths of sprouts and roots have no difference significantly between without plasma treatment and with plasma treatment.

Plasma treatment can increase length of sprouts by

- 15 second by 7.20%
- 60 second by 5.02%

Plasma treatment can increase length of roots by

- 60 second by 12.48%

Table 4.2 Result of with plasma treatment 4 conditions

Paddy	15 second	30 second	45 second	60 second
Germination rate	7.65%	14.50%	19.44%	17.98%
Weight of sprouts	11.49%	2.40%	30.92%	13.63%
Weight of roots	0%	0%	2.79%	1.40%
Length of sprouts	7.20%	0%	0%	5.02%
Length of roots	0%	0%	0%	12.48%

From the table 4.2 found that at 60 second can increase all factors of the germination rate, weight of sprouts and roots, and length of sprouts and roots (by 17.98%, 13.63%, 1.40%, 5.02% and 12.48% respectively). On the other hand, with plasma treatment at 45 second can improve the germination rate, weight of sprouts, and roots highest by 19%, 30.92% and 2.79% respective.

4.3 The study effect of atmospheric plasma on moisture content

Paddy were treated with varied times of exposure which are 30 second, 1 minute, 2 minute, 4 minute, 6 minute and 8 minute of atmospheric plasma. The weight of rice seeds after treated was measured to determine the moisture loss. Moisture content of rice seeds can be reduced after treated with plasma treatment follow the table below.

Table 4.3 Result of reduction of moisture content with plasma treatment

Times of exposed with plasma treatment	Percentage of reduction of moisture content (%)
30 second	3.47
1 minute	6.26
2 minute	6.76
4 minute	8.14
6 minute	9.90
8 minute	10.07

From the table 4.3 the moisture content decreases more when the time of exposure of atmospheric plasma increases. With plasma treatment can reduce the moisture content higher than without plasma treatment up to10% at 8 minute. The moisture content can reduce more when increased the times of exposure of atmospheric plasma treatment.

4.4 The study effect of atmospheric plasma on wettability

Base on the image J software analyze, it is found that contact angle of paddy and brown rice of sung-yod rice with plasma treatment reduce when the seeds were treated with atmospheric plasma. Contact angle with plasma treatment reduce higher than without plasma treatment significantly shown in the table 4.4.

Table 4.4 The reduction of contact angle of paddy and brown rice

With plasma treatment (second)	Percentage of reduction of contact angle (%)	
	Paddy	Brown rice
15 second	18.03	20.17
30 second	23.53	22.60
45 second	31.18	21.16
60 second	30.37	19.56

The result show that with plasma treatment at 45 second can reduce contact angle highest 31.18% for paddy. For brown rice the percentage of reduction between the different times have the same value around 19-22% of reduction. From the figure 4.2 and 4.3 that compared between without plasma treatment and with plasma treatment of paddy and brown rice have shown the drop of with plasma treatment spread more than without plasma treatment. The spread of water drop can indicate the water is absorbed.

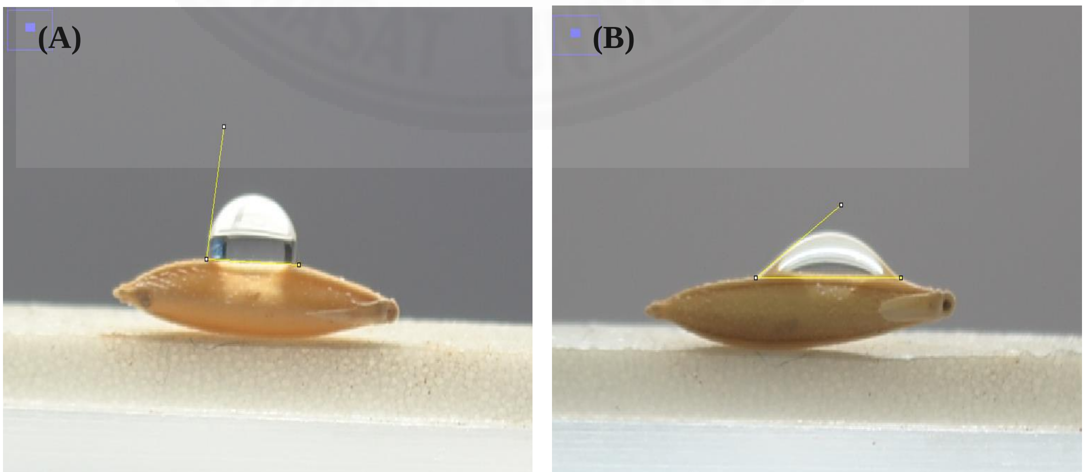

Figure 4.2 The comparison of the angle of paddy between (A)without plasma treatment and (B)with plasma treatment

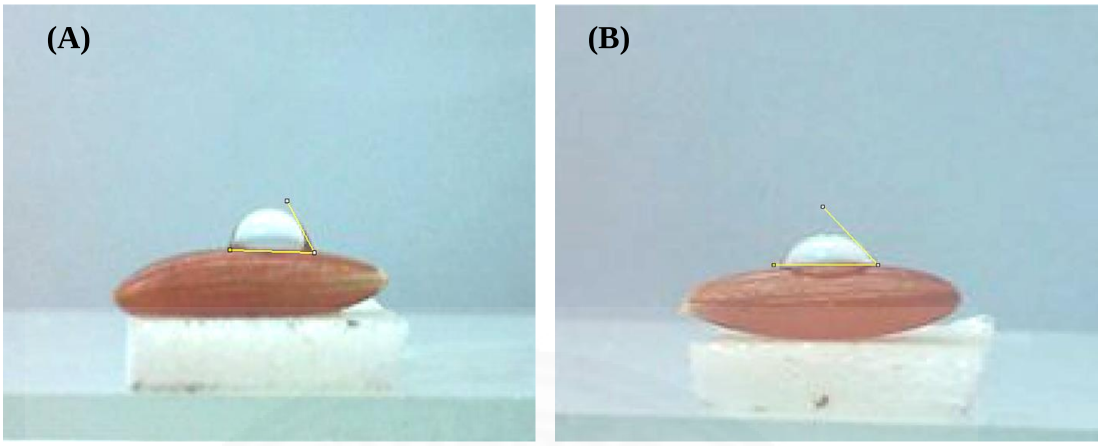

Figure 4.3 The comparison of the angle of brown rice of sung-yod rice between (A)without plasma treatment and (B)with plasma treatment

4.5 The study effect of atmospheric plasma on surface area

Base on the BET method analyze, with plasma treatment can reduced surface area highest at 15 second with plasma treatment 85.69% for paddy and 94.11% for brown rice. This result is similar to the report that looked on the surface of rice sample by using SEM method and found that the roughness become less after treat with plasma treatment[6].

Table 4.5 The percentage of reduction of surface area

With plasma treatment (second)	Percentage of reduction of surface area (%)	
	Paddy	Brown rice
15 second	85.69	94.11
30 second	49.07	49.01
45 second	62.38	62.30
60 second	62.38	43.82

4.6 The study effect of atmospheric plasma on GABA content

From the observation for 7 days after cultivated, paddy and brown rice with plasma treatment has grown better, by has longer roots than without plasma treatment. With the faster germination can increase the GABA content, which is a substance occurring while the rice is germinated the white root nodule of rice as show in figure 4.4 and figure 4.5.

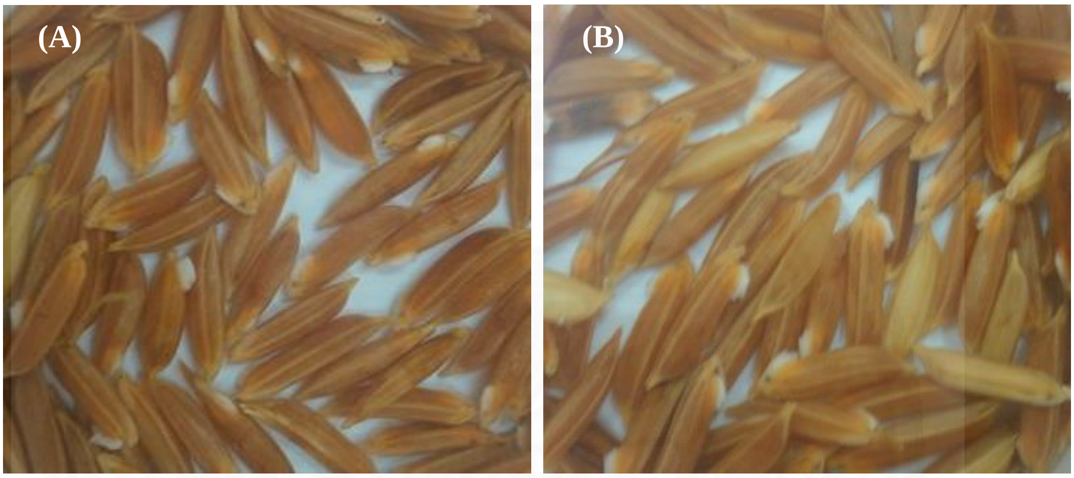

Figure 4.4 The comparison of paddy seeds between (A)without plasma treatment and (B)with plasma treatment 30 second

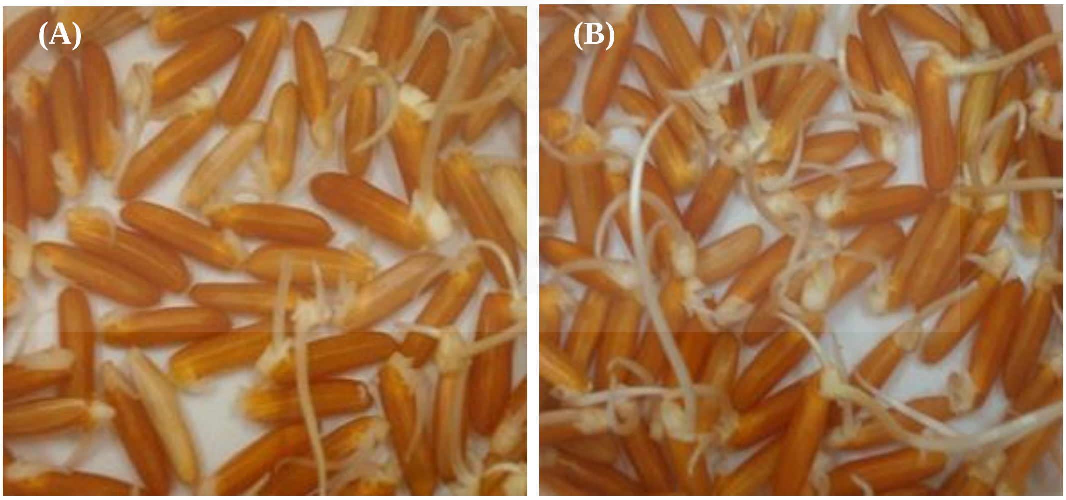

Figure 4.5 The comparison of brown rice seeds between (A) without plasma treatment and (B) with plasma treatment 30 second

The GABA content of rice seeds can be increased after treated with plasma treatment compared with without plasma treatment significantly at the 2nd, 3rd 4th and 7th days for paddy. The GABA content of brown rice with plasma treatment also increased higher than without plasma treatment at the 1st, 2nd, 3rd and 5th days after cultivated. Although the GABA content at the 1st, 5th and 6th days of paddy and 4th, 6th and 7th days of brown rice after cultivar of with plasma treatment and without plasma treatment was found no difference significantly that shown in the table 4.6.

Table 4.6 The percentage of increasing of GABA content

Days	Percentage of increasing of GABA content (%)	
	Paddy	Brown rice
1st day	0%	37.57
2nd day	25.45	0%
3rd day	50.44	16.05
4th day	25.52	0%
5th day	0%	43.03
6th day	0%	0%
7th day	47.57	0%

From Figure 4.6 and 4.7 the GABA content decline after 6th days for paddy and 2nd days brown rice because of the amount of GABA are transported into the Krebs cycle for generate energy to growth the seedlings.

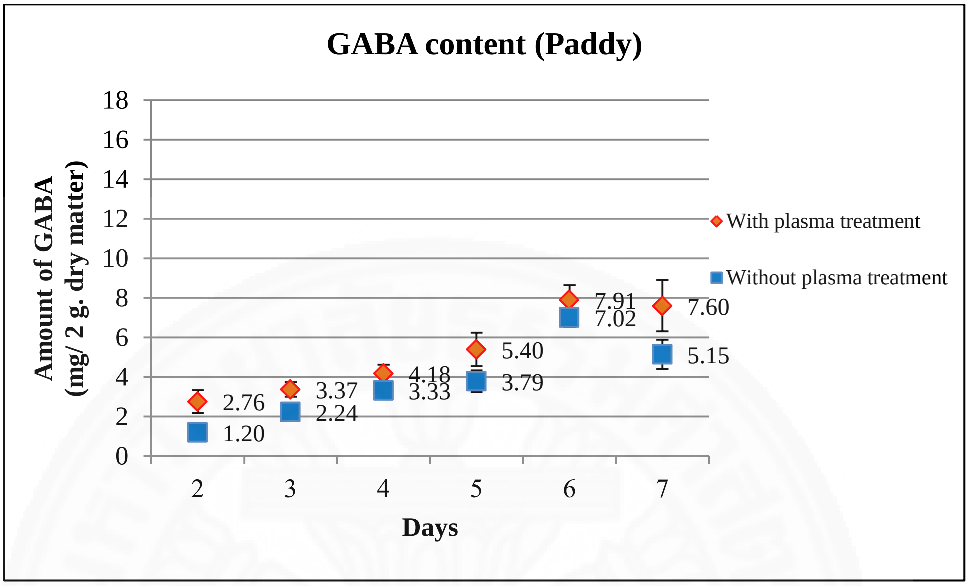

Figure 4.6 The comparison of GABA of content of paddy between with plasma treatment and without plasma treatment

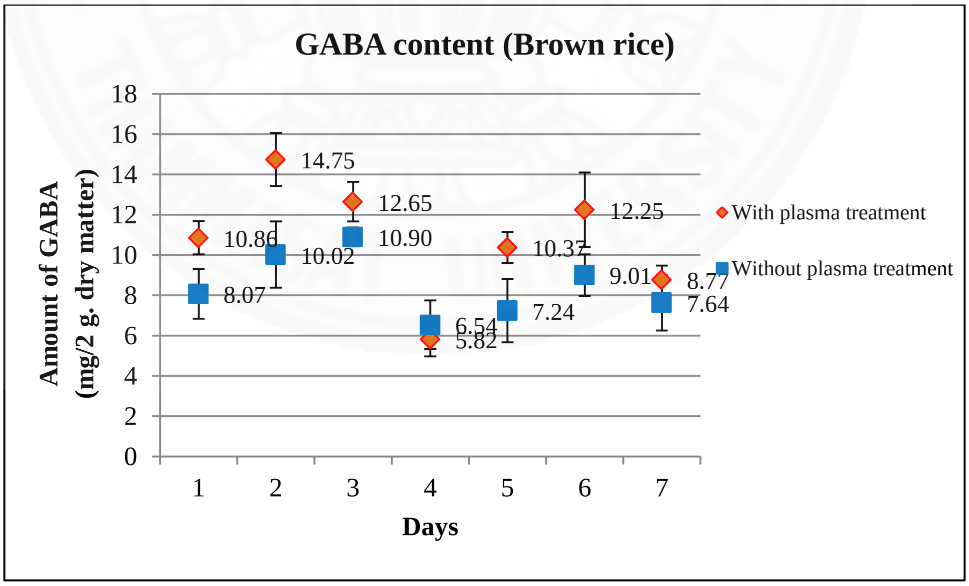

Figure 4.7 The comparison of GABA of content of brown rice between with plasma treatment and without plasma treatment

4.7 Summary

Based on the results in this chapter, it can be concluded that the germination rate and properties of sung-yod rice is significantly improved after the cold plasma treatment, which is similar to types of seeds: lettuce (Bermúde 2013), tomato (Pankaj 2013) and spinach (Shao 2013). This improvement can be explained by 2 possible mechanisms: the surface modification and sterilization. It is observed that after the cold plasma treatment, some properties of the seed’s surface change, especially the capability of water absorption and desorption. The surface area is reduced after the cold plasma treatment, resulting in the decrease of contact angle, implying better smoothness of surface. This shows that the treated seeds become more hydrophilic. As a result, the transport of water in and out the seeds occurs easily. In other words, the cold plasma treatment greatly affected the surface properties leading to reduction in hardness and stickiness of seed's surface. This result is similar to the previous report by Chen et al (2014) that showed the change of textural properties surface using SEM micrographs and Tipwimol et al (2014) that showed that properties were improved the surface of the rice after treated.

The second effect for germination enhancement is about the sterilization. This is similar to the report of Bermúdez et al (2013) and Choi et al (2006) that showed the cold plasma can reduce E.coli bacteria in food. In this work, the inhibition of bacteria and fungi can reduce the mold, occur during germination. That can increase the germination. The cold plasma not only damages bacteria cells, but also removes wax that covers on the rice seeds. These make the surface cleaner.

The cold plasma can impact not only germination rate but also germination properties. It shows that the amount of GABA in the seeds increases. It is known that GABA is an important substance during the seed growing. With the cold plasma treatment, it can increase the amount of GABA in both paddy and brown rice, which is similar to that reported by Shoichi et al (2004).

Chapter 5
Conclusions

5.1 Conclusions

Atmospheric plasma generated from Dielectric Barrier Discharge (DBD), it's used to improve the germination rate of sung-yod rice. Several aspects of the germination including the moldy rate, the weight of sprouts and roots, the length of sprouts and roots, the moisture content, wettability, the quantity of gamma-aminobutyric acid(GABA) content and surface area also considered. All results were used ANOVA software at 95%($P<0.05$) shown that with plasma treatment can significantly increase the germination rate highest at 45 second up to 19% and at 45 second can increase the weight of sprouts and roots up to 30% and 2% respectively. It is also found the germination rate and early state properties of the plasma rice plant during long photoperiod can increase higher than plant during short photoperiod, which are up to 44% for the germination rate, 18% for the weight of sprouts and 12% for the weight of roots. And also reduce the moldy rate both of paddy and brown rice up to 67% and 22% respectively, which can occur during germinated. For this result it has interrelated with the result of moisture content, with plasma treatment also reduce up to 10%. It is also found that increase of germination relates to the reduction of wettability and surface area, with plasma treatment can reduce wettability and surface area up to 31% and 86% respectively for paddy and 22% and 94% respectively for brown rice. The reduction of wettability and surface area show that the water can get in to the seeds easily and make it germinated faster after treat with plasma treatment. With the faster germination can increase the GABA content, which is a substance occurring while the rice is germinated the white root nodule of rice. With plasma treatment can increase GABA content both of paddy and brown rice up to 50% and 43%, respectively. With the high value of GABA content can effect to the growth of rice by greater strength and generate energy to growth the seedlings make it growth faster.

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Research Accomplishment

International conference proceeding

- P. Wongpanom, T. Traikool, T. Onjun,[1] N. Poolyarat, S. Chittapun,[3] N. Amnuaysin,[3] and M. Fuangfung. THE IMPROVEMENT OF GERMINATION RATE OF THAI SUNG-YOD RICE BY USING ATMOSPHERIC PLASMA. The 4th International Symposium on Engineering, Energy and Environments. Thammasat University, Pattaya Campus, Thailand (8-10 November 2015)

- P. Wongpanom, T. Traikool, T. Onjun,[1] N. Poolyarat, S. Chittapun,[3] N. Amnuaysin,[3] and M. Fuangfung. THE REDUCTION OF MOISTURE CONTENT IN THAI RICE USING COLD PLASMA. The 41st congress on science and technology of Thailand. Suranaree University of Technology Nakhon Rachasima, Thailand (6-8 November 2015

Appendices

Appendix A

ANOVA ANALYZED

ANOVA OF GERMINATION RATE

		Sum of Squares	df	Mean Square	F	Sig.
Germination15.2	Between Groups	.784	1	.784	3.784	.052
	Within Groups	206.780	998	.207		
	Total	207.564	999			
Germination15.3	Between Groups	.169	1	.169	1.861	.173
	Within Groups	90.630	998	.091		
	Total	90.799	999			
Germination15.4	Between Groups	.169	1	.169	3.256	.071
	Within Groups	51.806	998	.052		
	Total	51.975	999			
Germination15.5	Between Groups	.121	1	.121	2.703	.100
	Within Groups	44.670	998	.045		
	Total	44.791	999			
Germination15.6	Between Groups	.100	1	.100	2.279	.131
	Within Groups	43.784	998	.044		
	Total	43.884	999			
Germination15.7	Between Groups	.100	1	.100	2.279	.131
	Within Groups	43.784	998	.044		
	Total	43.884	999			
Germination30.2	Between Groups	2.916	1	2.916	15.058	**.000**
	Within Groups	193.260	998	.194		
	Total	196.176	999			
Germination30.3	Between Groups	.100	1	.100	1.072	.301
	Within Groups	93.084	998	.093		
	Total	93.184	999			
Germination30.4	Between Groups	.064	1	.064	1.134	.287
	Within Groups	56.336	998	.056		
	Total	56.400	999			

Germination30.5	Between Groups	.049	1	.049	1.011	.315
	Within Groups	48.350	998	.048		
	Total	48.399	999			
Germination30.6	Between Groups	.036	1	.036	.757	.384
	Within Groups	47.464	998	.048		
	Total	47.500	999			
Germination30.7	Between Groups	.036	1	.036	.757	.384
	Within Groups	47.464	998	.048		
	Total	47.500	999			
Germination45.2	Between Groups	5.476	1	5.476	30.190	**.000**
	Within Groups	181.020	998	.181		
	Total	186.496	999			
Germination45.3	Between Groups	.256	1	.256	2.899	.089
	Within Groups	88.140	998	.088		
	Total	88.396	999			
Germination45.4	Between Groups	.036	1	.036	.618	.432
	Within Groups	58.120	998	.058		
	Total	58.156	999			
Germination45.5	Between Groups	.144	1	.144	3.286	.070
	Within Groups	43.740	998	.044		
	Total	43.884	999			
Germination45.6	Between Groups	.144	1	.144	3.428	.064
	Within Groups	41.920	998	.042		
	Total	42.064	999			
Germination45.7	Between Groups	.144	1	.144	3.428	.064
	Within Groups	41.920	998	.042		
	Total	42.064	999			
Germination60.2	Between Groups	4.624	1	4.624	24.963	**.000**
	Within Groups	184.860	998	.185		
	Total	189.484	999			
Germination60.3	Between Groups	.169	1	.169	1.861	.173
	Within Groups	90.630	998	.091		
	Total	90.799	999			

Germination60.4	Between Groups	.036	1	.036	.618	.432
	Within Groups	58.120	998	.058		
	Total	58.156	999			
Germination60.5	Between Groups	.049	1	.049	1.011	.315
	Within Groups	48.350	998	.048		
	Total	48.399	999			
Germination60.6	Between Groups	.081	1	.081	1.808	.179
	Within Groups	44.710	998	.045		
	Total	44.791	999			
Germination60.7	Between Groups	.081	1	.081	1.808	.179
	Within Groups	44.710	998	.045		
	Total	44.791	999			

ANOVA OF LENGTH OF SPROUTS AND ROOTS

		Sum of Squares	df	Mean Square	F	Sig.
LengthofSprouts15	Between Groups	3.168	1	3.168	.592	.442
	Within Groups	5334.696	997	5.351		
	Total	5337.864	998			
LengthofSprouts30	Between Groups	4.489	1	4.489	.849	.357
	Within Groups	5276.273	998	5.287		
	Total	5280.762	999			
LengthofSprouts45	Between Groups	16.180	1	16.180	3.023	.082
	Within Groups	5341.362	998	5.352		
	Total	5357.541	999			
LengthofSprouts60	Between Groups	72.042	1	72.042	13.736	**.000**
	Within Groups	5228.902	997	5.245		
	Total	5300.944	998			
LengthofRoots15	Between Groups	18.333	1	18.333	5.524	**.019**
	Within Groups	3312.022	998	3.319		
	Total	3330.355	999			
LengthofRoots30	Between Groups	10.489	1	10.489	3.403	.065
	Within Groups	3072.991	997	3.082		

	Total	3083.480	998			
LengthofRoots45	Between Groups	9.761	1	9.761	3.250	.072
	Within Groups	2997.453	998	3.003		
	Total	3007.215	999			
LengthofRoots60	Between Groups	76.218	1	76.218	25.184	**.000**
	Within Groups	3017.383	997	3.026		
	Total	3093.602	998			

ANOVA OF WEIGHT OF SPROUTS AND ROOTS

		Sum of Squares	df	Mean Square	F	Sig.
WeightofSprouts15	Between Groups	.000	1	.000	75.971	**.000**
	Within Groups	.006	998	.000		
	Total	.006	999			
WeightofSprouts30	Between Groups	.000	1	.000	74.012	**.000**
	Within Groups	.006	998	.000		
	Total	.006	999			
WeightofSprouts45	Between Groups	.001	1	.001	112.717	**.000**
	Within Groups	.011	998	.000		
	Total	.012	999			
WeightofSprouts60	Between Groups	.001	1	.001	161.795	**.000**
	Within Groups	.007	998	.000		
	Total	.008	999			
WeightofRoots15	Between Groups	.000	1	.000	.243	.622
	Within Groups	.059	998	.000		
	Total	.059	999			
WeightofRoots30	Between Groups	.000	1	.000	.210	.647
	Within Groups	.057	998	.000		
	Total	.057	999			
WeightofRoots45	Between Groups	.000	1	.000	4.119	**.043**
	Within Groups	.059	998	.000		
	Total	.059	999			

WeightofRoots60	Between Groups	.001	1	.001	22.125	**.000**
	Within Groups	.048	998	.000		
	Total	.049	999			

ANOVA OF GABA CONTENT OF PADDY

		Sum of Squares	df	Mean Square	F	Sig.
PdGABA1	Between Groups	48.194	1	48.194	4.156	.111
	Within Groups	46.389	4	11.597		
	Total	94.583	5			
PdGABA2	Between Groups	3.642	1	3.642	18.228	**.013**
	Within Groups	.799	4	.200		
	Total	4.441	5			
PdGABA3	Between Groups	1.912	1	1.912	25.233	**.007**
	Within Groups	.303	4	.076		
	Total	2.215	5			
PdGABA4	Between Groups	1.088	1	1.088	8.371	**.044**
	Within Groups	.520	4	.130		
	Total	1.608	5			
PdGABA5	Between Groups	3.886	1	3.886	7.644	.051
	Within Groups	2.033	4	.508		
	Total	5.919	5			
PdGABA6	Between Groups	1.194	1	1.194	3.070	.155
	Within Groups	1.556	4	.389		
	Total	2.751	5			
PdGABA7	Between Groups	8.981	1	8.981	8.041	**.047**
	Within Groups	4.468	4	1.117		
	Total	13.449	5			

ANOVA OF GABA CONTENT OF BROWN RICE

		Sum of Squares	df	Mean Square	F	Sig.
BrGABA1	Between Groups	11.664	1	11.664	10.686	**.031**
	Within Groups	4.366	4	1.091		
	Total	16.030	5			
BrGABA2	Between Groups	33.444	1	33.444	15.037	**.018**
	Within Groups	8.896	4	2.224		
	Total	42.340	5			
BrGABA3	Between Groups	4.598	1	4.598	7.675	**.050**
	Within Groups	2.396	4	.599		
	Total	6.995	5			
BrGABA4	Between Groups	.763	1	.763	.701	.450
	Within Groups	4.354	4	1.089		
	Total	5.117	5			
BrGABA5	Between Groups	14.726	1	14.726	9.615	**.036**
	Within Groups	6.126	4	1.532		
	Total	20.852	5			
BrGABA6	Between Groups	15.826	1	15.826	7.061	.057
	Within Groups	8.965	4	2.241		
	Total	24.791	5			
BrGABA7	Between Groups	1.912	1	1.912	1.580	.277
	Within Groups	4.840	4	1.210		
	Total	6.752	5			

ANOVA OF MOISTURE CONTENT

		Sum of Squares	df	Mean Square	F	Sig.
Moisture30s	Between Groups	.000	1	.000	.000	.990
	Within Groups	.313	4	.078		
	Total	.313	5			
Moisture1min	Between Groups	.360	1	.360	4.158	.111
	Within Groups	.346	4	.087		
	Total	.706	5			
Moisture2min	Between Groups	.456	1	.456	5.188	.085
	Within Groups	.351	4	.088		
	Total	.807	5			
Moisture4min	Between Groups	.776	1	.776	8.550	**.043**
	Within Groups	.363	4	.091		
	Total	1.139	5			
Moisture6min	Between Groups	1.313	1	1.313	15.794	**.016**
	Within Groups	.332	4	.083		
	Total	1.645	5			
Moisture8min	Between Groups	1.369	1	1.369	14.447	**.019**
	Within Groups	.379	4	.095		
	Total	1.748	5			

ANOVA OF CONTACT ANGLE

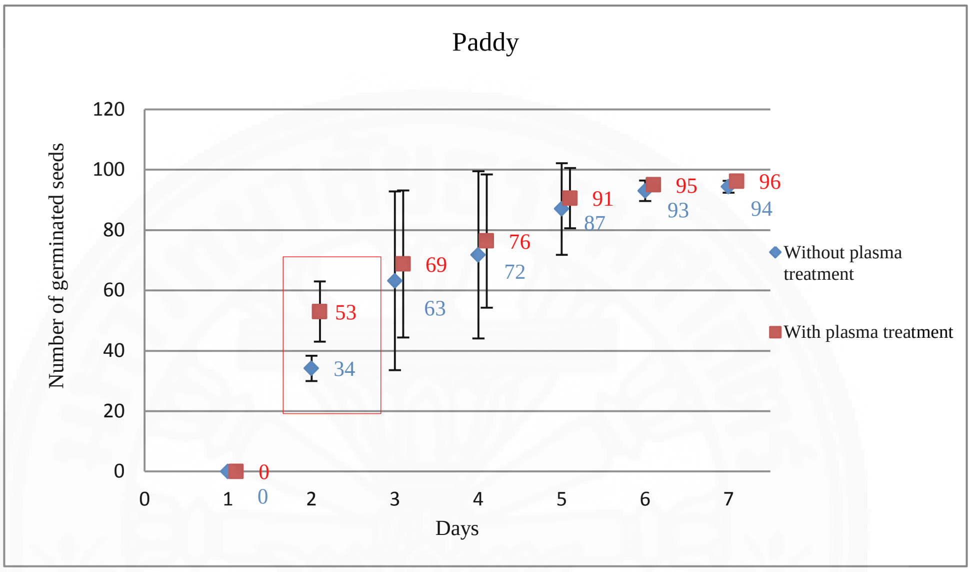
		Sum of Squares	df	Mean Square	F	Sig.
PdCA15s	Between Groups	306.739	1	306.739	9.704	**.014**
	Within Groups	252.876	8	31.609		
	Total	559.614	9			
PdCA30s	Between Groups	522.729	1	522.729	18.849	**.002**
	Within Groups	221.857	8	27.732		
	Total	744.586	9			
PdCA45s	Between Groups	1103.214	1	1103.214	32.638	**.000**
	Within Groups	270.416	8	33.802		
	Total	1373.630	9			

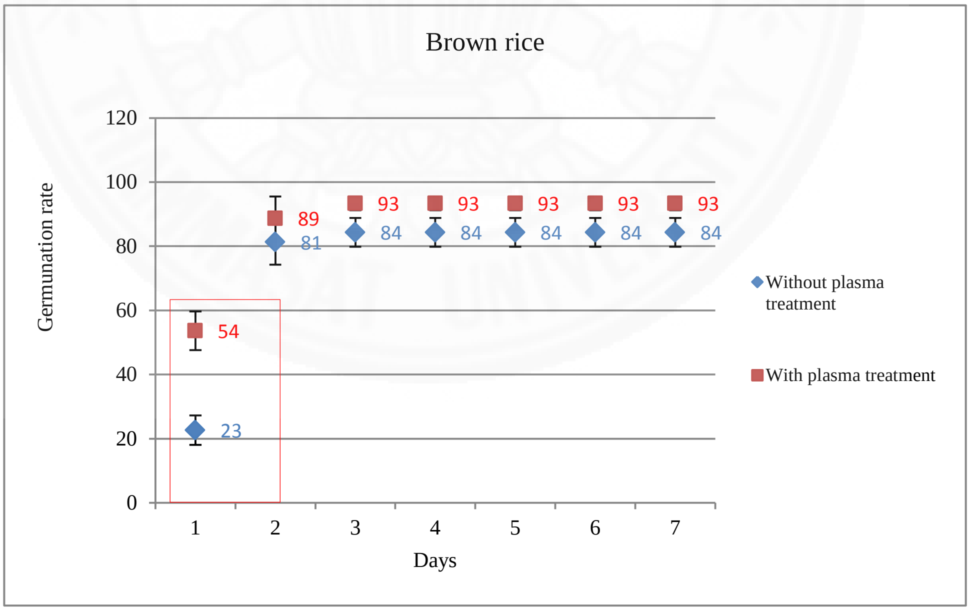
PdCA60s	Between Groups	870.769	1	870.769	24.211	**.001**
	Within Groups	287.723	8	35.965		
	Total	1158.492	9			
BrCA15s	Between Groups	311.052	1	311.052	28.441	**.001**
	Within Groups	87.495	8	10.937		
	Total	398.546	9			
BrCA30s	Between Groups	390.588	1	390.588	36.888	**.000**
	Within Groups	84.708	8	10.589		
	Total	475.296	9			
BrCA45s	Between Groups	342.330	1	342.330	34.800	**.000**
	Within Groups	78.697	8	9.837		
	Total	421.027	9			
BrCA60s	Between Groups	292.594	1	292.594	33.596	**.000**
	Within Groups	69.673	8	8.709		
	Total	362.268	9			

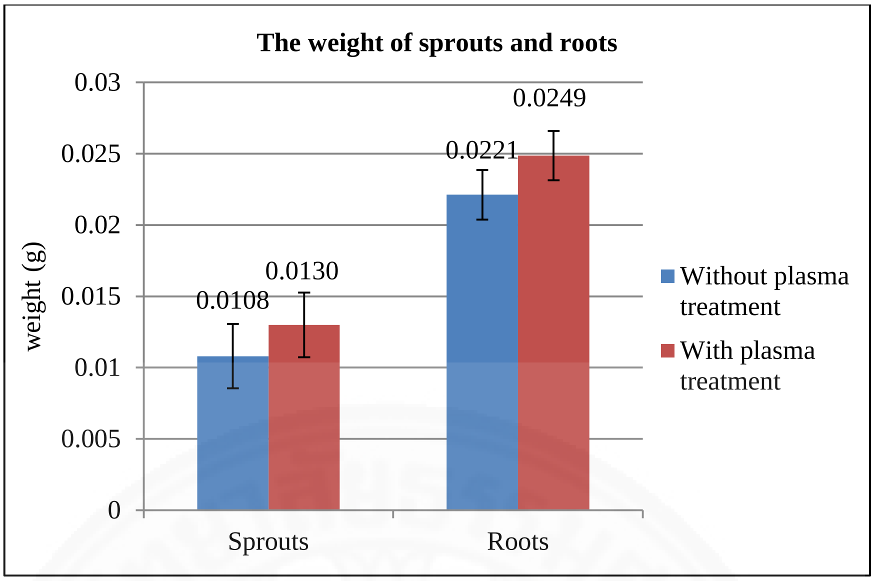
Appendix B

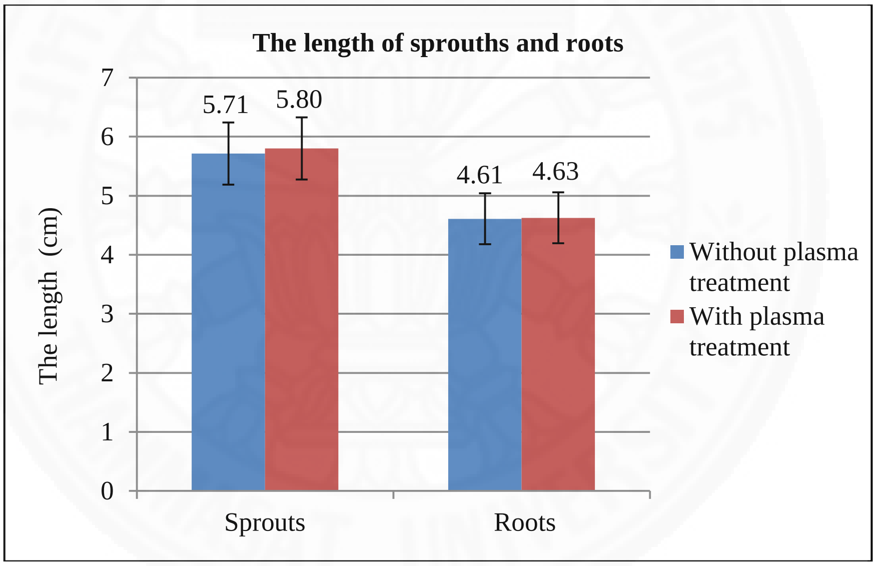
ALL RESULTS

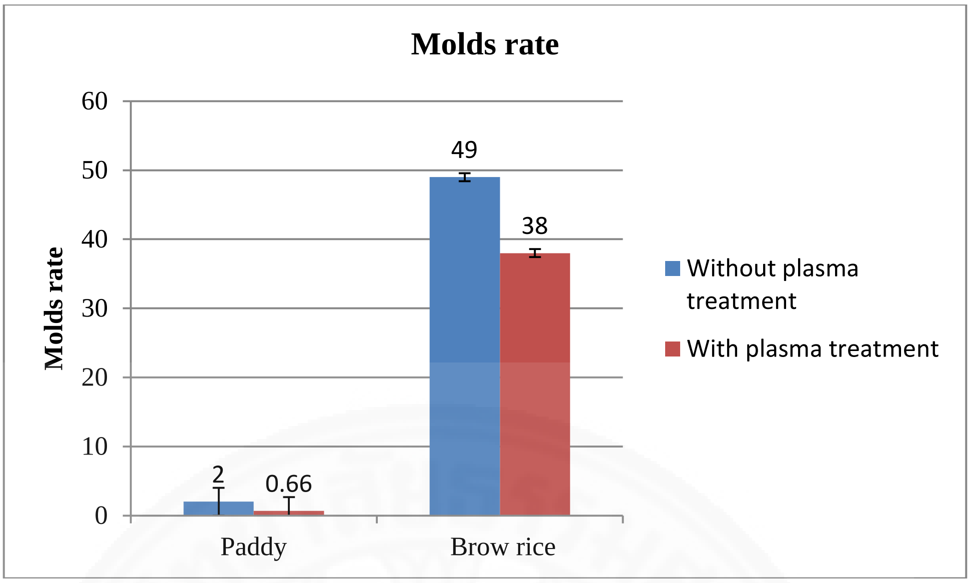
With plasma treatment 30 second

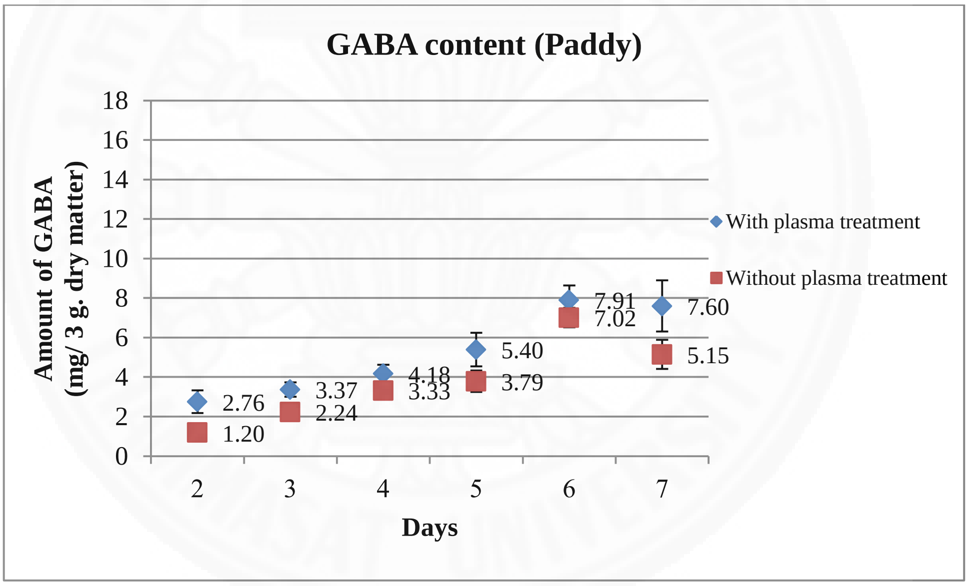


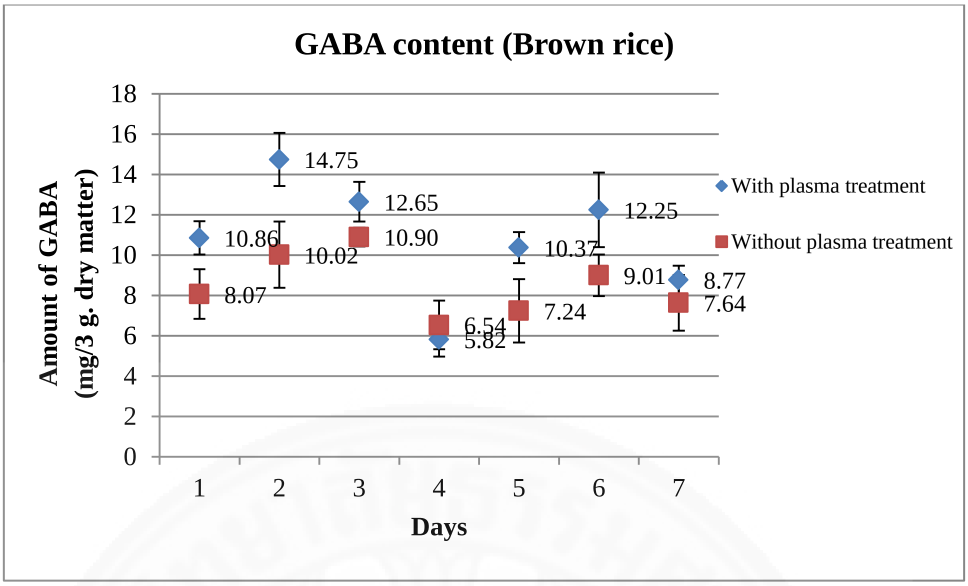



The weight of sprouts and roots
weight (g)
0.03
0.025
0.02
0.015
0.01
0.005
0
0.0108
0.0130
0.0221
0.0249
Sprouts
Roots
Without plasma treatment
With plasma treatment


The length of sprouths and roots
The length (cm)
7
6
5
4
3
2
1
0
5.71
5.80
4.61
4.63
Sprouts
Roots
Without plasma treatment
With plasma treatment

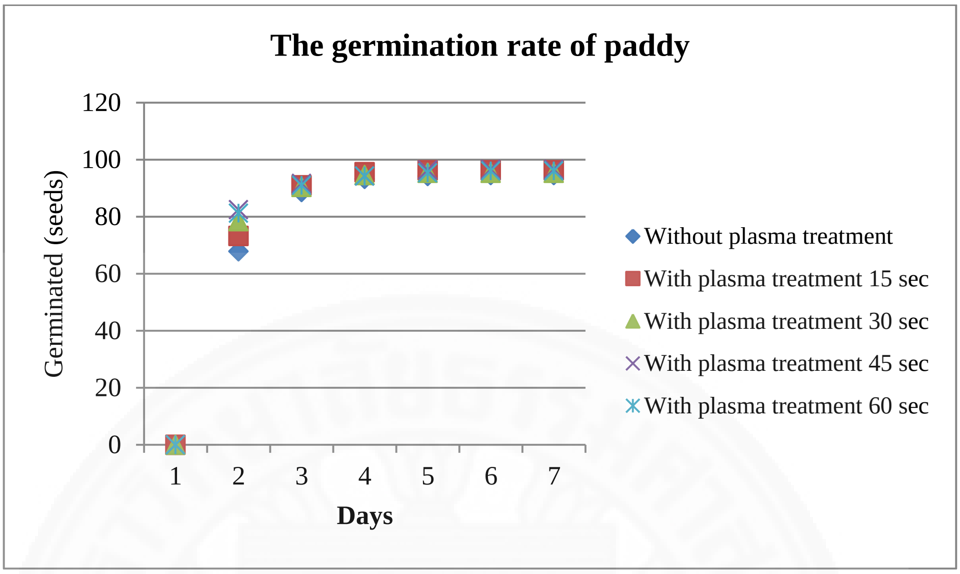

Molds rate
60
50
40
30
20
10
0
Molds rate
49
38
2
0.66
Paddy
Brow rice
Without plasma treatment
With plasma treatment

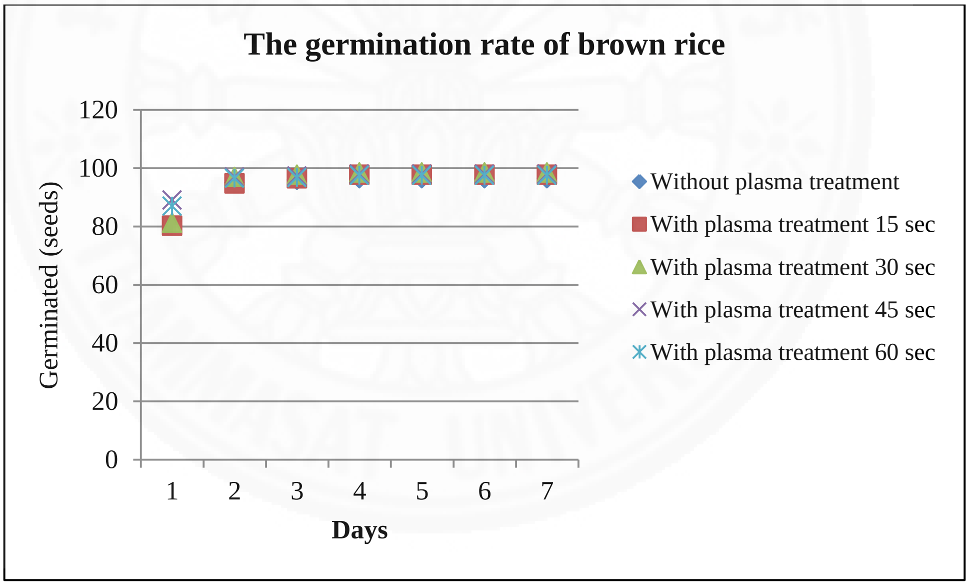

GABA content (Paddy)
18
16
14
12
10
8
6
4
2
0
Amount of GABA (mg/ 3 g. dry matter)
2.76
1.20
3.37
2.24
4.18
3.33
5.40
3.79
7.91
7.02
7.60
5.15
2
3
4
5
6
7
Days
With plasma treatment
Without plasma treatment

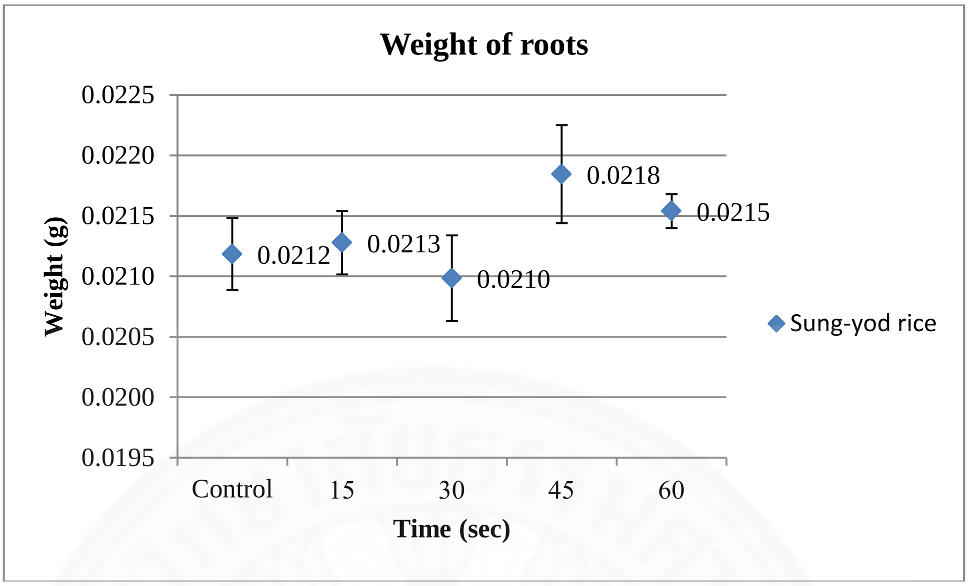


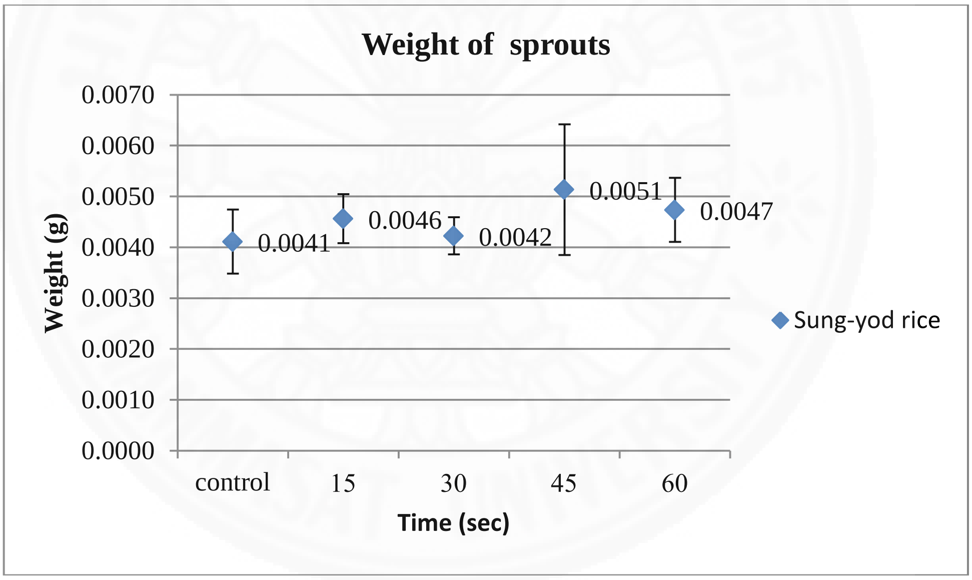
GABA content (Brown rice)
Amount of GABA
(mg/3 g. dry matter)
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
Days
14.75
10.86
12.65
10.90
10.02
8.07
6.54
5.82
10.37
7.24
12.25
9.01
8.77
7.64
With plasma treatment
Without plasma treatment

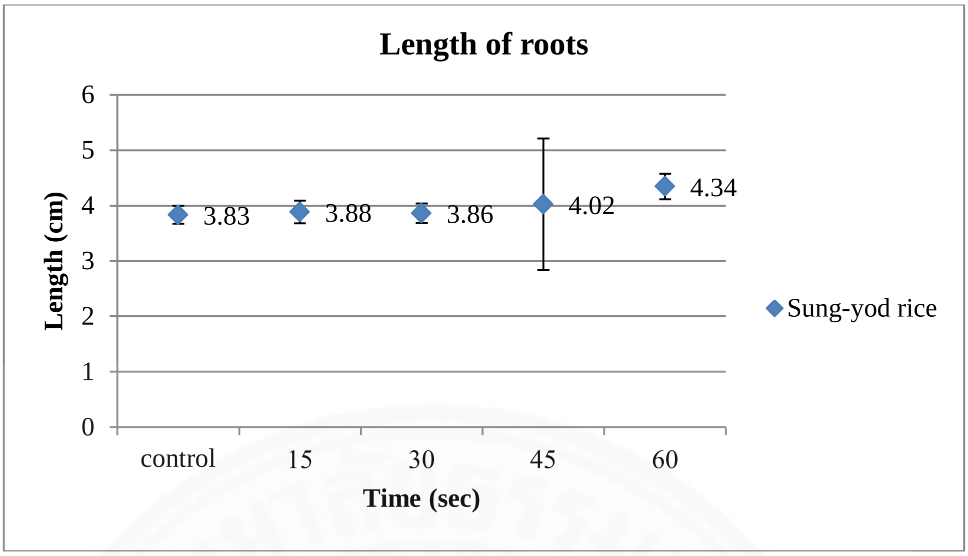
With plasma treatment 4 conditions

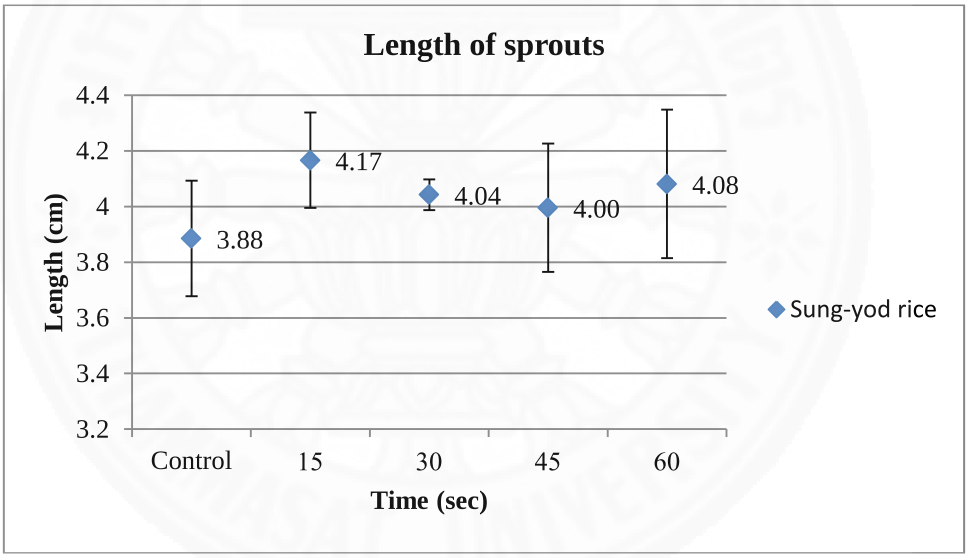


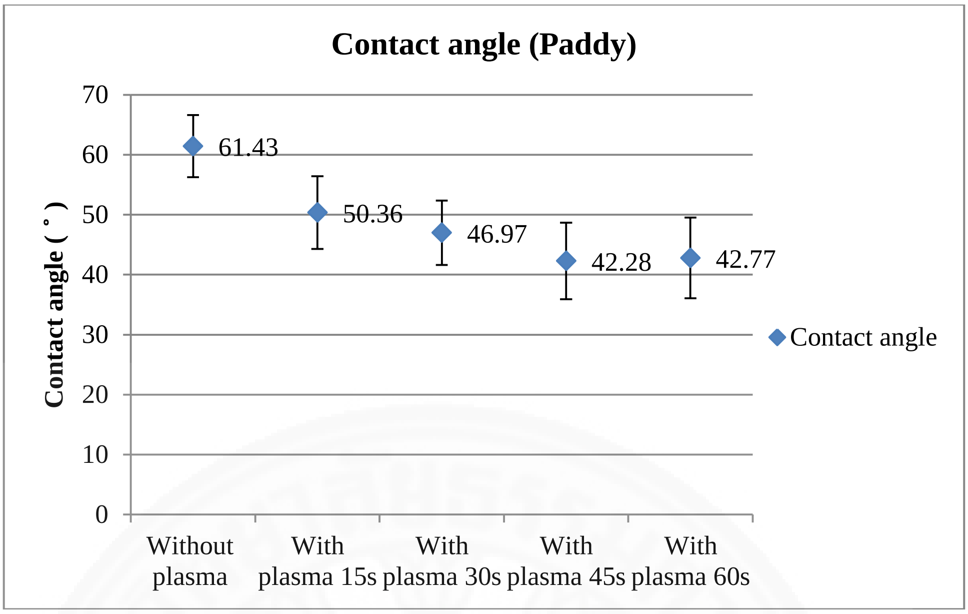



Weight of roots
0.0225
0.0220
0.0215
0.0210
0.0205
0.0200
0.0195
Weight (g)
0.0212
0.0213
0.0210
0.0218
0.0215
Sung-yod rice
Control
15
30
45
60
Time (sec)

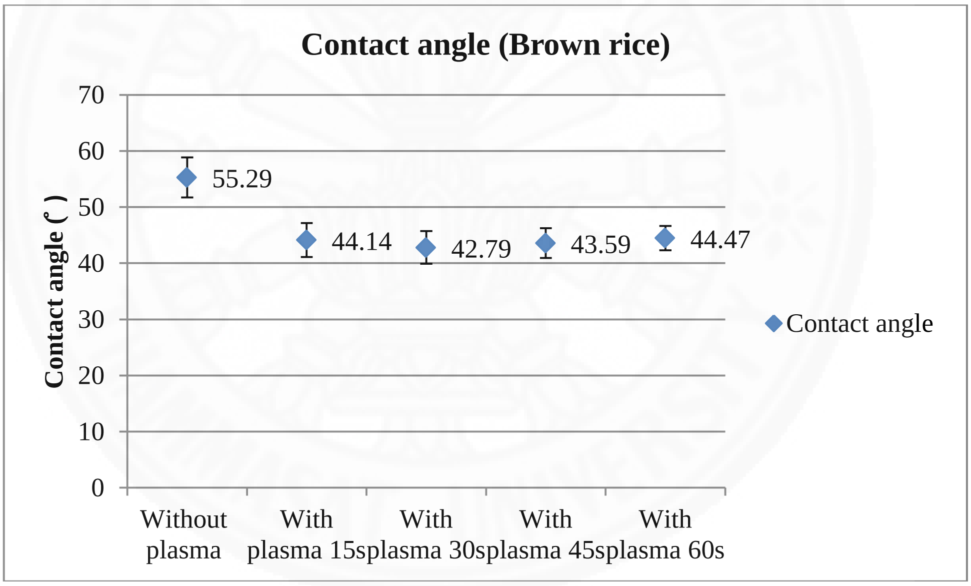

Weight of sprouts
0.0070
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
Weight (g)
0.0041
0.0046
0.0042
0.0051
0.0047
Sung-yod rice
control
15
30
45
60
Time (sec)


Length of roots
6
5
4
3
2
1
0
Length (cm)
3.83
3.88
3.86
4.02
4.34
control
15
30
45
60
Time (sec)
Sung-yod rice

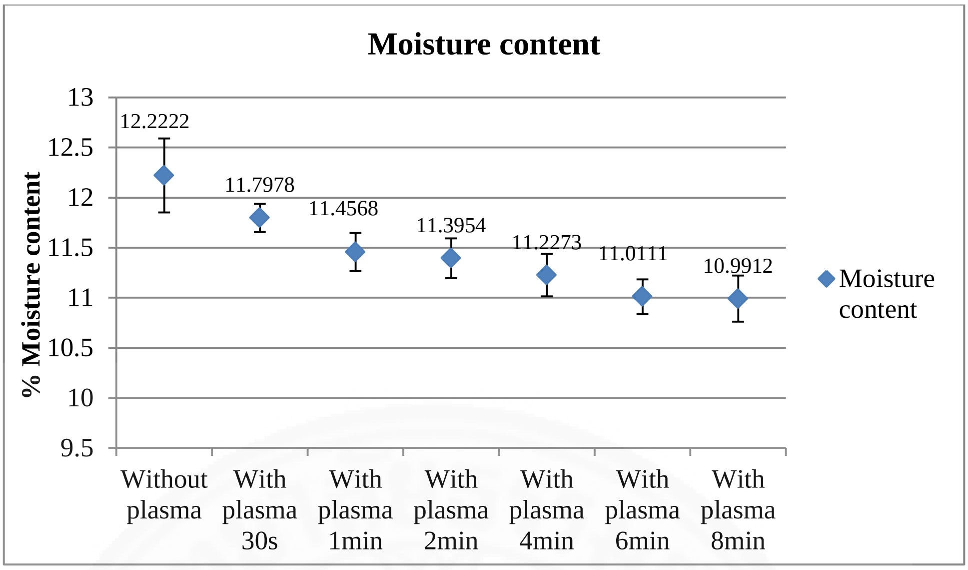

Length of sprouts
4.4
4.2
4
3.8
3.6
3.4
3.2
Length (cm)
3.88
4.17
4.04
4.00
4.08
Control
15
30
45
60
Time (sec)
Sung-yod rice



Contact angle (Paddy)
Contact angle (˚)
70
60
50
40
30
20
10
0
61.43
50.36
46.97
42.28
42.77
Without plasma
With plasma 15s
With plasma 30s
With plasma 45s
With plasma 60s
Contact angle



Contact angle (Brown rice)
Contact angle (˚)
70
60
50
40
30
20
10
0
55.29
44.14
42.79
43.59
44.47
Without plasma
With plasma 15s
With plasma 30s
With plasma 45s
With plasma 60s
Contact angle



Raw result of Surface area

With plasma treatment (second)	Surface area (m^2/g)	
	Paddy	Brown rice
Without plasma treatment	21.915	29.858
15 second	3.134	1.757
30 second	11.160	15.223
45 second	8.244	11.255
60 second	8.243	16.773

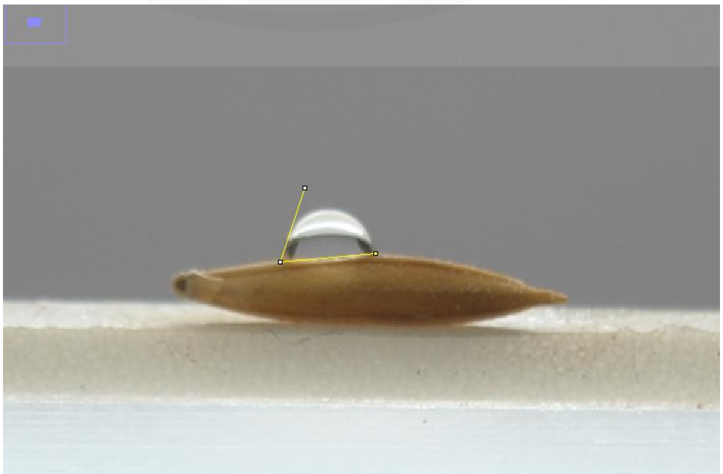
Appendix C

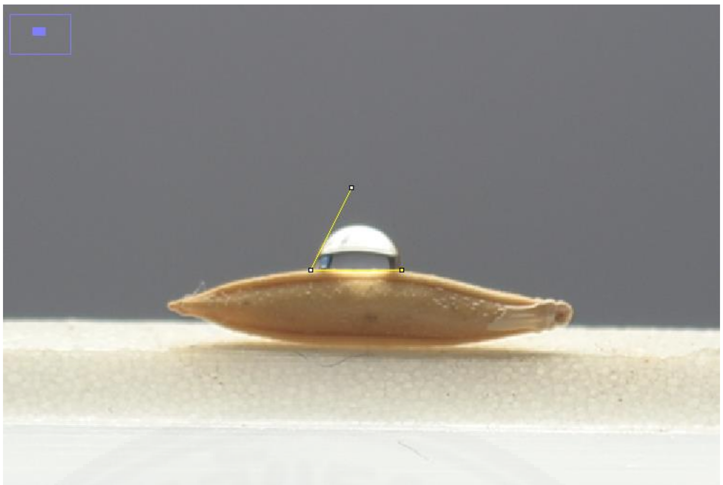
CONTACT ANGLE

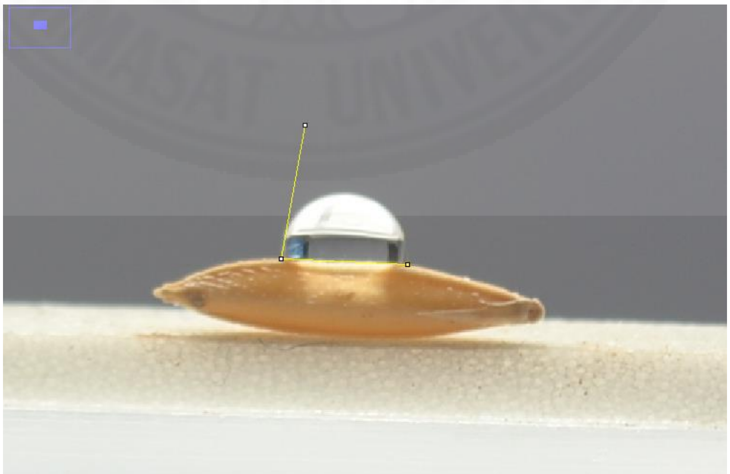
Contact angle of Paddy

Contact angle of Paddy				
Without plasma	With plasma 15s	With plasma 30s	With plasma 45s	With plasma 60s
68.839	46.47	52.462	40.443	52.53
55.376	56.166	48.013	37.466	36.529
64.026	56.312	51.625	50.437	46.747
59.974	50.357	41.274	40.766	37.777
58.955	42.481	41.496	33.024	40.272

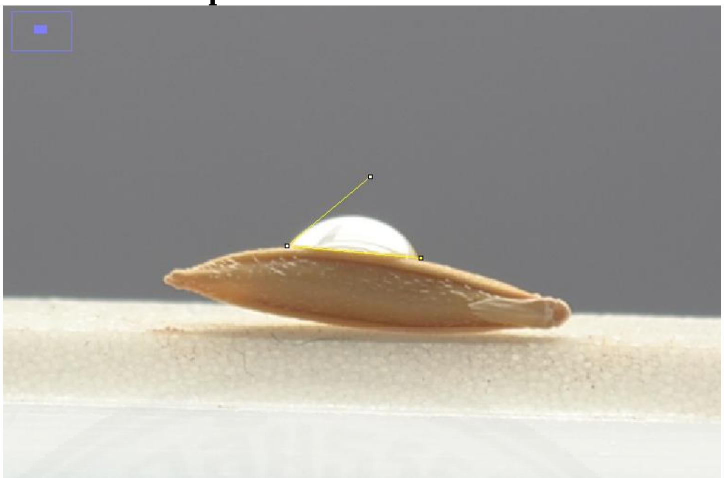
Without plasma treatment

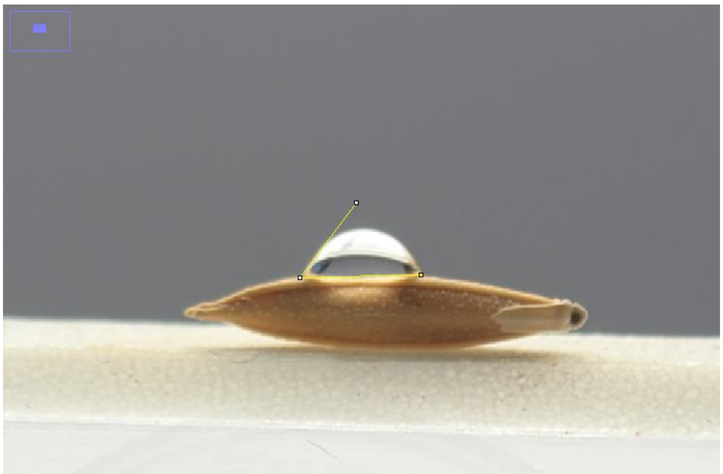






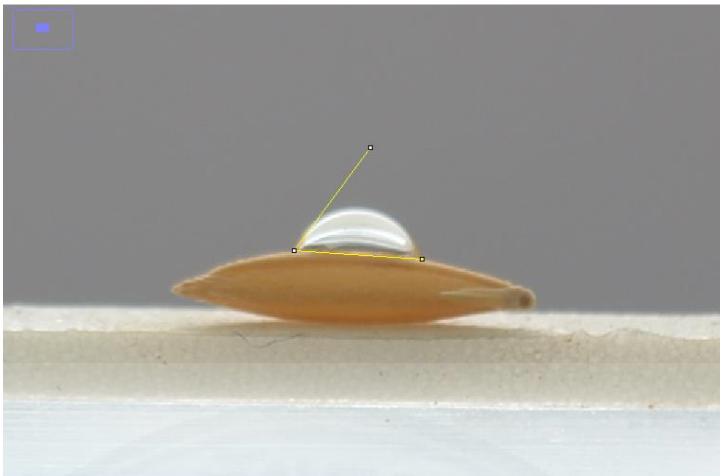
With plasma treatment 15 second



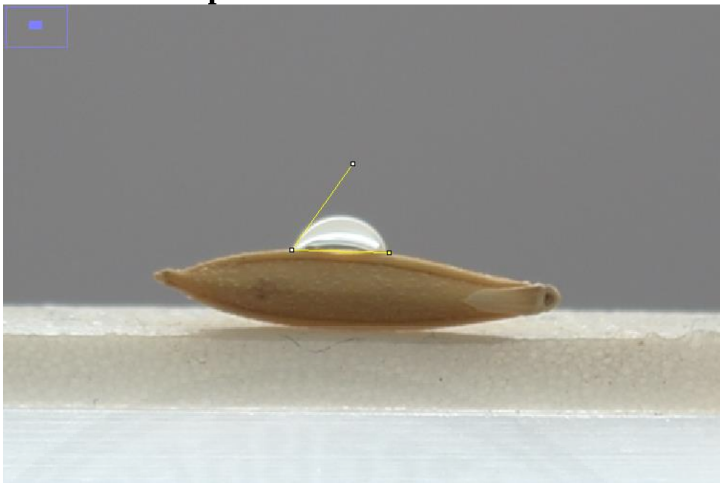


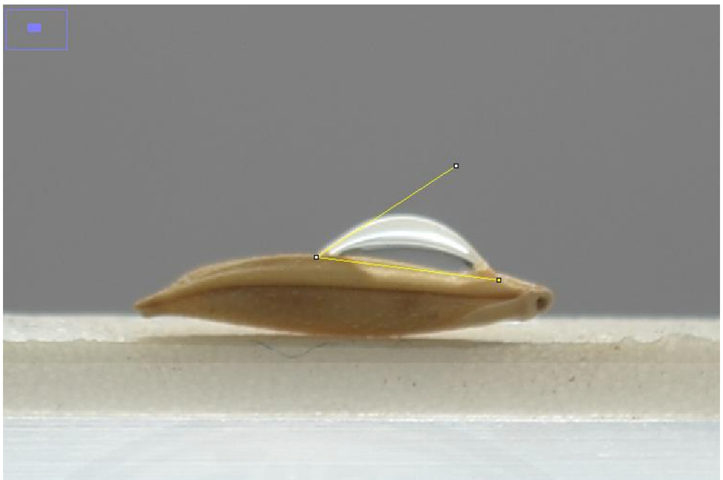
With plasma treatment 30 second

With plasma treatment 45 second



With plasma treatment 60 second

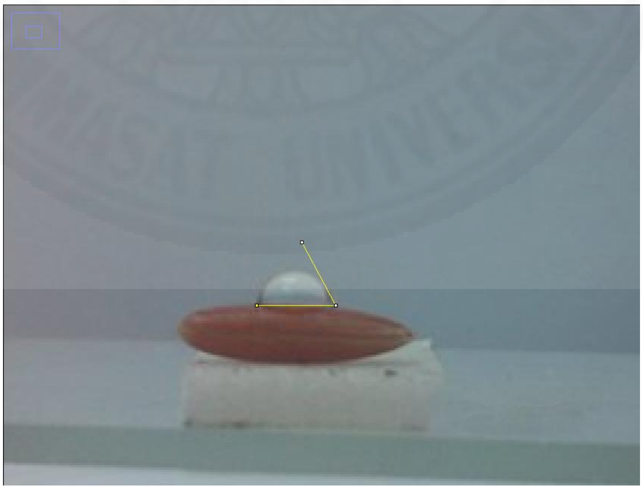


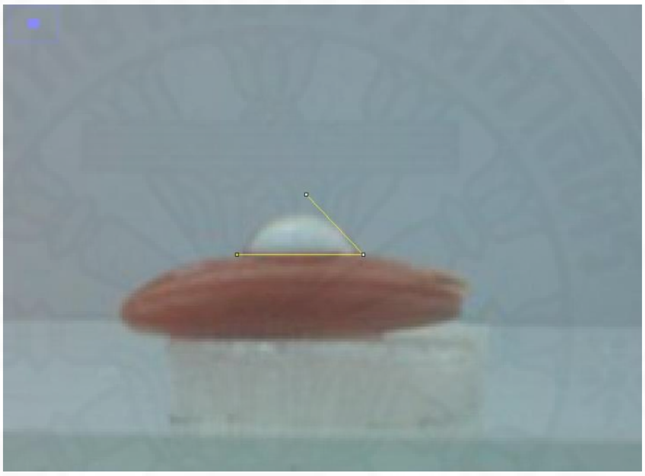


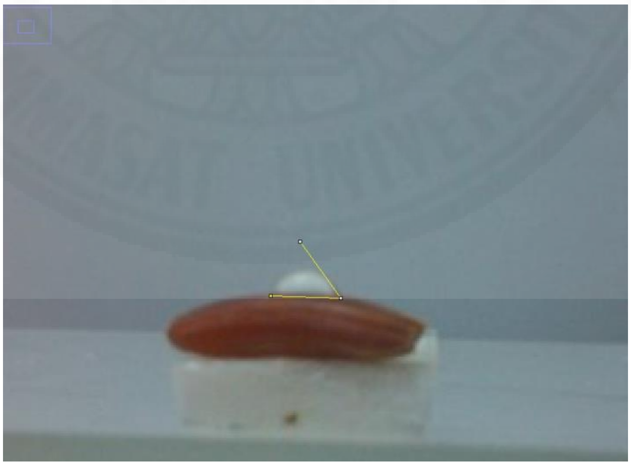
Contact angle of Brown rice

Contact angle of Brown rice				
Without plasma	With plasma 15s	With plasma 30s	With plasma 45s	With plasma 60s
58.247	45	40.176	41.634	43.295
59.203	41	45	41.774	45
55.589	45	44.684	45.909	46.273
52.399	41.348	39.09	46.987	46.469
51.009	48.327	45	41.634	41.318

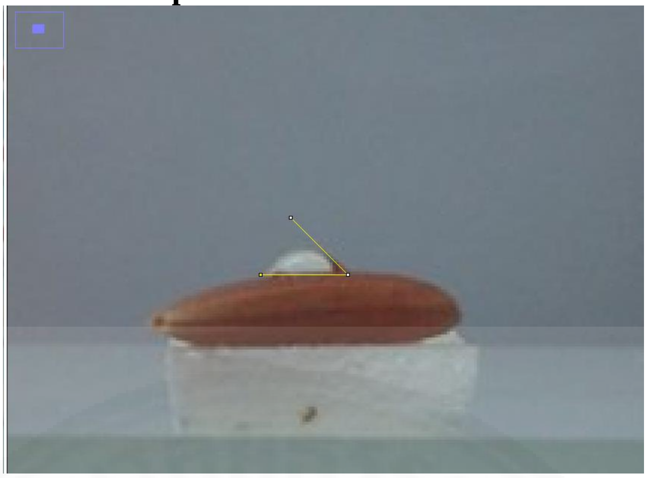
Without plasma treatment

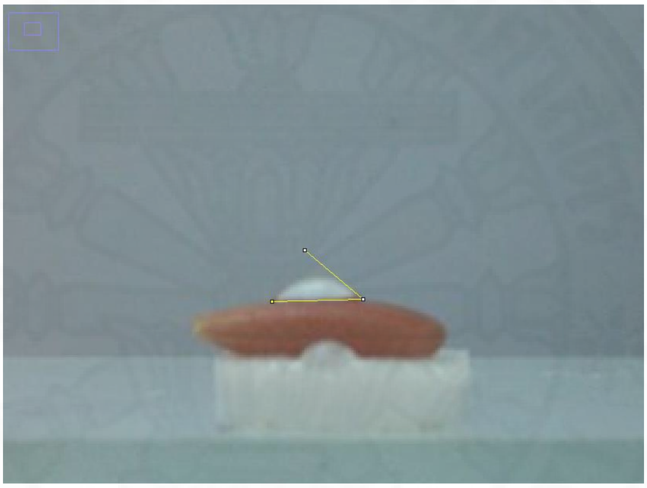


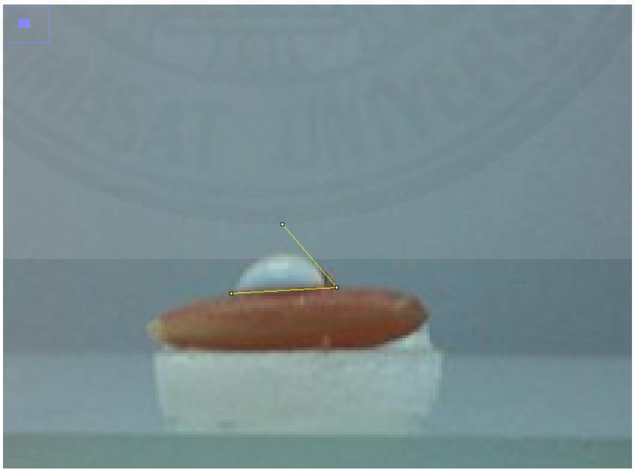


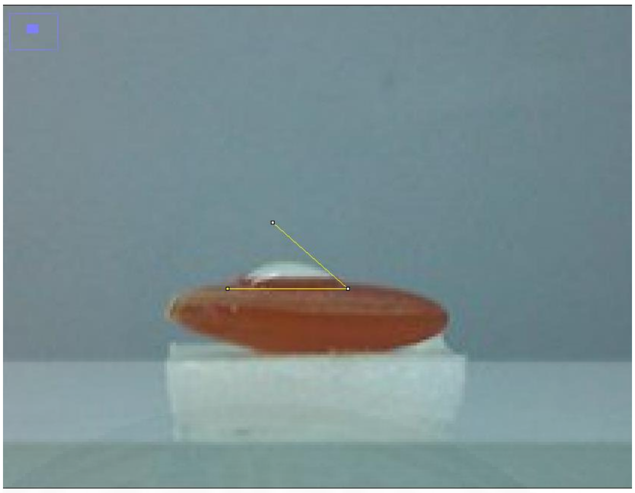


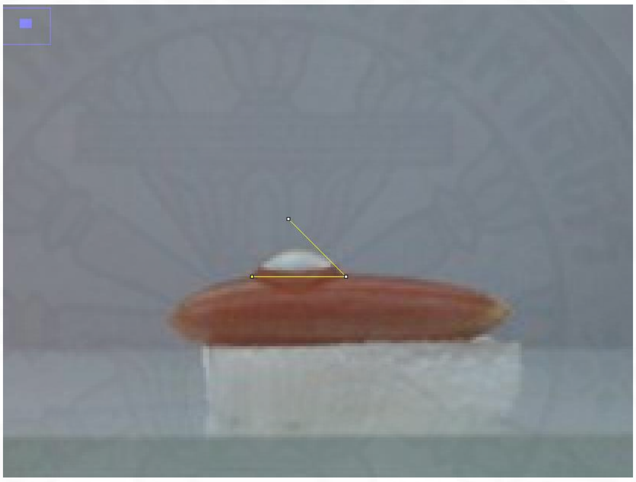
With plasma treatment 15 second



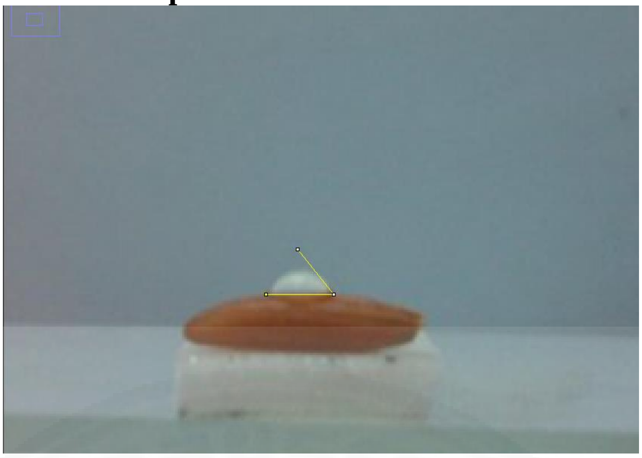


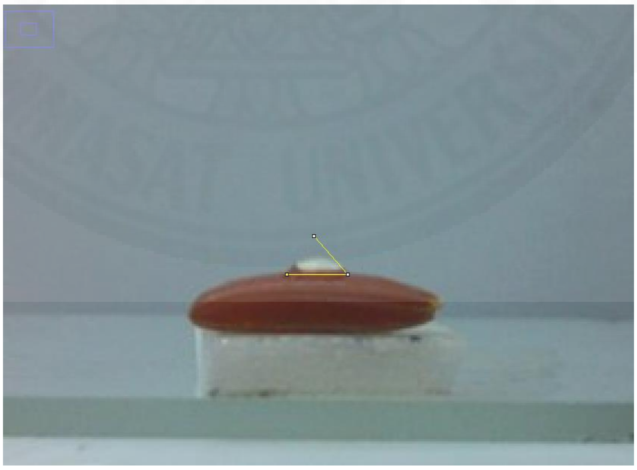


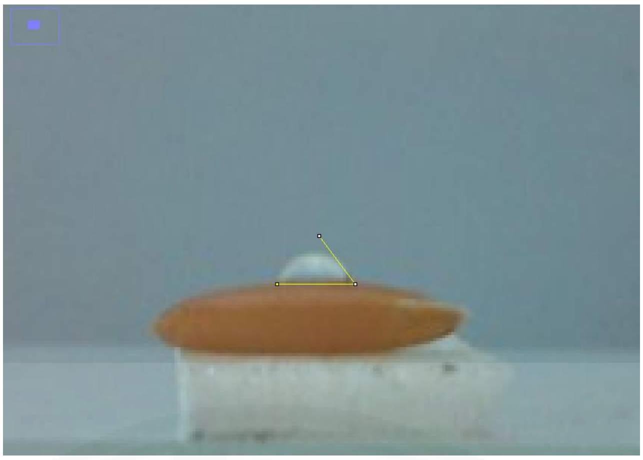


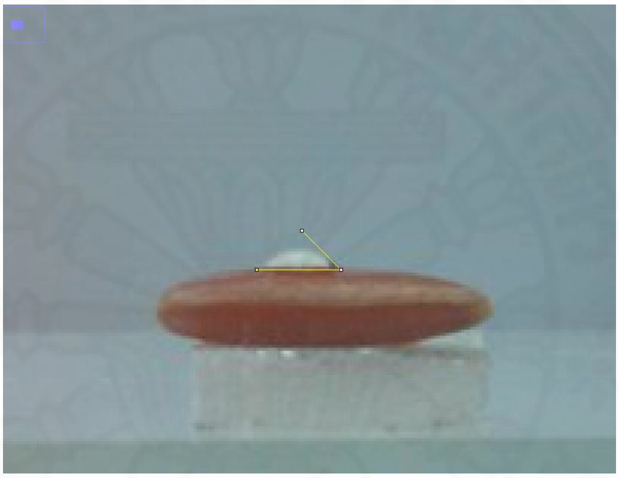


With plasma treatment 30 second

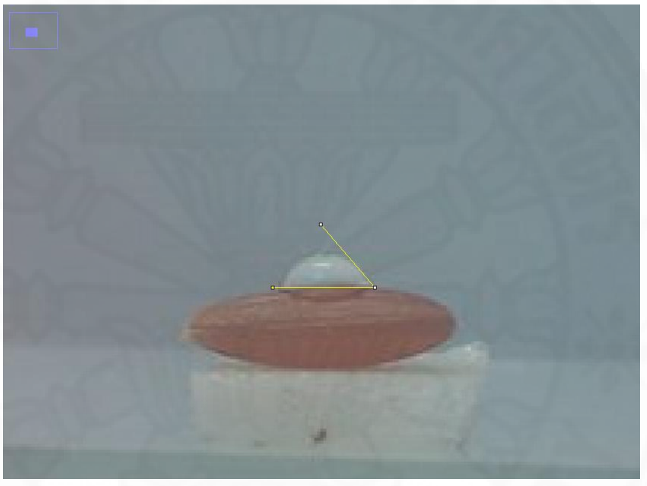


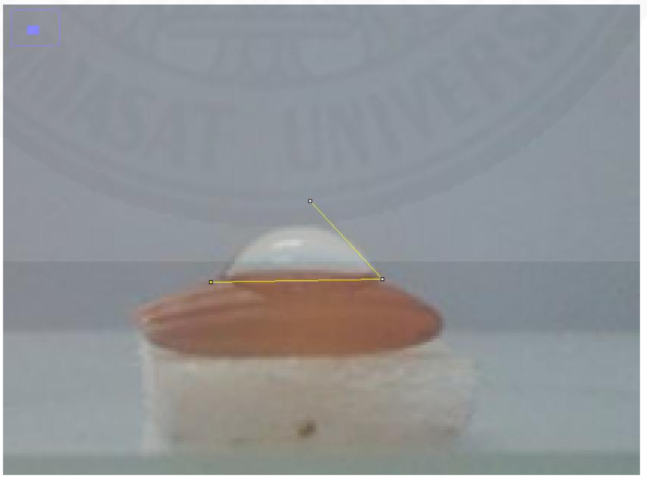


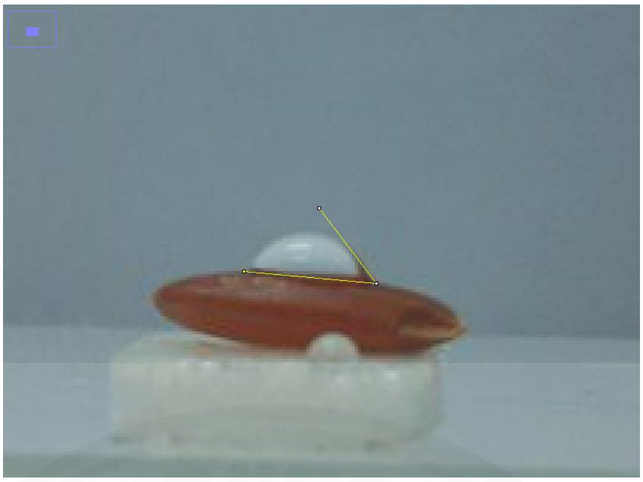


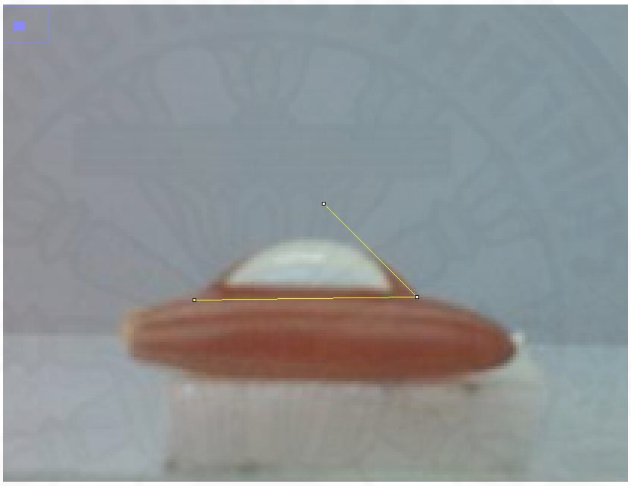


With plasma treatment 45 second









With plasma treatment 60 second