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Development and Performance Evaluation of an Automatic Vacuum Packer of the Continuous Type

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The objectives of this study were to develop an automatic vacuum packer of continuous type and to evaluate its performance for packing white rice with embryo. The vacuum packer consisted of a pressing board assembly, a vibrating conveyor assembly, a tape adhering assembly, and a gas filling system. The processing capacity of the vacuum packer was 6 pouch min^{-1}. The success rate of the vacuum packaging of the machine was 92·6%. The changes of the whiteness, moisture content, peroxide value, and acid value of non-vacuum-packed and vacuum-packed samples were investigated to analyse the preservation effects of vacuum packaging on rice quality during the storage of 3 months. The results obtained from the storage experiment were as follows: (1) the whiteness of the non-vacuum-packed and vacuum-packed rice decreased by 4 and 2, respectively; (2) the moisture content of the non-vacuum-packed and vacuum-packed rice decreased by 1·3 and 0·8% (w.b.), respectively; (3) the peroxide value of the non-vacuum-packed rice increased by 3·45 meq kg^{-1} and then dropped moderately; but the value of the vacuum-packed samples increased by 1·89 meq kg^{-1}; (4) the acid values of the non-vacuum-packed and vacuum-packed rice increased by 0·98 and 0·71 mg $g,^{-1}$ respectively; (5) The vacuum packaging suffocated all the insects in the pouches.

1. Introduction

High-quality rice should be produced to make native agricultural industry more competitive and to satisfy the consumers' requirements. Recently, several kinds of specialised rice products, such as white rice with embryo, germinated brown rice, pre-washed white rice that can be cooked without washing, rice fortified with other nutrients, and functional rice are produced and sold in some superstores in Korea. Rice in storage respires by consuming nourishment. As white rice with embryo has more nutrients, enzymes, and fibres than normal white rice (Houston, 1972), many consumers are attracted by white rice with embryo in market surveys. However, the embryos of white rice are easily deteriorated due to high temperature in hot seasons. Even mildews and insects are sometimes found in white rice. Non-vacuum packaging not only shortens the shelf-life of rice products but also decreases the rice quality because chemical components such as carbohydrate and fat in rice are dissolved and oxidised, and consequently free fatty acid and various organic acids are generated during the storage period. It is widely known that vacuum packaging can prolong the shelf-life of agricultural products and maintain their quality and freshness because it can attenuate their biological respiration rate (Hosokawa *et al*., 1995; Murcia *et al*., 2003).

Preventing insect pests in rice products is one of the important factors in producing high-quality rice. Stored-product insects, which outbreak in high temperature and humidity, are usually found in rice products. They are Indian meal moth (larval period), lesser grain borer, and rice weevil. Vacuum packaging is one of the effective physical methods of insect control. Dendy and Elkington studied that the lack of oxygen in hermetic storage was the major cause of insect death (Calderon & Barkai-Golan, 1990).

In this study, an automatic vacuum packer designed with virtual prototyping technology (Yan *et al*., 2003; Erdman *et al*., 2001) to prolong the shelf-life of white rice with embryo was manufactured and evaluated. The specific objectives of this research were: (1) to manufacture an automatic vacuum packer of continuous; (2) to conduct packing tests for evaluating the performance of the vacuum packer; (3) to analyse the relationship between vacuum time and vacuum level at different pouch sizes; (4) to investigate the preservation effects of vacuum packaging on white rice with embryo in physical and chemical changes.

2. Materials and method

2.1. *Development of a vacuum packer*

The function of the proposed vacuum packer was to remove the air from a pouch of rice by a needle in a short time and to seal the vacuum hole with a piece of transparent tape quickly. The vacuum packer (*Fig. 1*) consisted of the following three assemblies was designed and manufactured: (1) a pressing board assembly that accelerates the air removing process; (2) a vibrating conveyor assembly that shapes the vacuum-packed rice products for a good appearance; and (3) a tape adhering assembly that puts a transparent 5 cm by 3 cm tape piece on a pouch. All the moving parts of the vacuum packer were operated according to the developed control algorithm (*Fig. 2*) of a programmable logical controller (PLC) of the vacuum packer. The acting sequence for the vacuum packer was also designed. The vacuum packer was designed to pack cereal products of various sizes according to vacuum time, shape-forming time, and the intended position of the vacuum-hole on a pouch. The vacuum time and shape-forming time of the

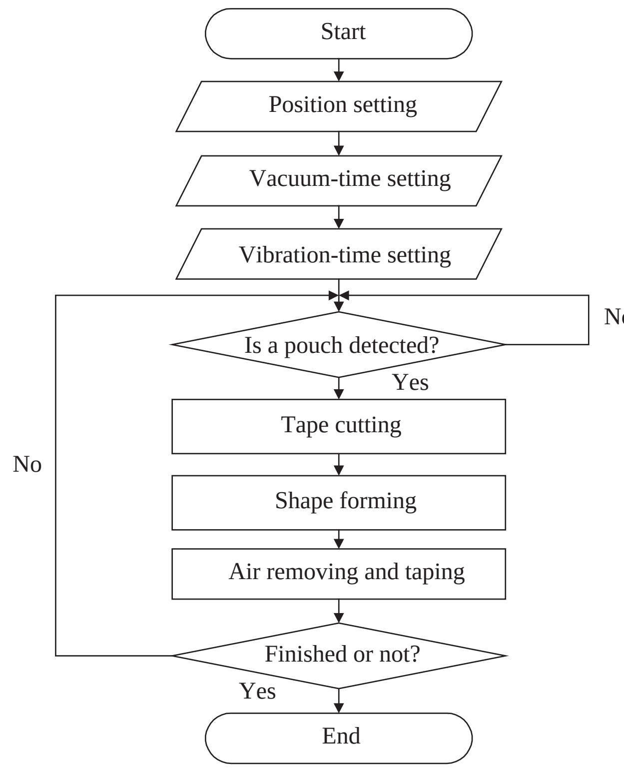

Fig. 2. Control algorithm of an automatic vacuum packer

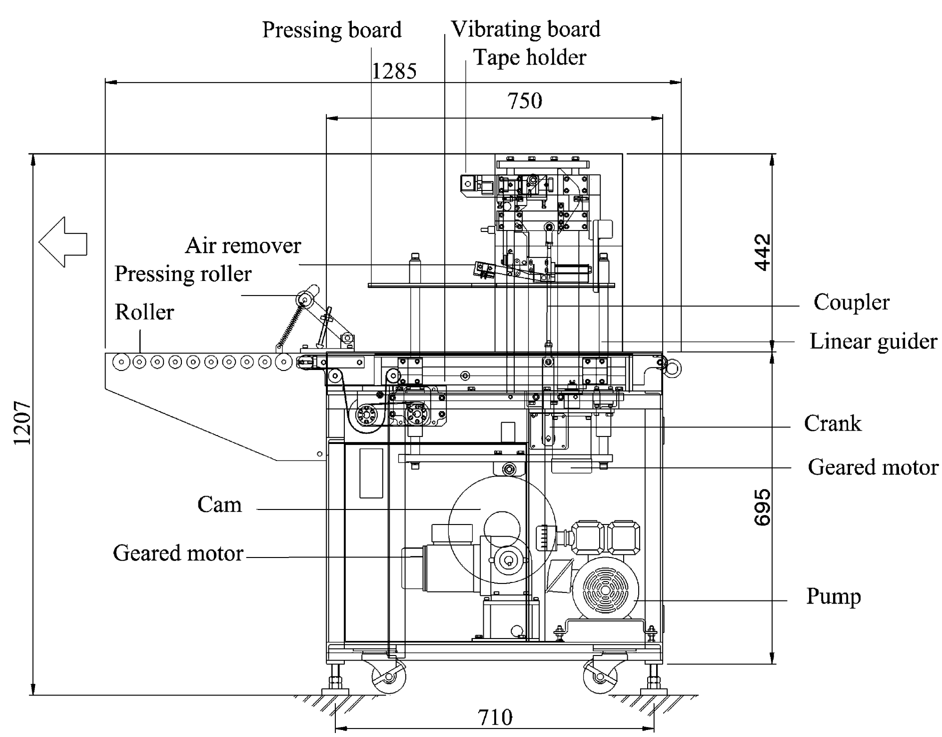

Fig. 1. The configuration of an automatic vacuum packer; all dimensions in mm

vacuum packer were controlled with an accuracy of 0·01 s. As modified atmosphere packaging can prolong the shelf-life of agricultural products, the function of gas filling was embedded in the proposed automatic vacuum packer. The gas-filling time of the developed packer was adjusted with an accuracy of 0·01 s. This study mainly covers the effects of vacuum packaging on white rice with embryo as chemical experiments related to gas filling were not finished.

2.1.1. *Pressing board assembly*

The pressing board assembly consisted of a cam–follower mechanism shown in *Fig. 3*. The follower of the cam mechanism was a roller-type follower. It was driven by a 0·1 kW geared motor with a reduction rate of 1:25 (model GM-H2B-RL, Mitsubishi Co., Japan). The cam was pivoted with the output shaft of the motor. As the shaft of the geared motor rotates, the pressing board undergoes an up-down translational movement. When the thickness of a pouch was too large, the cam and the follower were disconnected each other to suit different sized pouches. The 550 mm by 280 mm rectangular pressing board was utilised to accelerate the air removing speed. A 3 mm thick rubber plate with the same shape of the pressing board was attached to its down surface to protect the packaging film of a pouch during the vibrating process for shape forming. The pressing board was screwed onto two supports that mounted on two 522 mm linear motion guides.

2.1.2. *Vibrating conveyor assembly*

A vibrating conveyor (*Fig. 4*) mounted on two linear guides was used to make the vacuum-packed rice in shape for its commercial value. The air in the pouch was removed by a needle during the vibrating. The vibrating conveyor assembly was also a cam–follower mechanism. The eccentricity of the cam mechanism was 1 mm. A 90 W induction motor (model 51K91A-SF, Oriental Motor Co., Japan) was used to drive the vibrating board assembly. Another 90 W geared motor with a reduction rate of 1:10 (model GM-JB, Mitsubishi Co., Japan) was used to drive the belt conveyor for transferring pouches to a proper position. As soon as a pouch is positioned properly, the motor for driving the vibrating board starts to shape the pouch on the belt for a set time.

2.1.3. *Tape adhering assembly*

The tape adhering assembly had a slider–crank mechanism. The schematic view of this mechanism is shown in *Fig. 5*. The tape adhering assembly consisted of a tape holder containing 24 tiny holes of 1 mm in

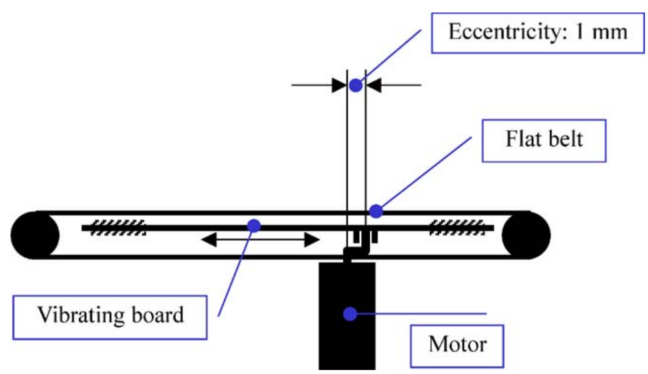

Fig. 4. Schematic view of the vibrating board assembly

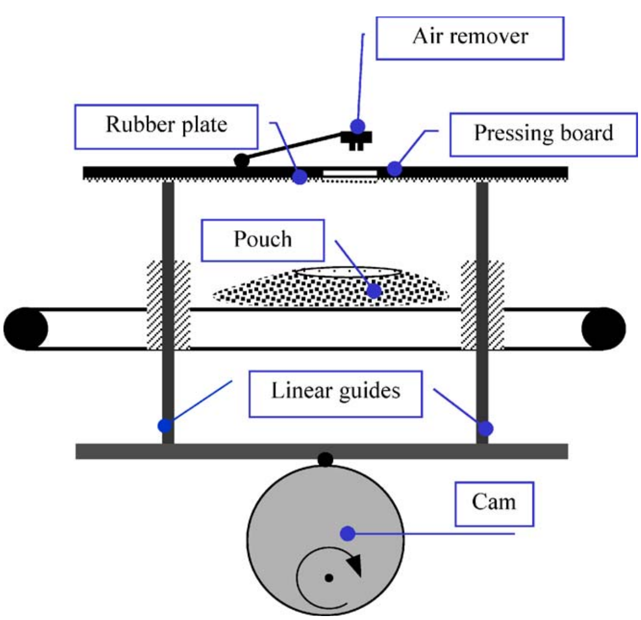

Fig. 3. Schematic view of the pressing board assembly

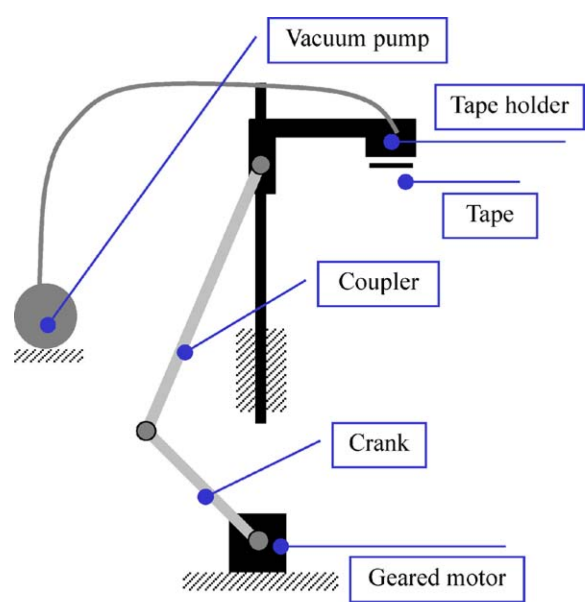

Fig. 5. Schematic view of the tape adhering assembly

diameter, a 170 mm long crank, a 300 mm long coupler, and a 25 W geared motor with a reduction rate of 1:50 (model GM-JB, Mitsubishi Co., Japan). The crank was pivoted with the shaft of the motor. The coupler was pivoted with the crank and the tape holder through two revolute joints. The tape holder was mounted on two linear guides through two prismatic joints. As the motor shaft rotates, the tape holder performs an up-down linear movement for tape adhering. When a rice pouch is too thick, then the tape holder can be separated into two parts to adjust it to different sized pouches. The geared motor was used to drive the slider–crank mechanism. As a flexible plastic hose was used to connect the tape holder to a vacuum pump (model KRX3-SS-4001-G3, Orion Machinery Co., Japan) through a solenoid valve, The tape holder could tightly hold a piece of transparent tape supplied by an electronic tape dispenser during a taping operation.

2.2. *Performance experiments*

White rice with embryo was produced at a rice mill of Chonnam National University. The milled white rice with embryo adherence rate of 52% and moisture content of 16·1% (w.b.) was used as experimental materials. The material was pre-packaged in 5 kg pouches with the film of nylon (15 μm)/polyethylene (95 μm) using an automatic vinyl packer. One hundred and eight vacuum-packed pouches of white rice with embryo were randomly selected to investigate the performance of the vacuum packer. The 108 pouches were left alone for 1 day for discriminating the pouches that were unsuccessfully packaged by the vacuum packer.

Among the 108 pouches, 100 pouches were successfully vacuum-packed (55·3 ± 0·293 kPa). Eight vacuum-packed pouches and one non-vacuum-packed pouch were randomly chosen and stored at 25 °C to investigate the effects of vacuum packaging on the moisture content, whiteness, peroxide value, and acid value. Five vacuum-packed pouches initially contaminated by the three kinds of insects were chosen for an insect control experiment to evaluate the effect of vacuum packaging on insect control. The insects alive in each pouch were counted before the experiment. The number of the initial insects in each pouch ranged from 5 to 20.

The developed vacuum packer was tested to pack pouches of 2 kg (pouch size of 25 cm by 30 cm), 3 kg (pouch size of 30 cm by 35 cm), and 5 kg (pouch size of 30 cm by 45 cm). The relationship between vacuum level and vacuum time at the different pouches was investigated to improve the productivity and efficiency of the vacuum packer.

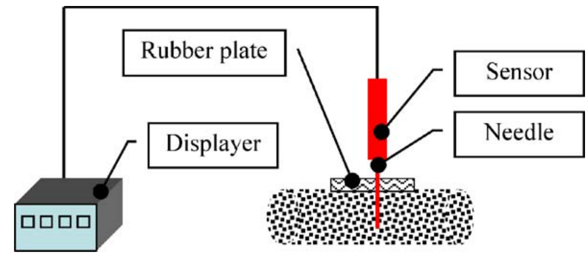

Fig. 6. The measurement of the vacuum level in a pouch

2.2.1. *Measurement of vacuum level*

A digital vacuum gauge (model KVC-700, range 0·13–199 kPa, Vacuum Research Co., USA) with ±13·33 Pa accuracy was used to measure the vacuum level in a pouch. The digital vacuum gauge consisted of a 16-bit analogue-to-digital converter, a sensor of diaphragm type, a 4-bit digital displayer, and a needle. A piece of 5 cm by 5 cm by 0·5 cm rubber plate was pressed on the pouch to be measured to prevent air leakage as shown in Fig. 6.

2.2.2. *Measurement of whiteness*

The whiteness of the samples for the storage experiment was measured using a whiteness meter (model C-300-3, Kett Electric Laboratory, Japan). Before each measurement, the whiteness meter was calibrated using a standard whiteness disk provided by the manufacturer.

2.2.3. *Measurements of peroxide value and acid value*

The peroxide value is a common measure that indicates the degree of oxidation of white rice with embryo, *i.e.* the amount of peroxides in the white rice with embryo by determining the milliequivalents (meq) of active oxygen per kilogramme of fat. The peroxide value was determined using the method of AOCS Cd 8-53 (AOCS, 1973). The acid value is the amount of free acid present in fat as measured by the milligrams of potassium hydroxide needed to neutralise it. The acid value was measured by the method of AOCS Cd 3a-63 (AOCS, 1973).

2.2.4. *Measurement of moisture content*

The moisture content of white rice is considered as a factor that directly related to the taste of cooked rice. The change of moisture content of the vacuum-packed white rice with embryo was investigated during the storage period. A moisture meter (model Riceter K305, Kett Electric Laboratory, Japan) with an accuracy of ±0·1%, was used for measuring the moisture content.

3. Results and discussion

3.1. *Development of an automatic vacuum packer of continuous type*

An automatic vacuum packer of the continuous type was designed with virtual prototyping and manufactured with a PLC control system (*Fig. 7*). An acting sequence for the developed vacuum packer is shown in *Fig. 8*. The maximum capacity of the vacuum packer was 6 pouches min^{-1} when packing 5 kg rice pouches. The vacuum packer could be set according to vacuum time for removing air, vibrating time for forming shape, and pouch position on the belt. Among the 108 pouches of rice products produced by the developed packer, 100 pouches were vacuum-packed successfully, and the other eight pouches failed. The failure of vacuum packaging could be classified into type I and type II failures. The type I failure was caused by an inappropriate taping of the automatic vacuum packer. The unsuccessful sealing of a vinyl packer, on the other hand, caused the type II failure. Among the failed eight pouches, six pouches were categorised to the type I failure and other two pouches to the type II failure. Through this experiment, it was observed that the success rate, type I failure rate, and type II failure rate were 92·6, 5·6, and 3·7%, respectively.

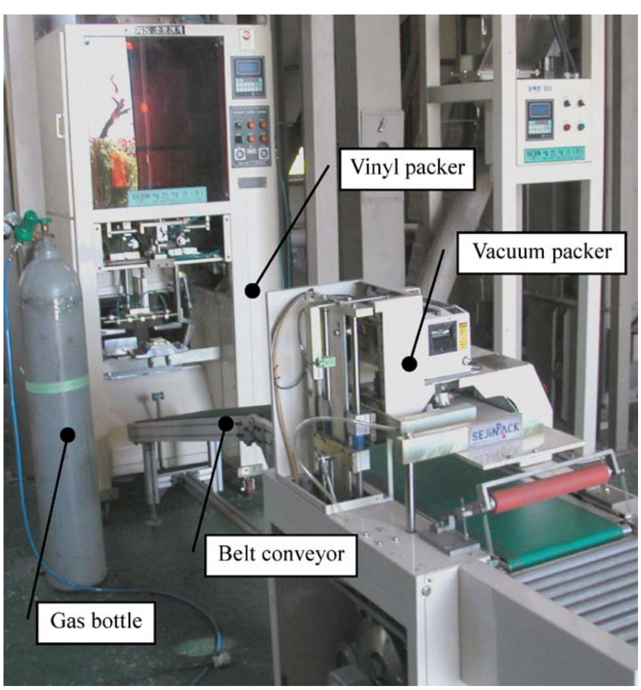

Fig. 7. The changes of acid values of differently packed white rice with embryo: ●, vacuum-packed white rice with embryo; ■, non-vacuum-packed white rice with embryo

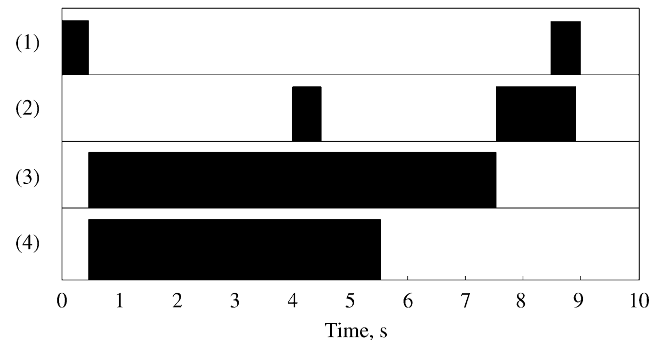

Fig. 8. The flowchart of acting sequence for an automatic vacuum packer; (1) motor for driving the pressing board assembly; (2) motor for driving the taping assembly; (3) vacuuming time; (4) motor for driving the vibrating assembly

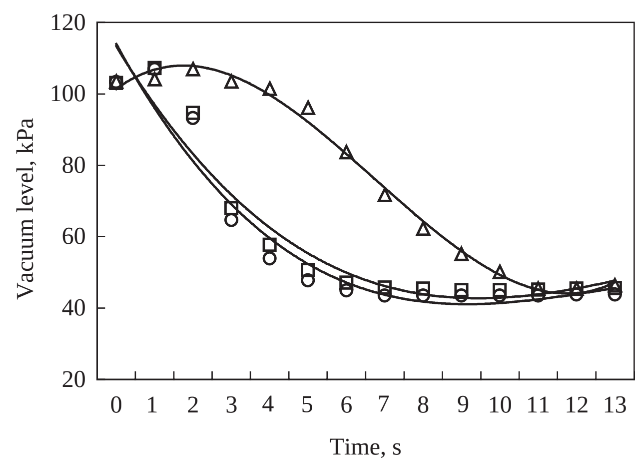

Fig. 9. Relationship between vacuum level and vacuum time at differently sized pouches: ○, 2 kg; □, 3 kg; △, 5 kg

3.2. *Relationship between vacuum time and vacuum level*

The relationship between vacuum level and vacuum time at pouches of different sizes was investigated as shown in *Fig. 9*. During the beginning period of vacuum packaging, the air pressures in pouches increased to certain extent due to the pressing effect of the pressing board. The maximum air pressures in 2, 3, and 5 kg pouches were 106·9 kPa, 107·2 kPa, and 106·9 kpa, respectively. As the air removing process continued, the vacuum levels in the pouches decreased gradually. When the vacuum time was 11 s, the vacuum level of a 5 kg pouch reached to the minimum value of 45·4 kPa. In the cases of 2 and 3 kg pouches, the minimum vacuum levels of 43·3 kPa and 45·1 kPa reached in 6 s and 8 s, respectively.

3.3. *Whiteness of white rice*

For both the vacuum-packed and the non-vacuum-packed rice, it was shown that the longer the storage

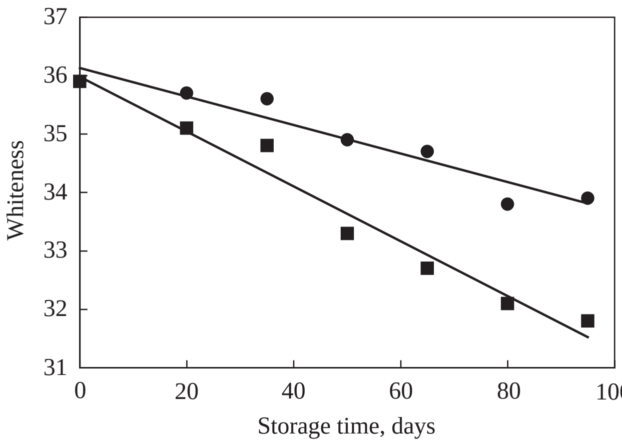

Fig. 10. The changes of whiteness of differently packed white rice with embryo: ●, vacuum-packed white rice with embryo; ■, non-vacuum-packed white rice with embryo

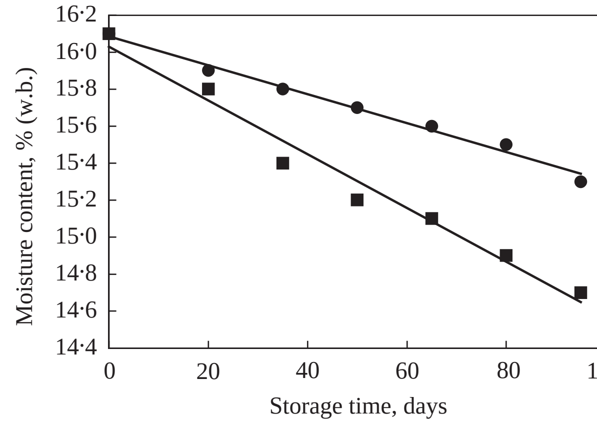

Fig. 11. The changes of moisture content (w.b.) of the vacuum-packed and non-vacuum-packed white rice with embryo: ●, vacuum-packed white rice with embryo; ■, non-vacuum-packed white rice with embryo

time was, the more the whiteness of milled rice decreased (*Fig. 10*). The whiteness of the vacuum-packed and non-vacuum-packed rice rapidly decreased from the original whiteness of 35·9 to the values of 33·9 and 31·9, respectively, in 95 days. However, the whiteness of the non-vacuum-packed rice decreased more rapidly than that of the vacuum-packed rice. It is mainly due to the fact that the non-vacuum-packed rice was exposed to oxygen, which accelerated the whiteness change. In contrast, the whiteness of the vacuum-packed rice changed moderately. An equation for the whiteness of the vacuum-packed rice *versus* storage time was expressed as

$$W_v = -0{\cdot}024t + 36{\cdot}13 \tag{1}$$

where: W_v is the whiteness of the vacuum-packed rice; t is storage time in days; The coefficient of determination is 0·923. Another equation for the whiteness of the non-vacuum-packed *versus* storage time was presented as

$$W_n = -0{\cdot}047t + 35{\cdot}98 \tag{2}$$

where, W_n is the whiteness of the non-vacuum-packed rice. The coefficient of determination is 0·968.

3.4. *Moisture content*

The moisture content of the vacuum-packed samples decreased slowly during the experimental period, but the moisture content of the non-vacuum-packed rice decreased rapidly. The moisture content of the vacuum-packed rice decreased form 16·1 to 15·3%, while the moisture content of the non-vacuum-packed rice quickly decreased from 16·1 to 14·8%. The changes of the moisture content of the samples are shown in *Fig. 11*. An equation for the change of moisture content of vacuum-packed rice *versus* storage time was

$$M_v = -0{\cdot}0078t + 16{\cdot}09 \tag{3}$$

where M_v is the moisture content of the vacuum-packed rice in % (w.b.). The coefficient of determination is 0·988. The equation expressing the change of moisture content of the non-vacuum-packed rice *versus* storage time was

$$M_n = -0{\cdot}0145t + 16{\cdot}03 \tag{4}$$

where M_n is the moisture content of the non-vacuum-packed rice in % (w.b.). The coefficient of determination is 0·974.

3.5. *Peroxide value*

Unfavourable smells were sensed in the non-vacuum-packed sample, and moulds were found on the surface of rice kernels in 45 days. The peroxide values *versus* storage time are shown in *Fig. 12*. The peroxide value of the vacuum-packed rice increased slightly, 1·89 meq kg^{-1}, over the entire experimental period. However, the peroxide value of the non-vacuum-packed rice increased to 10·22 meq kg^{-1} rapidly until the 80th day in storage and then dropped moderately to 6·67 meq kg^{-1}. The shelf-life of the vacuum-packed rice using the vacuum packer was relatively prolonged. Two equations for the peroxide values of the vacuum-packed rice and the non-vacuum-packed rice *versus* storage time were

$$P_n = -0{\cdot}3943t^2 + 3{\cdot}1186t + 3{\cdot}75 \tag{5}$$

and

$$P_v = -0{\cdot}1193t^2 + 1{\cdot}1853t + 4{\cdot}104 \tag{6}$$

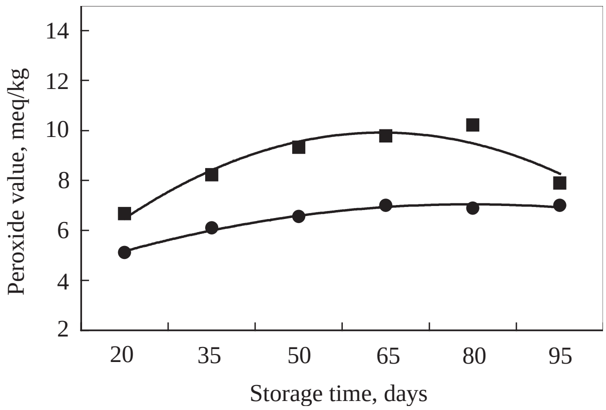

Fig. 12. The changes of peroxide values of differently packed white rice with embryo: ●, vacuum-packed white rice with embryo; ■, non-vacuum-packed white rice with embryo

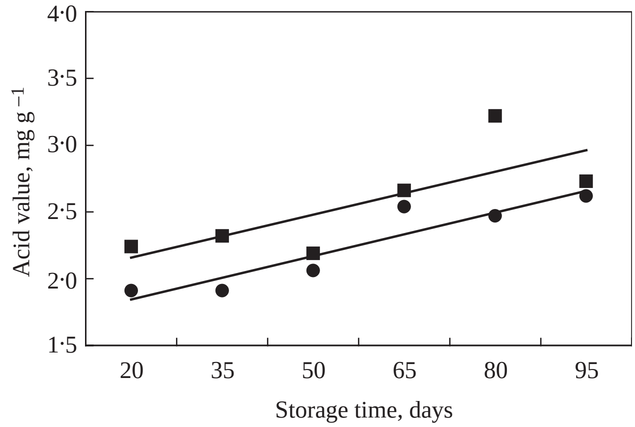

Fig. 13. The changes of acid values of differently packed white rice with embryo: ●, vacuum-packed white rice with embryo; ■, non-vacuum-packed white rice with embryo

where: P_v is the peroxide value of the vacuum-packed rice in meq kg^{-1}; and P_n is the peroxide value of the non-vacuum-packed rice in meq kg^{-1}. The coefficients of determination of Eqns (5) and (6) are 0·907 and 0·982, respectively.

3.6. *Acid value*

The relationship of the acid values *versus* storage time is shown in *Fig. 13*. The acid values increased consistently until the end of the storage experiment, but the acid value of the non-vacuum-packed sample increased more rapidly than the value of the vacuum-packed samples. The maximum acid values of the vacuum-packed and non-vacuum-packed rice were 2·62 and 3·22 mg g^{-1}, respectively. During the 3-month storage time, the acid values of the vacuum-packed and non-vacuum-packed rice increased by 0·71 and 0·98 mg g^{-1}, respectively. The change of the acid value of the vacuum-packed rice *versus* storage time was expressed as follows:

$$A_v = 0{\cdot}1636t + 1{\cdot}6807 \quad (7)$$

where A_v is the acid value of the vacuum-packed rice in mg g^{-1}. The coefficient of determination R^2 is 0·868.

The change of the acid value of the non-vacuum-packed rice *versus* storage time was expressed as follows:

$$A_n = 0{\cdot}1606t + 1{\cdot}998 \quad (8)$$

where A_n is the acid value of the non-vacuum-packed rice in mg g^{-1}. The coefficient of determination R^2 is 0·585.

3.7. *Insect control*

The effect of vacuum packaging on insect control was analysed by counting the number of the insects suffocated in each sample in 15 days after packing rice. It was found that all the insects in the pre-contaminated five samples were dead owing to lack of oxygen. It proved that vacuum packaging was very effective in insect control during the storage of market.

4. Conclusions

In this study, an automatic vacuum packer was especially developed to prolong the shelf-life and to maintain the freshness of white rice with embryo. The success rate of the packaging tests was 92·6%. The relationship between vacuum level and vacuum time at different pouch sizes was investigated for improving the productivity of the vacuum packer. It was found that it took 6, 8, 11 s to reach the minimum vacuum levels when packaging 2, 3, and 5 kg pouches. The whiteness of the non-vacuum-packed and vacuum-packed samples decreased by 4 and 2, respectively. The moisture content of the non-vacuum-packed and vacuum-packed samples decreased by 1·3 and 0·8% (w.b.), respectively. The peroxide value of the non-vacuum-packed sample increased by 3·45 meq kg^{-1} and then dropped moderately, but the peroxide value of the vacuum-packed samples increased continuously by 1·89 meq kg^{-1}. The acid values of the non-vacuum-packed and vacuum-packed samples increased by 0·98 and 0·71 mg g^{-1}, respectively. From the changes of whiteness, moisture content, and peroxide value of the vacuum-packed white rice with embryo, it was found the shelf-life of the vacuum-packed white rice with embryo was increased. In addition to the above effects, the vacuum packaging preserved rice quality by preventing the insect's development in the pouch.

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