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# Potential Evaluation of Wood–based Activated Carbon Fibers as Functional Desiccant for High/Intermediate/Low Water Activity Food

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This study used both Wood–Based Activated Carbon Fibers (WACFs) and made them into Wood–Based Activated Carbon Fibers Paperboard (WACFP) to investigate the feasibility of characteristic as functional food desiccant for High/Intermediate/Low Water Activity Food (HAwF/MAwF/LAwF) in a High/Low Humidity Environment System (HHES/LHES). The water activity (Aw) and percent weight (%) of HAwF/MAwF/LAwF with WACFs and WACFP increased in the HHES, the Aw variation of MAwF was gentler than that of HAwF and LAwF, and there was no significant difference in the moisture content uniformity of HAwF, MAwF, and LAwF when WACFP was used as desiccant. In a LHES, the Aw and percent weight of HAwF and MAwF decreased when WACFs and WACFP were used, but LAwF exhibited the reverse, and when the WACFs and WACFP were used respectively, there was no significant difference in the moisture content uniformity of HAwF, MAwF, and LAwF. The WACFs and WACFP had a better effect on the stability of MAwF and LAwF than that of HAwF in the HHES/LHES. Therefore, the WACFs and WACFP have more potential as food desiccants for different Aw foods.

**Key words**: Wood–Based Activated Carbon Fibers (WACFs), Wood–Based Activated Carbon Fibers Paperboard (WACFP), Water Activity (Aw), High/Intermediate/Low Water Activity Food (HAwF/MAwF/LAwF), Moisture Content Uniformity

## INTRODUCTION

The statistical database of the Environmental Protection Administration, Executive Yuan (2016) indicates that the average annual quantity of waste of Taiwan was about 10 570 000 tons/year during 2013–2015, with agricultural and forestry wastes, such as wood, bamboos, straws, and leaves, accounting for about 33%. Waste paper is about 16% and is mostly used for making recycled paper. However, if agriculture and forestry and paper wastes can evolve into high value–added products/materials, such as biomass energy, agricultural biochar, and other recycled products, then the quantity of wastes as well as the pollution resulting from incineration treatment can be reduced.

There are numerous kinds of precursors for preparing Wood–Based Activated Carbon Fibers (WACFs), such as wood/bamboo, waste paper, and coconut shell. Huang *et al*. (2010) use wood pulp as a precursor, which is made into WACFs by steam activation, which has the natural fiber and surface pore structure of wood and can be used as gas/liquid adsorbing material. Lin *et al*. (2015 a) report that the WACFs prepare at activation temperature 800°C and steam flow 300 mL/h have better yield and iodine value and are free of cytotoxicity and mutagenicity according to Ames test results. Lin *et al*. (2015 b) indicate that the WACFs produced no systematic poison for the 28–day feeding study of Sprague–Dawley rats, and was in the dose range, 1.0, 2.5, and 5.0 g/kg/day, of biological safety assessment. Moreover, The Aw of WACFs is 0.50–0.60 (Huang *et al*., 2010; Liou, 2012), and the iodine value increases and the percent weight of WACFP are relatively stable with the addition weight (%) of WACFs (Lee *et al*., 2016; Lin *et al*., 2017). The WACFs are presented in Type IV, and the monolayer and multilayer adsorption phenomena are generated in the pore wall (Lin *et al*., 2017), according to Brunauer–Deming–Deming–Teller (BDDT) classification (Gregg and Sing, 1982). Therefore, the WACFs have the potential to be developed into functional food desiccant.

Food storage duration is significantly correlated with water activity (Aw); as Aw represents the free water in food, which is defined as the ratio of the equilibrium vapor pressure of food (P) to the saturated vapor pressure of pure water at the same temperature ($P_o$), i.e. $Aw=P/P_o$. When food Aw is 0.0–1.0, they are high Aw foods (HAwF, >0.9), such as: fresh fruits and vegetables, fish and so on; intermediate Aw foods (MAwF, 0.6–0.9), such as: dried meat, preserves, etc and low Aw foods (LAwF, <0.6), such as: rice, dried grains, etc (Nicolau and Turtoi, 2006; Fontana, 2008). Besides, Silica gel and calcium oxide (CaO) mainly use for the commercial food desiccant in Taiwan, but the appearance of silica gel is a transparent particle which can be eaten as crystal sugar, possibly resulting in uncomfortable pain, and for CaO it is white or gray–white with toxicity, that, if eaten, results in an illness of the intestines and stomach (National Poison Center, 1990).

This study therefore used wood waste resource

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(sawdust) and waste paper (kraft carton) as the precursors and prepared WACFs by physical activation at activation temperature 800˚C with different steam flow, which were made into WACFP. The Aw of WACFs and WACFP were evaluated according to the CNS 5255 food Aw determination method. The packing material–sealed bag for HAwF/MAwF/LAwF was put in WACFs and WACFP, respectively, and the environmental system at relative humidity 90 or 40% and temperature 25˚C is simulated in order to investigate the Aw, color difference, and percent weight for evaluating the moisture–proof potential of WACFs and WACFP with different Aw foods in the High/Low Humidity Environment System.

## MATERIALS AND METHODS

### Test materials

1. *Leucaena leucocephala* sawdust was from Wood Working Factory, National Chiayi University, Taiwan.
2. Waste kraft carton (excluding printed portion) recycled from Wood Working Factory, National Chiayi University, Taiwan. The specimen from waste kraft carton with dimensions of 10 mm × 10 mm was prepared and then defibrillated by a grinder to be used as the precursor. The basic properties and morphological characteristics of the specimens refer to (Huang, *et al.*, 2010; Liou, 2012).
3. Sealed bag (OYN/PE) was offered from Great & Power Top Co., Ltd, Chiayi, Taiwan.
4. Water activity foods (AwFs): toast, cotton candy, and rice cracker as high, intermediate, and low Aw food (HAwF, MAwF, and LAwF), which were bought from Nabeisi Bread, Chiayi, Taiwan.

### Experimental

*Preparation of Wood–based activated carbon fibers (WACFs)*

The sawdust and kraft carton, 60 g of absolute dried specimen, was carbonized in a closed container of super–high temperature vacuum carbonization activation equipment (Chi–How Heating Co., Ltd.) for the first stage at nitrogen flow 200 mL/min, carbonization temperature of 800˚C, and heating rate 10˚C/min. Afterthat, Stage II activation was implemented at steam flow 90, 120 and 300 mL/h and activation temperature of 800˚C for 60 min. Finally, it was cooled at nitrogen flow 200 mL/min for 4 h, and removed at normal temperature to obtain WACFs. (Huang *et al.*, 2010; Wu, *et al.*, 2010; Lin *et al.*, 2015a, b, Lee *et al.*, 2016; Lin *et al.*, 2016; Lin *et al.*, 2017). The specimen code with different steam flow is L–90, L–120 and L–300 for *Leucaena leucocephala* sawdust; R–90, R–120 and R–300 for waste kraft carton.

*Yield and Iodine value of WACFs*

The equation for the WACFs yield (Y) is Y (%) = (absolute dry weight of WACFs / absolute dry weight of sawdust or kraft carton) × 100. The iodine values of the WACFs were measured according to the Japanese Industrial Standard (JIS) K 1474 (1991) Test Methods for Activated Carbon. The formula for iodine value is: $I = [(10 - K \times f) \times 12.69 \times 5] / M$. The abbreviations for the formula are I: iodine adsorption capacity (mg/g); K: the volume of titrated sodium thiosulfate (mL); f: the ratio of 0.1 N sodium thiosulfate to 0.1 N iodine solution, and M: the weight of absolute dried WACFs (0.5 g).

*Making method of Wood–based activated carbon fibers paperboard (WACFP)*

Referring to the making method of Lin *et al.* (2015a; 2017), the basis weight of WACFP was 360 g/m$^2$ by using the method of Beating Chinese National Standards (CNS) 12495 combined with the method of preparation of handsheets CNS 11212. During the method of CNS 12495, the waste kraft carton specimen was mixed with 40% WACFs by weight (%), made by a cylinder paper machine with the CNS11212 method of preparation of handsheets.

*Determination of Aw of WACFs, WACFP, and various Aw foods*

Aw of WACFs, WACFP, and all twst types of HAwF, MAwF, and LAwF specimens was determined according to CNS5225 Food Water Activity Determination, respectively. The food Aw>0.9 is HAwF; the Aw 0.6–0.9 is MAwF; Aw <0.6 is LAwF (Nicolau and Turtoi, 2006; Fontana, 2008).

*Hygroscopic ability of WACFs and WACFP*

About 1 g of air–dried WACFs and WACFP were placed in the programmable constant temperature and humidity machine (TERCHY HRM, Taiwan), the hygroscopicity test was implemented at relative humidity (RH) 90 or 40% and the temperature of 25˚C, the weights were measured at 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 6.0, 12.0, and 24.0 h, and measured once every 12 h, then the percent weight was calculated till the moisture equilibrium (about 120 h). The computing equation is maximum percent weight (%) = [(WACFs or WACFP weight – air–dried weight of WACFs or WACFP) / air–dried weight of WACFs or WACFP] × 100 (Wu *et al.*, 2010; Lin *et al.*, 2015a; b; 2017).

*Tests for WACFs and WACFP as gas/liquid adsorbing material in food*

This test is designed by the Laboratory of Environmental Functional Materials, Department of Wood–Based Materials, National Chiayi University in Taiwan, where different functional food desiccant is WACF and WACFP, and place in tightly sealed bags (ONY/PE) together with HAwF, MAwF, and LAwF, and then seal by a capper, respectively. The HAwF, MAwF, and LAwF (without WACFs or WACFP, that is; Aw foods only) were used as the control groups (Blank), placed in the environmental systems at the temperature of 25˚C with either RH 90/40% (HHES/LHES). Basically, all specimens were tested once every 6 h till the test food became moldy according to visual observation. The test items were the Aw, color difference change, and percent weight. The Aw and color differences change investigated the changes in food state. The WACFs and WACFP were tested according to percent weight to evaluate the adsorption and desorption results of various Aw foods at different RH. HAwF, MAwF and LAwF are placed in the specimen (the functional food desiccant – WACFs and WACFP) code are such as HAwFWACFs and HAwFWACFP, as well as the same to MAwF and LawF. The control group is Blank (without WACFs or AwF only) that is showed by HAwF, MAwF and LAwF.

*Determination of color difference (ΔE*) change*

As above, the ΔE* of various AwFs in different environmental systems were determined at the same duration as Aw determination. The ΔE* of various food specimens was determined by a color difference meter (ZE–2000 color meter, Nippon Denshoku, Tokyo). The results are represented by L*, a*, b* and the calculated $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (Macdougall, 2010).

*Determination of percent weight*

When the Aw and the ΔE* were determined, the weight changes of various AwFs, WACFs and WACFP were evaluated, and represented by the percent weight, respectively. The equation is percent weight (%) = [(specimen weight – air–dried weight of specimen) / air–dried weight of specimen] * 100 (Lin *et al.*, 2015a; b; 2017).

*Analysis of food moisture content uniformity*

According to the test results of HAwF/MAwF/LAwF with WACFs and WACFP, this test weighed HAwF, MAwF, and LAwF and equally divided HAwF into 4 pieces, equally divided MAwF into 3 pieces, and equally divided LAwF into 4 pieces. Various AwFs were absolutely dried in an oven (105˚C), and the moisture content of each piece was calculated, so as to evaluate the effect of WACFs and WACFP on the moisture content uniformity of HAwF/MAwF/LAwF. The equation is moisture content (%) = [(air–dry weight of piece – absolutely dry piece weight) / absolute dry weight of piece]*100.

**Statistical analysis**

The test results of color difference and moisture content uniformity are represented by a mean (standard deviation), and the control group (Blank) and test group are compared by Duncan's multiple range analysis. If the $\rho$ value is smaller than 0.05, meaning a significant difference between the test group and the Blank, it is represented by different superscript upper case letters. Besides, the results of hygroscopic ability, Aw, and percent weight are linearly regressed by Plots 32 software to judge the trends.

## RESULTS AND DISCUSSION

**Yield and iodine value of WACFs**

Referring to Lin *et al.* (2015a), the WACFs prepare at activation temperature 800˚C and steam flow 300 mL/h have better yield and iodine value. This study used *Leucaenal eucocephala* sawdust and waste kraft carton as the precursors of WACFs. According to the yield and iodine value of WACFs prepared at different steam flow, the yield range was about 20–28%, and the yields of *Leucaenal eucocephala* sawdust and waste kraft carton at 300 mL/h of steam flow were 24.15% and 20.37% respectively (results no show in Table), which were lower among the preparation conditions, but the iodine value increased with the steam activation flow. It is said that the activated carbon has better porosity as the flow increases (Lua and Guo, 2000; Yun *et al.*, 2001; Wu *et al.*, 2010; Lin *et al.*, 2017). As the yield 24.15% and iodine value 430.62 mg/g of the WACFs (L–300) prepared from *Leucaenal eucocephala* sawdust were better than those from waste kraft carton, L–300 was used as the specimen and made into WACFP for the follow evaluations.

**Hygroscopic ability of WACFs and WACFP**

The performance of Aw extremely correlates with food storage time, not only influencing the moisture transfer between food and outside air, but also influencing microbial growth and reproduction. Different microorganisms have a limiting Aw, as a microorganism lower than this limiting value cannot grow (Beuchat, 1981; Robertson, 2005; Chang *et al.*, 2006; Powitz, 2007).

The hygroscopic ability of WACFs and WACFP at RH 90 and 40% and temperature 25˚C indicated that at RH 90%, the hygroscopic curve of WACFs and WACFP reached a peak at about 72 h, the maximum percent weight was increased by 2.5–5.0%, and the correlation coefficient ($r^2$) was 0.85–0.93 (results no show in Figure). At RH 40%, the maximum percent weight of WACFs was increased by about 60%, and the $r^2$ was 0.23–0.66, whereas there was little change in the maximum percent weight of WACFP. This suggests that the WACFs and WACFP can influence the hygroscopic ability, meaning the main cause for moisture absorption and desorption phenomena.

For the above results, as Aw reaches equilibrium with the RH of air, the Aw of WACFs and WACFP is close to the ambient RH, then there will not be moisture absorption and desorption phenomena (Gowen, 2012). In other words, there will be moisture absorption phenomenon when Aw is lower than ambient RH, and there will be moisture desorption phenomenon when it is higher than ambient RH. The WACFs and WACFP; therefore, can be regarded as a kind of moisture–proof material with moisture adsorption and desorption properties as the ambient RH changes (Lin *et al.*, 2015a; 2017).

**Aw of WACFs, WACFP, and various Aw foods**

The food storage time is highly correlated with Aw. As microbial growth and reproduction are mainly controlled by moisture content, the range of Aw can be regarded as the situation of food spoilage. The limiting Aw for the growth of bacteria, yeast, fungi, halophilic bacteria, xerophilic bacteria, and osmotolerant yeast is respectively 0.90, 0.87, 0.80, 0.72, 0.62, and 0.60, where the Aw lower than 0.60 is unsuitable for microbial growth and storage life is relatively longer (Nicolau and Turtoi, 2006). The Aw results of WACFP, WACFs, and HAwF/MAwF/LAwF indicated that the Aw of WACFP, WACFs, and MAwF/LawF was 0.58, 0.45, 0.50, and 0.38, respectively (results no show in Table), which were all lower than 0.60 and lower than the Aw for the growth of all microorganisms. The Aw of toast was 0.96. It is indicated that toast is a high moisture food (0.90–1.00) (Gowen *et al*., 2007; Fontana, 2008). Therefore, this study regards toast, cotton candy, and rice cracker as HAwF, MAwF, and LawF, respectively. The Aw for various AwF in this study are close to previous report (Lin *et al*., 2017).

## Evaluation of food in WACFs and WACFP

*Aw variation*

The moisture in food is divided into free water and bound water. The amount of free water is the magnitude of Aw, as well as one of the indices for testing food preservation (Maltini *et al*., 2003; Sandulachi, 2012). Figure 1 showed the Aw variation of HAwF, MAwF, and LAwF when the WACFs and WACFP were used in either HHES or LHES. The HAwF, MAwF and LAwF were toast, cotton candy, and rice cracker, respectively, representing HAwF/MAwF/LAwF. In a HHES, there was little change in the Aw of HAwsF and MAwF with WACFs and WACFP, and the Aw of the Blank (food only: HAwF and MAwF) increased slightly with the storage time. The Aw of HAwF (0.89) decreased very small with time, the variation was about 0.05, as well as the Aw of WACFs and WACFP was closer to that of HAwF. In LHES, the Aw of HAwF and MAwF decreased slightly, and the Aw of WACFs and WACFP was closer to that of LAwF. In both HHES and LHES, the Aw of LAwF increased greatly, but the Aw of WACFs and WACFP was lower than in the Blank. Therefore, the WACFs and WACFP might modify the food moisture in both environment systems. The Aw of HAwF, MAwF, and LAwF changed, because the free water in food gradually reached equilibrium with the free water in the environment; the Aw of HAwF at either RH 90 or 40% decreased very small; whereas that of LAwF increased gradually, until it reached equilibrium with RH of the environment system.

*Color difference*

Table 1 showed the color difference (ΔE*) of HAwF/MAwF/LAwF with WACFs and WACFP in the environment system at HHES or LHES for different storage time. Three time points were taken from the storage time, for HAwF – 1, 9, 48 h and 1, 12, 72 h – so as to compare the color difference. The results showed all values < 5.0, meaning the variation was little change. The Duncan's multiple range tests showed no significance in color difference under various conditions. For the ΔE* of MAwF with WACFs and WACFP, three point times were also taken for each HHES/LHES specimen – 4, 144, 336 h and 24, 288, 504 h – so as to compare ΔE*; indicating the variation was not large due to all results < 4.0. The statistical analysis showed that in the HHES, there was significant difference between the color differences of Blank and MAwF with WACFs in the intermediate stage (144 h), whereas that in WACFP had no significant difference. In the LHES, there was no significant difference for the color difference of the three point times.

Moreover, for the ΔE* of LawF with WACFs and WACFP, the AwFs were also taken from three time points – 24, 168, 336 h and 24, 480, 840 h – in either HES. As shown in the same Table 1, the color difference of the Blank without WACFs and WACFP changed from 1.57 to 3.98 in the intermediate stage (168 h), and the

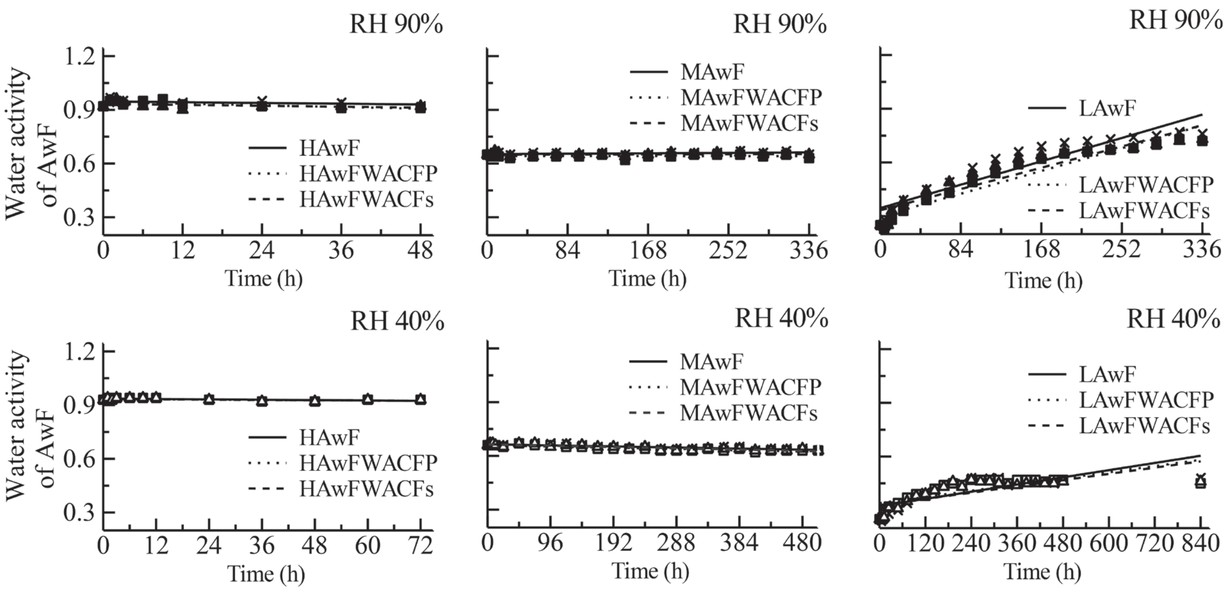


**Fig. 1.** Water activity of HAwF/MAwF/LAwF with WACFs and WACFP in HHES/LHES during different storage time
Legends ×: AwF only; ■: AwFwith WACFP; ▲: AwF with WACFs; □: AwFwith WACFP; △: AwF with WACFs;
Notes: WACFP is Wood–based activated carbon fibers paperboard. WACFs is Wood–based activated carbon fibers. HAwF is food of high water activity. MAwF is food of intermediate water activity. LAwF is food of low water activity

results of statistical analysis showed that the color difference had a significant difference after 168 h in the HHES. As for the LAwF in WACFs and WACFP, the color difference > 4.0 was showed in the late stage (336 h). There was a significant difference in color difference after 336 h in the HHES. However, the color difference was < 3.0 in the LHES, meaning the variation was not large and had no significant difference. As mentioned above, the ΔE* of the food in HHES was easier to change than in LHES. The variance in color difference of the food in WACFs and WACFP was about < 5.0, and the AwFs with WACFP had the minimum variation of color difference.

*Percent weight*

Figure 2 showed the percent weight of HAwF, MawF, and LAwF with WACFs and WACFP in the HHES. The WACFs and WACFP were able to reach moisture absorption equilibrium after a period of time. The percent weight of WACFs and WACFP varied with the Aw of food; that is, WACFs and WACFP were effective on moisture absorption for the aforementioned three kinds of foods. The HAwF placed in WACFs and WACFP that was decreased by about 2.5%, while that not placed in them was increased by about 2.5%. There was little change in the percent weight of MAwF placed in WACFs and WACFP, whereas that not placed in WACFs and WACFP was increased by about 2.0%. The LAwF placed in WACFs and WACFP was increased by about 5 and 10%, respectively, while that not placed in WACFs and WACFP was increased by over 20%.

For the HAwF, MAwF, and LAwF in the LHES with WACFs and WACFP (Fig. 3), the percent weight of HAwF and MAwF increased, and it changed due to Aw. The percent weight of HAwF placed in WACFP was decreased by about 10%, and there was little change in the weight of that placed in WACFs and not placed in WACFs and WACFP. The percent weight of MAwF placed in WACFP was decreased by about 13%, and that placed in WACFs and that not placed in WACFs and WACFP were decreased by about 2%. The percent weight of LAwF placed in WACFP was increased by about 4%, and that placed in WACFs and that not placed in WACFs and WACFP were increased by about 14%.

As mentioned above, the percent weight of various AwFs placed in WACFs and WACFP in the HHES decreased slightly or hardly changed, because the WACFs and WACFP could absorb moisture in the environment and absorb the moisture of food, and to balance (equilibrium) the moisture in the environment; that is, the weight of the food not placed in WACFs and WACFP increased, and then the food absorbed this moisture. It is inferred that the food is likely to spoil when it has absorbed excess moisture, as decreasing the Aw of food moderately contributes to prolonging the storage life. In the LHES, the percent weight of various AwFs placed in WACFP decreased a lot because the food placed in WACFP absorbed the moisture in the environment and absorbed the moisture of AwF. It is said that the weight of the food placed in WACFs and WACFP and that not placed in them will decrease slightly, because in a low humidity environment and the moisture in the environ-

**Table 1.** Color difference (ΔE*) of various AwFs with WACFs, WACFP in HHES/LHES at three storage times

| Food in HES [1] | Storage time (h) | Blank | with WACFP | with WACFs |
|---|---|---|---|---|
| HawF in HHES | 1 | 4.04 (1.76)[a1)] | 4.07 (3.65)[a] | 1.58 (1.00)[a] |
| | 9 | 2.93 (1.24)[a] | 2.65 (1.36)[a] | 2.26 (2.20)[a] |
| | 48 | 3.41 (0.78)[a] | 4.64 (1.06)[a] | 3.15 (2.50)[a] |
| HawF in LHES | 1 | 1.98 (1.73)[a] | 2.74 (1.55)[a] | 2.22 (0.89)[a] |
| | 12 | 2.31 (1.60)[a] | 3.16 (1.14)[a] | 2.32 (0.48)[a] |
| | 72 | 2.02 (0.71)[a] | 1.77 (0.57)[a] | 3.57 (1.47)[a] |
| MawF in HHES [2] | 4 | 0.48 (0.12)[a] | 1.25 (0.35)[a] | 0.48 (0.15)[a] |
| | 144 | 2.94 (0.81)[b] | 2.02 (1.16)[a] | 2.73 (0.58)[ab] |
| | 336 | 2.25 (0.46)[b] | 2.17 (0.01)[a] | 3.90 (1.62)[b] |
| MawF in LHES | 24 | 1.62 (1.50)[a] | 2.22 (1.11)[a] | 1.96 (0.97)[a] |
| | 288 | 1.10 (0.59)[a] | 1.88 (0.62)[a] | 2.88 (0.73)[a] |
| | 504 | 1.70 (0.79)[a] | 2.79 (1.69)[a] | 3.11 (0.78)[a] |
| LawF in HHES | 24 | 1.57 (0.11)[a] | 1.44 (0.55)[a] | 2.17 (0.14)[a] |
| | 168 | 3.98 (0.98)[b] | 1.62 (0.52)[a] | 2.43 (0.14)[a] |
| | 336 | 4.85 (1.08)[b] | 5.89 (0.04)[b] | 6.97 (0.28)[b] |
| LawF in LHES | 24 | 2.39 (0.72)[a] | 2.56 (0.72)[a] | 2.48 (1.46)[a] |
| | 480 | 1.83 (0.53)[a] | 2.47 (0.46)[a] | 1.48 (0.46)[a] |
| | 840 | 1.61 (0.33)[a] | 2.31 (0.40)[a] | 1.96 (0.63)[a] |

[1] HAwF/MAwF/LAwF: High/Intermediate/Low Water Activity Food; HHES/LHES: High/Low Humidity Environment System

[2] Mean (standard deviation) separation within block (the AwF in different time) by Duncan's multiple range tests at 5% significant level

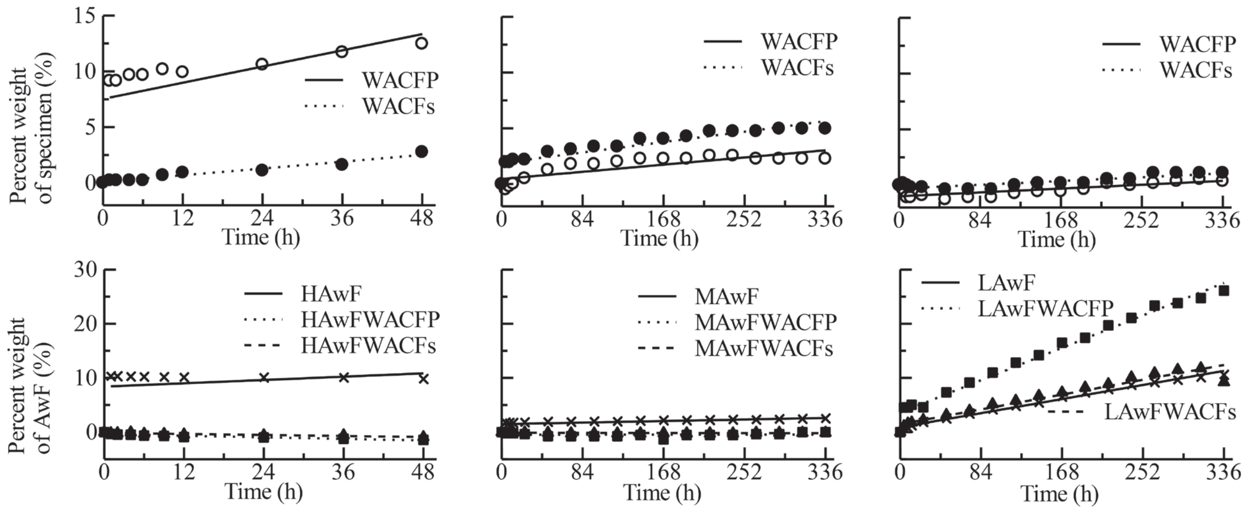


**Fig. 2.** Percent weight of HAwF/MAwF/LAwF with WACFs and WACFP in HHES during different storage time
Legends ○: WACFP; ●: WACFs; ×: AwFonly; ■: AwFwith WACFP; ▲: AwF with WACFs;
Note: WACFP/WACFs and HawF/MawF/LawFare the same as Fig. 1.

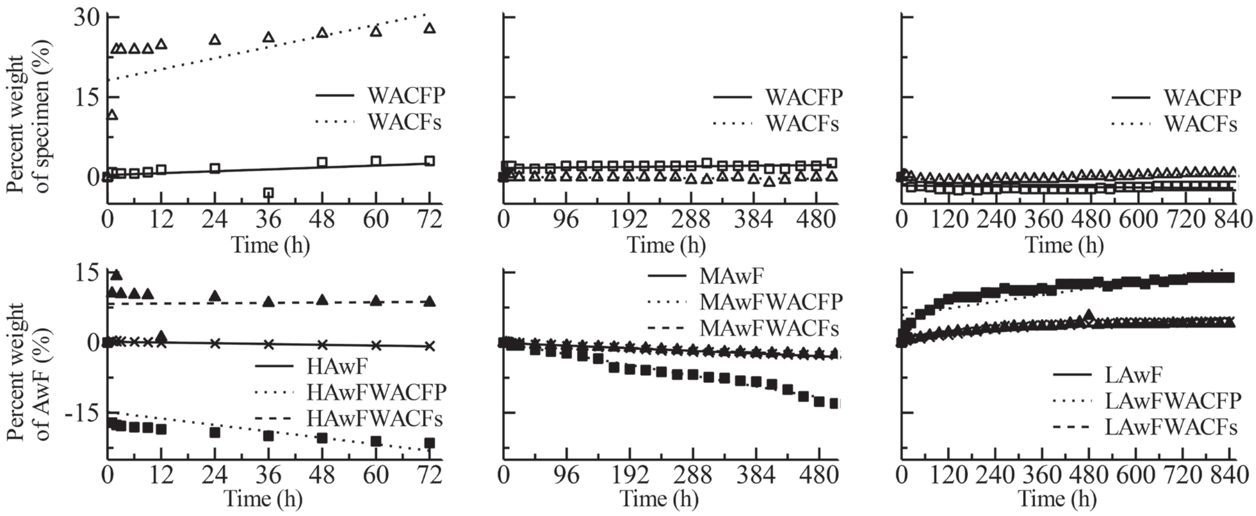


**Fig. 3.** Percent weight of HAwF/MAwF/LAwF with WACFs and WACFP in LHES during different storage time
Legends ○: WACFP; ●: WACFs; ×: AwFonly; ■: AwFwith WACFP; ▲: AwF with WACFs;
Note: WACFP/WACFs and HawF/MawF/LawFare the same as Fig. 1.

ment is less than HAwF and MAwF, and so the effect on that placed in WACFs and WACFP is slighter.

*Moisture content uniformity*

The WACFs and WACFP simulate the moisture–proof of HAwF/MAwF/LAwF in HHES/LHES, and there are differences in the moisture absorption results for the different experimental methods. WACFs are particle–like, packed in bags, and contact the food non–uniformly. WACFP is plate–like, contacts the food surface uniformly, and might have more uniform moisture absorption than WACFs. The horizontal axis in Fig. 4 represents the number of pieces of various AwFs, and the vertical axis represents moisture content (%). They were placed with WACFP and WACFs in the HHES/LHES to measure the food weight, so as to judge moisture content uniformity.

According to the results, when WACFs and WACFP were used for HAwF, The AwF had closer average moisture content, but the Blank (AwF only) had the highest value. The HawF specimen without moisture–proof material has the highest average moisture content, and the moisture content results of LAwF are free of the aforesaid trend. This is because LAwF has lower Aw than WACFs and WACFP. According to Duncan's multiple range tests of moisture content in the pieces of HAwF, the histogram showed very large differences, but there were no significant difference (the results in the top of Fig. 4). The moisture content results of MAwF with WACFs and WACFP are shown in middle of Fig. 4. MawF with WACFP had no significant difference in the HHES/LHES, but the MawF only (Balnk) exhibited significant difference, while the MawF dividing into three pieces. The results in the bottom of Fig. 4 showed using

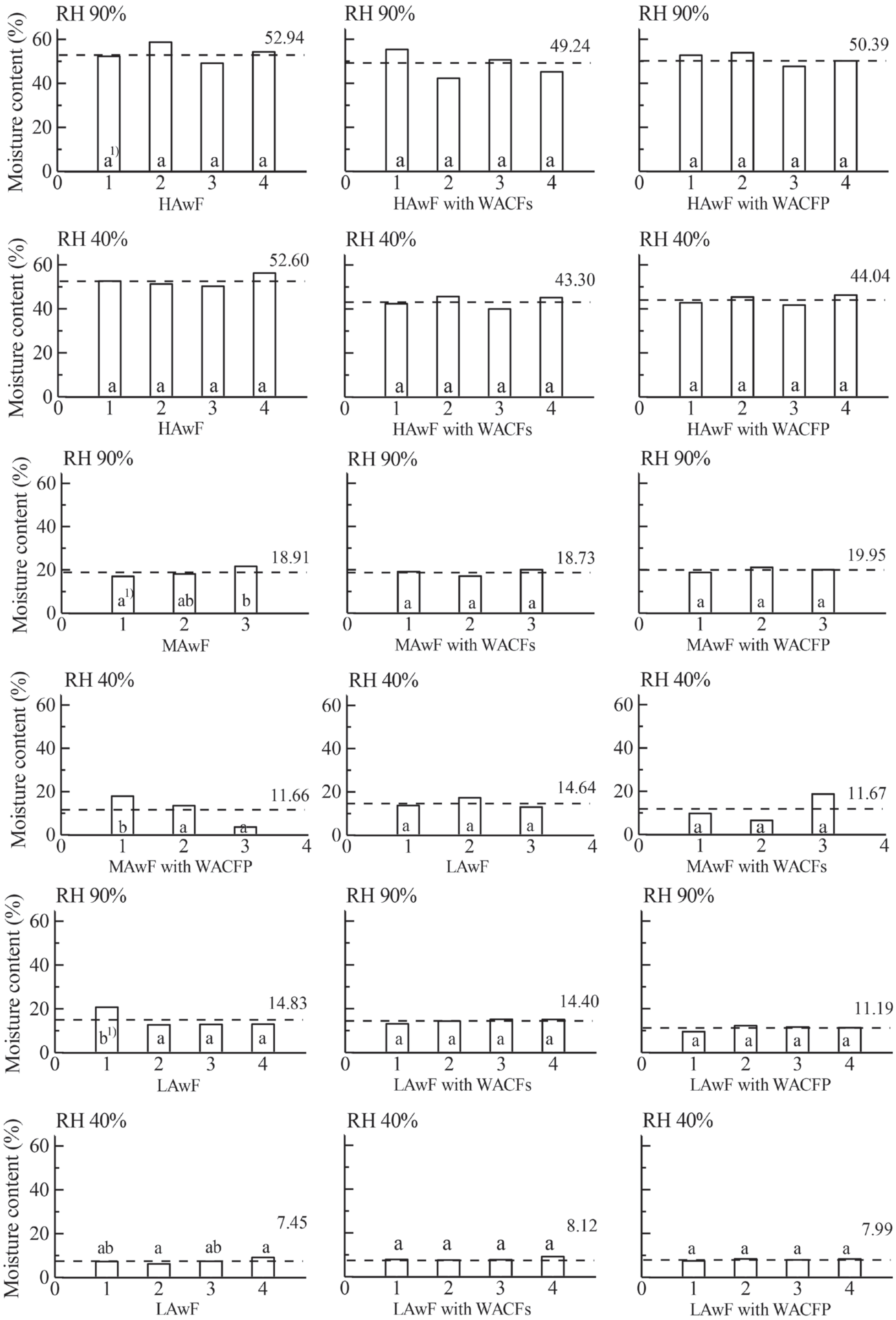

**Fig. 4.** Moisture content uniformity of pieces of various AwFs with WACFs/WACFP in HHES/LHES during different storage time

Notes: [1] Mean (standard deviation) separation within each AwF by Duncan's multiple range tests at 5% significant level; WACFP/WACFs and HAwF/MAwF/LAwF are the same as Fig. 1.

WACFs and WACFP for LawF at the HHES, the moisture content for LAwF only had significant difference, while WACFP used, had no significant difference.

As mentioned above, in the environment system at RH 90% (HHES), WACFP is a more suitable desiccant for MAwF and LAwF, because it has more uniform moisture absorption. WACFs are also applicable to HawF and there is no significant difference in the moisture content uniformity at RH 40% (LHES) for various AwFs.

## CONCLUSION

WACFs prepared from *Leucaenal eucocephala* sawdust and kraft carton at carbonization and activation temperature 800°C with activation duration 60 min and steam flow 300 mL/h, and then made into WACFP to evaluate the Aw, color difference, percent weight, and moisture content uniformity with HAwF/MAwF/LAwF in the HHES/LHES. The results were as follow:

1. The yield 24.15% and iodine value 340–431 mg/g of WACFs from *Leucaenal eucocephala* sawdust were better than the yield 20.37% and iodine value 183–252 mg/g of that from kraft carton.
2. The Aw of WACFs was 0.45, which of WACFP was 0.58, which of HawF/MawF/LAwF was 0.89, 0.50, and 0.38, respectively. According to hygroscopic ability, in the environment at RH 90%, the maximum percent weight of WACFs was increased by about 5%, while that of WACFP was increased by 2–3%.
3. In terms of color difference, there was no significant difference when WACFs and WACFP were used for HAwF, and there was no significant difference between the Blank and the food placed in WACFs when they were used for MAwF.
4. WACFP and WACFs were used for HAwF, MAwF, and LAwF respectively at RH 90%. There was little change in the percent weight of MAwF, and the percent weight of WACFs and WACFP was increased by about 2.5%, meaning they absorbed excess moisture in the environment. The percent weight of HAwF decreased insignificantly with time, but for LAwF it was increased, meaning the food absorbed moisture at the same time. The percent weight of MAwF and LAwF decreasd at RH 40% and WACFs and WACFP decreased, because the Aw of HAwF, MAwF, WACFs, and WACFP was higher than 0.4.
5. According to moisture content uniformity, WACFP with food had better moisture absorption uniformity than the Blank and WACFs with food, and the Duncan's multiple range analysis showed there was no significant difference when WACFP was used for LAwF and MAwF in the environment system at RH 90%.

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## AUTHOR CONTRIBUTION

Han Chien LIN designed, performed the experiments, and wrote the paper. The students, Miao–Han Yang, Shih–Ching Chen, Bin–Chen Xu and Jia–Yun Tsai, performed the detail experiments and analyzed the data with statistical analysis. Noboru FUJIMOTO participated in the design of the study and supervised the work. The authors assisted in editing of the manuscript and approved the final version.

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