

Physical Insights into Homemade Radish Pickling: Optimizing Flavor and Health through Capillary Action and Osmosis

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ABSTRACT

Based on the motivation of making home-cooked meals more tasty while not harming the body by consuming too much seasoning. This study explores the best way to pickle radish using three different types of seasoning liquids: chicken broth, soy sauce, and salt water. The goal of this study is to find out how different factors, including geometrical properties of the radish sample used and the solution's fluid properties, affect the pickling process. The mechanism behind the pickling process is first revealed by including capillary action and osmosis into theoretical and experimental discussions, showing the dominance of osmosis. The distribution of gray scale value across the diameter is also measured, showing relatively uniform pickling for soy sauce and salt water. Through the experiment, higher solution concentrations accelerated water loss in soy sauce and salt water through osmosis, as shown by the fact that radish pickled in 80% soy sauce decreased in weight at a rate of 0.078 g/min, while those pickled in 60% soy sauce decreased at a rate of 0.052 g/min. On the other hand, chicken broth showed irregular weight changes due to its complex solutions and molecules, which is discussed and explained by the Stokes-Einstein relation. For the contact area ratio, 59.8% is found to be the most ideal ratio as it maximizes the weight reduction rate, achieving a maximum value of 0.361 in both soy sauce and salt water. Lower water content created by predrying the sample leads to better pickling results for soy sauce and salt water, especially around 86%, but opposite for chicken broth. This study provides a comprehensive view of a qualitative explanation for physical insight into radish pickling by various physics models referenced, providing a way to healthier vegetable pre-processing.

Keywords: Pickling; Capillary Action; Osmosis; Healthy Food; Food Processing; Vegetable Physics

INTRODUCTION

Food prepared at home is often less flavorful because it lacks sufficient seasoning, while food from restaurants

is usually too salty and less healthy. This study aims to identify how different sauces and related factors can provide the best method for pickling radish. In doing so, the work seeks to make meals both healthier and more enjoyable in taste.

Radish is selected as the research subject because its internal structure makes it ideal for studying solution transport during pickling. The cells of radish allow osmosis, while its vascular tissues contain narrow channels that support capillary action. Together, these processes govern how pickling solutions move into

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the vegetable. Water permeability of cell membranes is a key factor in plant–water relations, influencing water uptake, growth, and adaptation to environmental changes (1). In radish root cells, this permeability is especially high, which makes them particularly responsive during osmotic treatments (1).

Osmosis drives water out of the radish and allows solutes from the pickling solution to enter. The efficiency of this process depends on solute concentration: higher concentrations of salt or sugar reduce water retention in the radish, leading to greater moisture loss but also more solid uptake (2). This exchange is powered by osmotic pressure differences between the radish and the surrounding solution, which force water to move outward and draw solutes inward (3). Factors such as sample size and surface area also influence the rate of water loss, with thinner or smaller pieces experiencing faster changes due to greater exposure (3).

Capillary action complements osmosis in transporting the solution into the radish. The vascular vessels of plants are extremely narrow, which allows solution to rise to significant heights relative to their diameter (4). This mechanism is also described as capillarity, where water moves through fine plant tissues by adhesion, cohesion, and surface tension forces (5). Just as water travels upward in celery stalks, the pickling solution can move through the radish's vascular tissues by capillary forces, enabling deep absorption of the solution (5).

For doing further analysis and explain the experimental result, a combination model of capillary action and osmosis is introduced in the results section, and a coefficient as contribution ratio of capillary action is set to 76% in the model as a study (11) shows “The bulk of the storage organ consisted of secondary xylem, which made-up approx. 76.0% of the cross-sectional area in Lt and Rt plants,” where in this experiment Rt type radish is used as experimental sample and capillary action happens in the xylem structure in radish, thus the contribution ratio of capillary action is set to be 0.76 of the full mechanism. However, there are still other parameters included in the calculation that this contribution ratio is not dominant and will be discussed.

This study investigates how factors such as viscosity of the solution, solute concentration, contact area ratio, and water content affect the pickling of radish. Beyond these observations, the aim is to construct an empirical equation that models the pickling process. Such an equation would not only contribute to the theoretical

understanding of osmosis and capillarity in plant tissues but also provide practical applications for improving food preparation at home.

METHODS AND MATERIALS

Software and Analysis Method

Three software programs are used in this research; ImageJ is used mostly for the analysis of experimental pictures to acquire the gray scale variation through time. Firstly, import the image into the ImageJ software, then use the freehand selection to crop the image until only the radish is left. After that, the measure tool is used to find the gray scale value, a huge area is selected for measurement, the mean value is calculated, and the data is later recorded in Excel for further analysis. Besides ImageJ, Tracker is also used, mostly for tracking the solution motion as capillary action is making an impact. The experiment video of the solutions rising within the capillary action is imported into Tracker software, and then the height of the solution within the capillary action is tracked every second within Tracker. After that, the value is recorded in Excel for further calculation.

Solution Preparation

The required volume of each solution is calculated according to the designated concentration percentage (out of 100%), and later, the fluid is measured using a measuring cup. Finally, the measured fluid is transferred into the Petri dish.

Properties of Radish Measurement

The size of the radish slices (radius and thickness) is measured with a vernier caliper, and each radish sample is weighed with an electronic scale. Pictures of the radish samples were finally taken with a smartphone camera for analysis of the gray scale value.

Surface Tension Measurement

The density of each fluid is first calculated by measuring its mass and volume. After that, the fluid is transferred into a Petri dish. Three capillary tubes are put straight up into the Petri dish with the fluid. The fluid later rises in the tubes until stoppage (make sure the tube bottoms do not touch the dish). The height of the fluid is measured in each tube. The values are put into the surface tension equation to calculate the surface tension value of each solution. According to static equilibrium, the surface tension of fluid in a capillary tube perpendicular to the fluid surface can

be calculated (1), as the equation: $\sigma = \frac{\rho g d h}{4}$, where σ is surface tension, ρ is the density of fluid, g is gravity, d is the diameter of the capillary tube, and h is the height where the solution stops climbing up.

Measuring Viscosity

The solutions are transferred into a Petri dish. Capillary tubes are placed perpendicular to the Petri dish containing the fluid. Solution is allowed to rise in the capillaries until the movement stops, indicating equilibrium (ensure the bottom of the tubes does not touch the Petri dish). While the solution is moving, the height of the solution climbing in the capillary tube is tracked using Tracker. As the dynamic data is acquired, Lucas-Washburn equation (2) is used to calculate the viscosity of the solution as the equation shows the relationship between surface tension and viscosity under capillary action, as the tube is perpendicular to the surface of the solution, viscosity can be derived:

$$\eta = \frac{r\gamma t}{4h^2}, \text{ where } \eta \text{ is the viscosity, } r \text{ is the diameter of}$$

capillary tube, γ is the surface tension of solution, h is the climbing height and t is the time taken for fluid to climb up. For the accuracy of calculation, the dynamic data is processed by fitting the $t - h^2$ graph for the slope of the linear fitting line, reducing the deviation while calculating viscosity by using dynamic motion data and surface tension value already known.

Procedure for Doing the Experiment

The radish samples are put (with measured size and weight) into Petri dishes with the prepared solution, using gloves to keep clean. A timer is set for 1 minute. Every 1 minute, the radish is taken out, weighed for its mass. Later, the sample is moved to another clean Petri dish, and a picture of it is taken under the same environment, with an unprocessed sample beside it used as a comparison of the gray scale value. The procedures are repeated until 10 minutes pass. ImageJ is used to check the images and calculate the gray scale value of the radish at each time point, and then the data recorded is analysed using Excel.

RESULTS

Assumed Theoretical Model of Mechanism

In fruit and vegetable processing, there are two

main mechanisms motivating solutes to transfer in and out of the sample itself, which are capillary action in xylem and phloem and osmosis of solutes between the cell membranes. The significance of the two physical mechanisms is assumed by some reference research. In a study investigating radish cross-sectional area (11), the area of xylem is said to occupy approximately 76% of the total area, which leads to the significance of the capillary action's contribution. Where the rest 24% is left for the cell to do the osmosis by our assumption.

Here we can now build a model to describe the water content variation through time of the radish while pickling, a study (10) shows that there's a mathematical model of osmosis based on Fick's law of diffusion, while applying to cone shaped vegetable. The water content ratio of a vegetable dehydration while pickling can be described by multiple coefficients times on an exponential decay function, where we here simplify it as: $W_{osmosis} = -0.24\alpha e^{-\beta t}$ where 0.24 is the contribution ratio, α , β are the coefficients of osmosis, t is time, since the value of solution concentration inside the radish cell is not accurately measured, and the goal of the study is aiming for discussing the physics behind the pickling of radish, so the simplified model is used here. Same for the model of capillary action, Lucas-Washburn's equation is used (12), and a simplified model is derived as $W_{capillary} = 0.76\sqrt{Dt}$, where 0.76 is the contribution ratio, D is the coefficient of capillary action, and t is time. From the two models and the assumptions, the water content change through time model can be written as: $W = -0.24\alpha e^{-\beta t} + 0.76\sqrt{Dt}$, where different conditions are simulated by Python.

Figure 1 shows three theoretical patterns of water-content change in radish samples, which serve as assumptions for the analysis. These patterns qualitatively represent how different mechanisms may contribute, recognizing the model's measurement-related limitations: (A) capillary action dominates, (B) equal contribution, and (C) osmosis dominates.

Mechanism and Viscosity

This experiment first investigated the mechanisms of the pickling process in radish by using the assumed model $W = -0.24\alpha e^{-\beta t} + 0.76\sqrt{Dt}$ to explain relationships between parameters. For capillary action, radish strips were positioned vertically, and the movement of solutions upward through the small pores was observed. The solution rose along these pores due to capillary action, a process where the adhesive forces between the solution and the radish's pore walls pull the solution

upward against gravity. The height of the solution rise varied depending on the solution's viscosity; thinner solutions with lower viscosity moved faster, while thicker ones rose more slowly. After several minutes, the solution's height stabilized, indicating that equilibrium was reached as the adhesive and cohesive

forces balanced.

For osmosis, the gradual penetration of solution across the radish tissue into the cells occurred. Osmosis happens when water moves across a semipermeable membrane from an area of lower solute concentration to an area of higher solute concentration, driven by the concentration gradient. In this case, the radish cells absorbed or lost water based on the external solution's concentration, leading to increased color intensity in the radish cross-section over time. The rate of penetration depended on the concentration gradient of the solution, with higher gradients accelerating the movement. Both capillary action and osmosis contribute to the pickling process: capillary action explains the upward movement of solution in vertical slices, while osmosis explains the penetration of solution into the tissue.

This research also examined the role of viscosity, defined as a solution's resistance to flow, in governing the penetration of solutions into radish tissue through capillary action. According to Jurin's Law, the equilibrium height of solution rise in a capillary depends on surface tension, contact angle, density, and tube radius, while the Lucas–Washburn equation further describes the dynamics of solution penetration as proportional to the square root of time and inversely proportional to viscosity. Consequently, solutions with lower viscosity are expected to advance more rapidly through the radish's capillary-like pores, as reduced internal friction facilitates fluid movement. In contrast, higher-viscosity solutions face greater resistance, which theoretically slows their progression and limits the extent of capillary rise within the tissue.

As shown in Figure 2 and Table 1, the viscosity of chicken broth, soy sauce, and salt water, alongside the

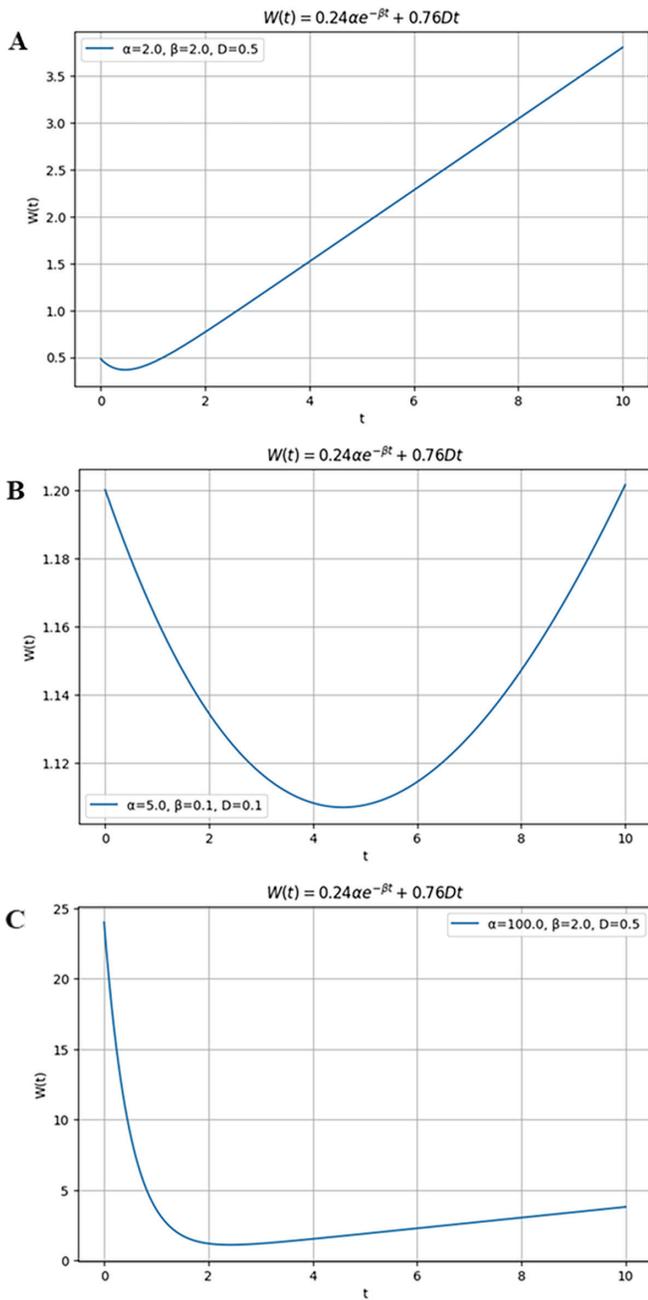


Figure 1. Simulations of water content through time in radish samples, showing three kinds of patterns of theoretical changes.

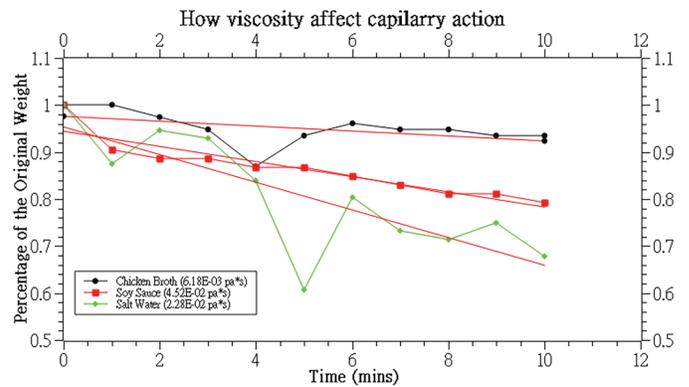


Figure 2. The percentage of weight variation through time and compare three solutions.

Table 1. Comparison of viscosity and slope of linear fitting of weight variation through time between three solutions

	Salt Water	Soy Sauce	Chicken Broth
Slope of linear fitting (g/min)	-0.03	-0.02	approx. 0
Viscosity (Pas)	0.02	0.04	0.01

weight change of radish samples pickled in each over 10 minutes. According to theory explained, the change of weight of radish in solutions with lower viscosity should be higher due to more efficient capillary action. However, the change in weight of radishes in salt water is greater than that in chicken broth, which has a lower viscosity than salt water. This rejects the theoretical assumption that capillary action is the main leading mechanism in the process, if capillary action is the main mechanism, the weight variation should be positive, from the phenomenon of weight reduction of the three experiment samples, and the slope of linear fitting of all three solutions are all negative (salt water = -0.03, soy sauce = -0.02, chicken broth = -0.01), which the slope of fitting rejects the assumption of “capillary action will be the main mechanism of pickling radish.” Though the slice of radish has a small area contacted with the solution (less than 10%), osmosis dominates the pickling process as qualitatively examined by the assumed mechanism model, providing a possible qualitative explanation of the dominance factor.

Gradient Analysis

As shown in Figure 3, the gradient analysis, conducted using ImageJ to measure gray scale changes across radish slices, revealed the uniformity of solution penetration. Salt water exhibited the least variation in gradient across the slice distance, indicating uniform penetration due to its consistent diffusion pattern, predictable and even across the tissue. Soy sauce showed medium variation, with fluctuations in the gradient caused by its higher viscosity, leading to less uniform diffusion and the formation of concentrated flavor pockets. Chicken broth displayed the highest variation, with significant gradient fluctuations attributed to its diverse components, which diffused at different rates, resulting in irregular color and flavor distribution.

The variance values derived from the gradient analysis in Figure 4 represent the degree of fluctuation in color intensity across the radish slices, serving as

an indicator of diffusion uniformity. Lower variance reflects more consistent penetration of the solution, while higher variance indicates irregular distribution caused by uneven diffusion processes. Salt water maintained relatively low to moderate variance throughout the experiment, aligning with its predictable and stable diffusion profile. Soy sauce exhibited intermediate variance, with fluctuations reflecting the interplay of its viscosity and solute complexity, which occasionally restricted uniform penetration and produced localized concentration zones. Chicken broth, by contrast, showed markedly higher variance,

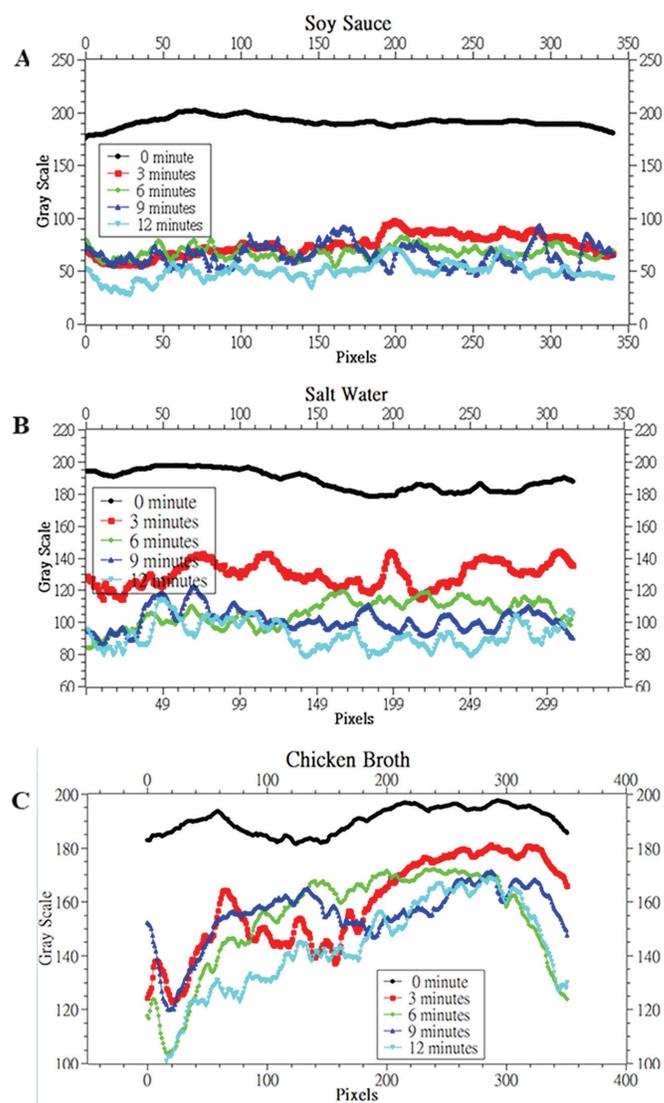


Figure 3. Grayscale value distribution along the diameter of radish samples treated with (A) soy sauce, (B) salt water and (C) chicken broth.

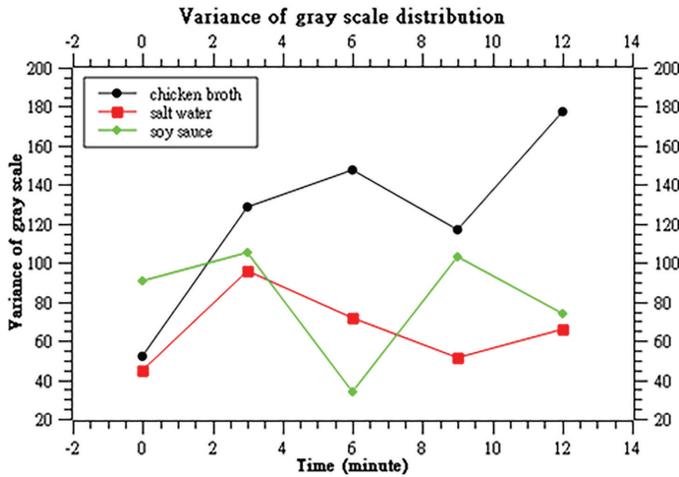


Figure 4. Gray scale value distribution's variance varies through time.

especially after 3 and 6 minutes, highlighting its heterogeneous composition; proteins, fats, and seasonings diffused at disparate rates, producing non-uniform gradients of absorption. This elevated variance underscores how multi-component solutions interact with radish tissue in complex, non-linear ways, leading to irregular color and flavor distribution compared to simpler saline solutions.

Solution Concentration

This experiment tested the impact of varying solution concentrations on weight and gradient changes, as illustrated in Figure 5 and Table 2. In soy sauce, lower concentrations slowed the weight decrease due to reduced osmotic pull (10), but at 0% (plain water), the weight increased as the radish absorbed water, with the gradient decreasing more slowly at lower concentrations, reflecting a gradual color spread. Salt water followed a similar trend, with slower weight loss at lower concentrations and an increase at 0%, alongside a steady gradient drop, indicating a consistent osmotic response. Chicken broth differed, with faster weight gain at lower concentrations due to increased water uptake by the radish, and the gradient decreased slowly, from 100% to 60%, dropped sharply from 60% to 40%, and remained stable from 40% to 0%, suggesting a complex solute interaction. These trends can be explained by the van 't Hoff equation $\Pi = iCRT$ where i is the dimensionless van 't Hoff index, C is the molar concentration of solute, R is the ideal gas constant, and T is the absolute temperature, which shows that lower molar concentrations reduce osmotic pressure, slowing

water loss in soy sauce and salt water, while in chicken broth, dilution may disrupt molecular structures like emulsions, altering permeability abruptly before stabilizing at low levels.

As shown in Figure 5, the weight change analysis across varying concentrations further illustrates the influence of osmotic gradients on radish tissue. In soy sauce and salt water, higher concentrations exhibited steeper negative slopes, reflecting more rapid weight loss

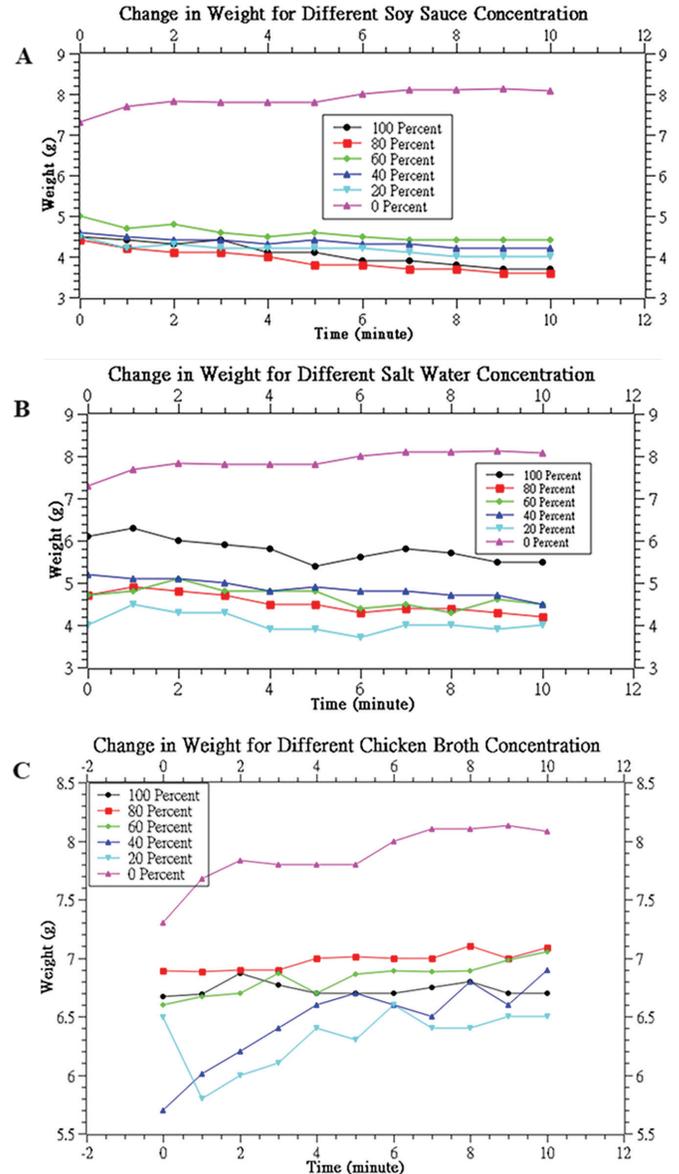


Figure 5. Change in weight of radish samples pickled in different concentrations of (A) soy sauce, (B) salt water, and (C) chicken broth.

Table 2. Statistical values of weight change in radish pickled at different concentrations

Soy Sauce						
	100 Percent	80 Percent	60 Percent	40 Percent	20 Percent	0 Percent
Slope of linear fitting (g/min)	-0.09	-0.08	-0.05	-0.04	-0.04	0.07
R square	0.95	0.95	0.81	0.87	0.79	0.79
Salt Water						
	100 Percent	80 Percent	60 Percent	40 Percent	20 Percent	0 Percent
Slope of linear fitting (g/min)	-0.06	-0.06	-0.05	-0.06	-0.04	0.07
R square	0.66	0.84	0.47	0.92	0.29	0.79
Chicken Broth						
	100 Percent	80 Percent	60 Percent	40 Percent	20 Percent	0 Percent
Slope of linear fitting (g/min)	approx. 0	0.02	0.04	0.09	0.04	0.07
R square	approx. 0	0.79	0.85	0.76	0.35	0.79

as stronger osmotic pressure drove water efflux from the radish cells. Conversely, lower concentrations reduced the osmotic gradient, slowing weight decrease, while at 0% (plain water), the slope shifted positively, indicating net water uptake due to the absence of external solutes. The high R-square values at 100% and 80% for soy sauce suggest a predictable osmotic response, while reduced R-square values at lower concentrations imply more variable tissue behavior, possibly due to competing minor solutes and non-linear diffusion patterns. Salt water followed a comparable trend, though the generally lower R-square values suggest that structural heterogeneity in the radish tissue introduced variability into the osmotic response. Chicken broth displayed a distinct pattern: higher concentrations showed minimal or slightly positive slopes, suggesting limited net water loss despite the presence of solutes, likely due to larger molecules such as proteins and fats that diffuse slowly and hinder osmotic balance. At moderate dilutions (60–40%), steeper positive slopes appeared, indicating that dilution disrupted broth emulsions, enhancing water entry into the tissue. At lower concentrations, the slopes stabilized, suggesting a new equilibrium where the osmotic pull of dissolved solutes was balanced by the steric hindrance of macromolecules. These findings align with Van't Hoff's principle (6) that osmotic pressure is proportional to solute molarity, while also demonstrating how solution composition and molecular complexity can significantly modulate diffusion and osmotic dynamics in plant tissue.

Contact Area Ratio

By Fick's law's simplified osmosis model, $W_{osmosis} = -0.24\alpha e^{-\beta t}$ where 0.24 is the area contribution ratio, α , β are the coefficients of osmosis, t is time, the total diffusion flux amount should be proportional to the contact area of the sample to the solution (if the concentration gradient is the same), so the assumption is therefore set to examine if a bigger contact area will lead to a faster pickling process, which represents faster reduction of water content of radish. In the experiment, radish is sliced to be all 10 mm thin, and a parameter, which is defined as contact area ratio, is defined by contact area divided by solution volume, because of the limitation of the Petri dish, solution volume is all set to 26 mL.

From the result shown in Figure 6, the initial assumption: "contact area ratio is proportional to weight reduction rate" is rejected under this experimental condition. The experimental data shows that for salt water and soy sauce, the weight reduction process will continue, and the weight reduction rate will increase mostly when contact area ratio is set to 59.8, for chicken broth, there is no weight reduction when contact area ratio is bigger than 104.3, and the weight reduction rate will also increase mostly when contact area ratio is set to 59.8.

Water Content of Radish

In this part of the research, the shape and size of the radish slices are fixed, different water content amount is created for examination by a hair dryer, temperature of

the sample is also controlled.

From the results shown in Figure 7, changes of the water content ratio are plotted, where the soy sauce and salt water experiment shows a decreasing trend, as the theoretical model indicates, radish under the two

kinds of experimental conditions is the to have osmosis as its dominant mechanism(as the qualitative model shows that the reduction of water content is caused by osmosis), especially for all of the results of soy sauce, for salt water, data is showing (lower than 86.21%) that

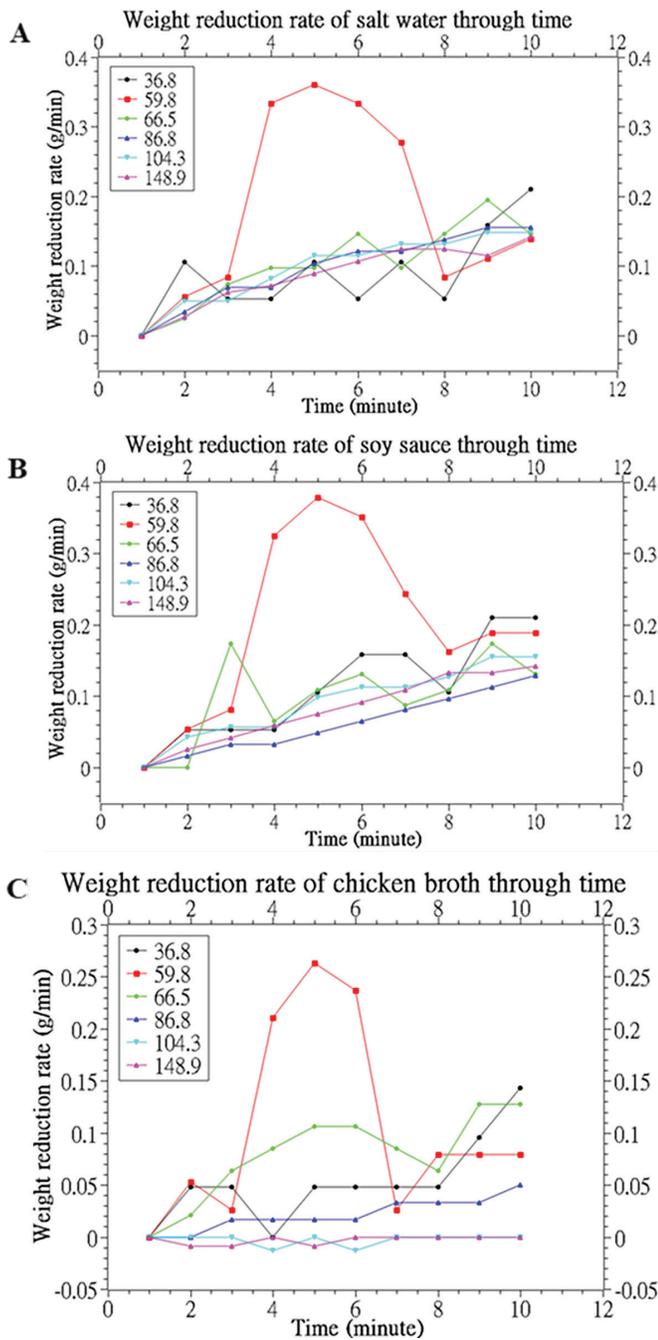


Figure 6. Temporal weight-reduction rates of radish samples under different treatment conditions: (A) soy sauce, (B) salt water, and (C) chicken broth.

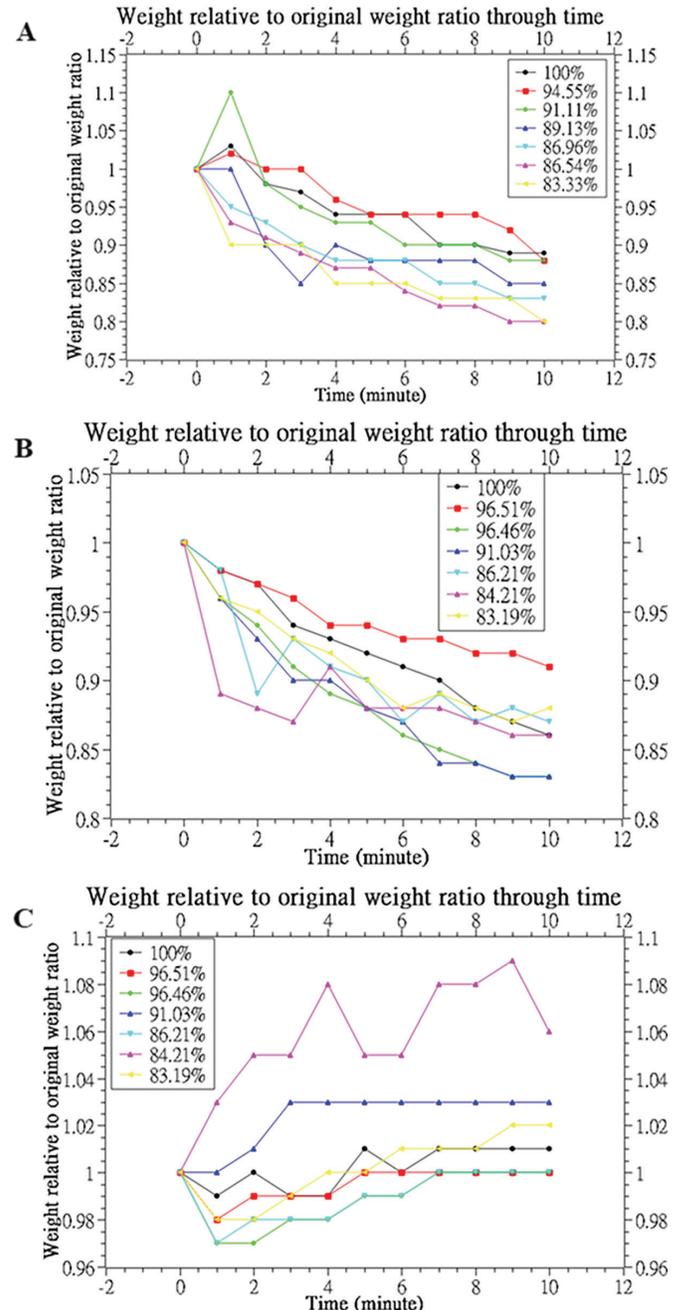


Figure 7. Temporal variation in the relative weight ratio of radish samples under different treatment conditions: (A) soy sauce, (B) salt water, and (C) chicken broth.

the mechanism changes to a more equally dominance between osmosis and capillary action. About the pattern of chicken broth, its heterogeneous composition is shown to have an impact, with proteins, fats, and seasonings diffusing at disparate rates, producing an unpredictable pattern of water content changes.

DISCUSSION

Limitations on Experimental Result Interpretation

This study aims to provide an overview of the physical components coupling behind the pickling of radish. A main limitation is that each condition was tested with a single radish sample and presented a single-trial result, with no error ranges or confidence intervals constructed. Although radishes were sourced from the same supplier, biological materials inevitably exhibit individual deviations in density, water content, or vascular structure. Without replicates, variability could not be quantified, and statistical analyses such as t-tests or ANOVA were not feasible. Moreover, the absence of error ranges or confidence intervals precludes assessment of result reproducibility or precision. Yet, this study is still capable of providing qualitative explanations by examining various parameters, and condition-based experimental results can be applied an empirical results in daily lives vegetable processing application.

Why Osmosis Still Contributes More in Most Cases, Discussed by Simulation

Though the assumed theoretical model is showing that from the thesis review, capillary action should contribute most as an important factor providing solution to travel up through the xylem in radish as xylem occupies up to 76% of the cross-sectional area of the radish sample used in this experiment. However, most of the experimental results didn't match that as the experimental weight loss slopes were consistently negative: -0.03 g/min (salt water), -0.02 g/min (soy sauce), approximately 0 g/min (chicken broth), proving net water efflux driven by osmosis. A negative slope means mass is leaving the radish; osmosis pulls water out, while capillary action would cause influx and a positive slope. Here is the discussion about what might be causing this. In the assumed model, the original fluid in the xylem of the experimental sample is not taken into consideration, this will cause a lower surface tension gradient of the solution to climb up the xylem's capillary tube-like structure, with that into consideration, python is used to simulate the dynamics of solution, with a

two force model, solving the differential equation for result. The capillary tube diameter is considered as 62 as the research measured (11), surface tension of the original fluid in xylem is assumed to be around 20 mN/m as a research (13) investigated tree's xylem's fluid content, and also the viscosity is calculated as 1.03 Pas as a research (14) measured tree's sample under 305 K temperature condition. From the simulation shown in Figure 8, the solution height is simulated as it needs multiple minutes to climb up to the top of the sample, by combining this result we can assume that the water content didn't change much in most of the experiments is due to the low climbing rate of the solution, and also the fluid content in xylem originally is already occupying volume, causing the increase of water content to be easily neglected from the results. Combining the explanations above, osmosis was mainly responsible for the observed mass change in soy sauce and salt water. The consistent negative slopes, such as -0.09 g/min at 100% soy sauce and -0.05 g/min at 60% soy sauce, provide direct experimental evidence that osmosis, not capillary action, dominates mass transfer during radish pickling within the 10 minutes timeframe. However, this assumption is only verified in simulation in experiment-related parameters, providing a limited point of view of the explanation of the contribution of osmosis.

Chicken Broth is Not A Good Method of Pickling

Although chicken broth exhibits lower viscosity compared to the other two solutions, its solute

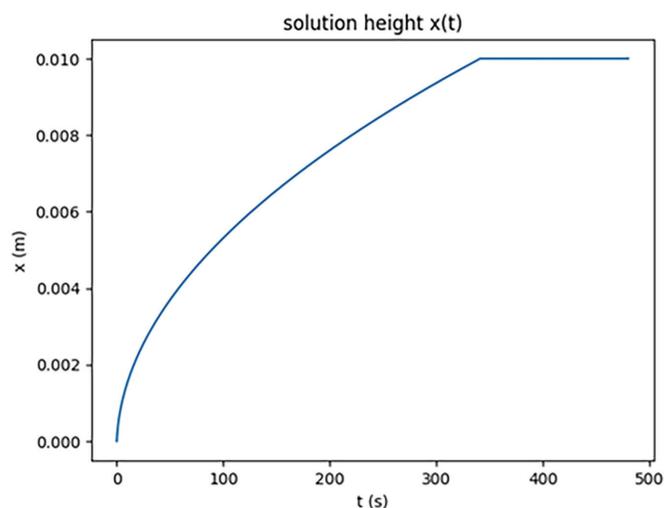


Figure 8. Solution height's dynamical changes in the radish sample's simulation.

composition is dominated by macromolecules and proteins with relatively large radii that are typically larger than 2 nanometers (15). In contrast, salt water contains small ions such as sodium ions with a radius of 0.09 nanometers (16) and chloride ions with a radius of 0.37 nanometers (17), while soy sauce contains a mixture of small ions and peptides with radii between 0.2 and 1 nanometers (18). According to the Stokes-Einstein relation (19), the diffusion coefficient of a solute decreases with increasing molecular size. Consequently, despite its fluidity, chicken broth is characterized by slow solute diffusivity and limited osmotic efficiency.

Why 59.8% is the Best Contact Ratio for Pickling?

The total volume of the solution is fixed, through the changes of the geometric properties of the radish sample, the ratio between the sample volume and the solution is decreasing, though the gradient of the concentration difference between the cell membrane is fixed, during the dynamical changes, the gradient will decrease, and it's neglected in the assumption, as the parameter representing solution concentration of seasonings is seen as a constant, which causes the result to not match the assumption. In a study about osmosis (9), bigger than 1:10 of mass ratio is suggested to prevent the decrease of the concentration gradient; however, in the experiment, the lowest mass ratio is 1:13.2 (for a 36.8% contact area ratio), and the highest is 2.4 (for 148.9% contact area ratio), causing the fact that pickling efficiency isn't proportional to contact area ratio, and performs best in 59.8% contact area ratio, leads to an explainable limitation under this study's experimental condition.

CONCLUSION

This experiment, aiming to optimize the flavor and health benefits of radish, investigates the mechanism behind pickling radish and how different factors affect this process with three different solutions: soy sauce, salt water, and chicken broth.

With viscosity calculated, this experiment discovered that osmosis dominates the pickling process as solutions with lower viscosity are expected to boost capillary action.

Through the experiment, higher solution concentrations accelerated water loss in soy sauce and salt water through osmosis. On the other hand, chicken broth showed irregular weight changes due to its complex solutions and molecules. For the contact

area ratio, 59.8% is found to be the most ideal ratio as it maximizes the weight reduction rate in salt water and soy sauce, indicating efficient water loss and solute uptake. For water content, lower levels in the radish led to a shift toward a more balanced relationship between osmosis and capillary action in salt water, while soy sauce and salt water mostly showed a drop in water content due to osmosis; chicken broth gave unpredictable patterns from its mixed parts. Other factors like size and shape of the radish also played a role, with smaller or thinner pieces speeding up changes from more exposure, and solution concentration affected weight loss, with higher levels in soy sauce and salt water driving faster osmosis, while chicken broth's weight gain at lower concentrations suggested complex solute interactions. Gradient analysis revealed the uniformity of solution penetration, with salt water showing the least variation for even diffusion, soy sauce displaying moderate fluctuations due to higher viscosity, and chicken broth exhibiting the highest variance from its diverse components diffusing at different rates.

In conclusion, soy sauce at full concentration with a 59.8% contact area ratio and radish around 86% to 89% water content works best for even flavor, good water loss, and health balance, while salt water is a simple choice, and chicken broth is not ideal for vegetable pre-processing.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest related to this work.

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