

THE EXPERIMENT OF PERMEABILITY OF PLASTIC WRAP TO WATER VAPOR (EVAPORATION): TAGUCHI METHODS APPROACH

Fairul Anwar A.B.
Universiti Kuala Lumpur, Johor Bahru, Malaysia.
fairulanwar@unikl.edu.my

Sahfinah Z.
Universiti Kuala Lumpur, Johor Bahru, Malaysia.
sahfinah.zulkifle@s.unikl.edu.my

Deffeny L.
Universiti Kuala Lumpur, Johor Bahru, Malaysia.
defenny.lapom13@unikl.edu.my

Iqbal Hairil F.
Universiti Kuala Lumpur, Johor Bahru, Malaysia.
iqbal.hairil@s.unikl.edu.my

*Corresponding author's email: fairulanwar@unikl.edu.my

ARTICLE INFO

ABSTRACT

Handling Editor: Rahimah Mahat

Article History:

Received 1 February 2024
Received in revised form 2 May 2024
Accepted 15 May 2024
Available online 12 June 2024

Keywords:

Plastic wrap; Cling film; Permeability; Taguchi Methods

Plastic wrap, cling film, saran wrap, cling wrap, glad wrap or food wrap is a thin plastic film typically used for sealing food items in containers to keep them fresh over a longer period of time. Plastic wrap, typically sold on rolls in boxes with a cutting edge, clings to many smooth surfaces and can thus remain tight over the opening of a container without adhesive. However, different types of plastic wrap are already on the market, making it difficult for consumers to choose the best option. Therefore, this experiment was designed to evaluate the permeability of the polymer using various types of plastic wrap to prevent evaporation and, indirectly, to study and understand about the factors that can affect plastic wrap evaporation during the permeability of plastic wrap. This experiment assists users in determining which plastic wrap to use using Taguchi Methods approach.

1.0 Introduction

The different polymers used to make plastic wraps have different permeabilities or the ability to transmit a gas through a solid surface. Polymers are chains of molecules combined during a chemical reaction. Plastic appears solid to the eye; it can still allow water molecules to pass through and evaporate. The permeabilities, or ability to transport a gas through a solid surface, of the various polymers used to manufacture plastic wraps vary. Polymers are chains of molecules that are joined together during a chemical reaction. Polyvinylidene chloride, or PVdC, was once used to make several plastic coverings. This plastic is less permeable than many other plastic polymers, and it adheres to other materials well, providing a tight seal. Many companies, however, have switched to low-density polyethylene due to concerns about the chloride's environmental impact and the health effects of the phthalates used in this synthetic polymer (LDPE). PVdC is less permeable than LDPE. Polyethylene plastics are used in this experiment. These plastics are among the most permeable polymers available. PET (polyethylene terephthalate) is the material used to make mylar [1]. This is a less permeable plastic, but it doesn't cling like the other plastic wraps.

Plastic wrap's ability to keep something fresh is influenced by several factors. The permeability of a wrap is affected by its thickness; for example, if two plastic wraps are made of the same polymer, the thicker wrap will be less permeable. Because moisture can move much more easily through a piece of wrap that can cling tightly, it can also help keep food from dehydrating.

1.1 Problem Statement

Packaging materials made of plastic, as opposed to materials made of glass and metal, are permeable in amounts varying from one package to another to organic vapor, gases, and other low molecular weight compounds found in foods, such as aromas, flavors, and additives. The barrier properties of the material affect the rate of transfer of molecules. The performance of polymer packages may be affected by many factors, so choosing the correct package market solution is crucial [2]. Therefore, because interaction with foods might affect polymer performance, it is critical to investigate the material's barrier properties under realistic situations. Absorption of ambient vapor or liquid, for example, might produce an increase in polymer plasticization, resulting in a loss in mechanical characteristics [3].

The problem that been faced in this experiment is the difficulty of permeability of the polymer by using the different types of plastic wrap for the water. Then, the problem that been faced in this experiment is many factors can affect the evaporation of the plastic wrap during the permeability of the plastic wrap.

1.2 Experiment Objective

The objective of this experiment is to evaluate the permeability of the polymer using different

types of plastic wrap to prevent evaporation. Next, to analyzing the factor that affect the evaporation of a plastic wrap during the experiment of permeability of the plastic wrap to water vapor. To make a comparison and then choose which plastic wrap is the most permeable based on which factor is better and more suitable.

2.0 Literature Review

In contrast to glass or metal packaging materials, plastic packaging is permeable to small molecules such as gases, water vapor, and organic vapor, as well as other low molecular weight substances such as smells, flavor, and additives found in food, to varying degrees. Because of the material's barrier qualities, the transfer of these molecules varies from high to low. In recent years, understanding the solution / diffusion / permeation behaviors of these molecules through polymer films has become increasingly important, particularly for polymers used in the food packaging field, where contamination from the outside environment must be avoided and the shelf life of the food must be controlled using modified atmosphere packaging (MAP) techniques. Many aspects that can affect the performance of polymer packages must be considered while designing the best package market solution [4]. The qualities of the food product determine which polymers are used in the food packaging sector. Also, manufacturing, handling, and packaging engineering procedures can affect the final properties of packaging materials, particularly in terms of barrier properties, which are closely linked to the intrinsic structure of the polymer, such as degree of crystallinity, crystalline/amorphous phase ratio, nature of polymer, thermal and mechanical treatment before and after food contact, chemical groups present in the polymer (polar or not), and degree of cross-linking [5]. The optimum packaging material for the food market must be versatile enough to bear handling process forces while keeping physical and chemical integrity, as well as suited for barrier qualities to many gases utilized in MAP procedures (e.g., O₂, N₂, CO₂).

Furthermore, the intrinsic composition of the packaged food (e.g., pH, fat content, fragrance component) may change the sorption characteristics of the packaging materials, while external conditions such as temperature and, for some polymers, relative humidity may affect their barrier properties [6]. Cling film or plastic wrap (also known as Glad wrap or Saran in some countries) is a thin plastic film used to keep food fresh. The most important feature of this film is its vapor permeability, as various foods require varied vapor permeabilities when it comes to gases like oxygen and carbon dioxide. It is critical to select materials with the appropriate permeability, as well as conduct quality control tests [7]. The oxygen vapor permeability of the wrap determines the shelf life of most items - sometimes it is necessary to exclude it, and other times it is critical to guarantee it is present. To allow the food to perspire or breathe, the pace at which oxygen must flow through the film must usually be controlled. Even with frozen meals, poor permeability packing generates freezer burn and "off" odors. Strawberries are a fantastic illustration of how food packaging may help preserve freshness and extend shelf life

or raspberries. Perforated-top containers are widely used to package both of these items. However, the fruit "respires" within, and the CO₂ content quickly approaches the critical 10-15% level required to stop Botrytis from growing [8][9]. The term "vapor permeability" refers to a material's ability to prevent the passage of any gas through a barrier such as water vapor, Oxygen, CO₂ or a hydrocarbon). From outdoor apparel to missiles, and from pizza to industrial seals, vapor permeability has a significant impact on the physical properties of most items and materials [10].

3.0 Methodology

3.1 Selection of Factors and Levels

Table 1. Experiment Strategy.

Signal Factor	Water
Controllable Factors	Type of plastic wrap Temperature Time
Response	Percent of water loss Water loss (%) = $\frac{w_1 - w_2}{w_1} \times 100$
Constant Variables	Type of glass Volume of water Layer of plastic wrap
Noise Factor	Plastic wrap stretch

Table 2. Factors and Level.

Factor	Level	
	1	2
Type of Plastic Wrap	Glad Mini cling wrap	Mr. DIY cling wrap
Temperature (°C)	Room temperature (35)	Fridge Temperature (5)
Time (hours)	12	14

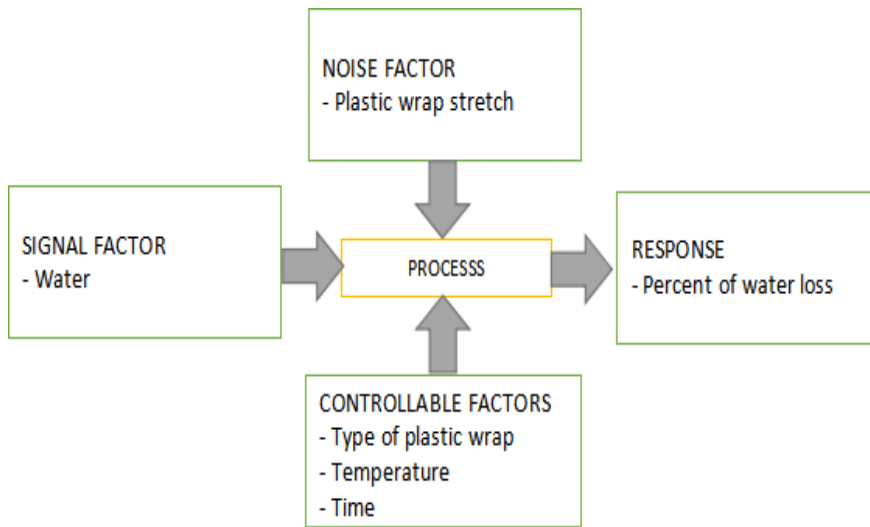


Figure 1. P-Diagram

3.2 Design of Experiment

The experiment used three two-level factors (2^3) for the experiment.

Orthogonal Array: L-4

Replication of experiment: 2 times

Table 3: Orthogonal Array L-4

Run	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

3.3 Apparatus and Procedure

Equipment and Material

1. Glad Mini cling wrap
2. Mr. DIY Cling wrap
3. Glass/ cup - 16pcs
4. Rubber band
5. Digital kitchen scale

Procedure

1. Prepare all of the material and apparatus needed for the experiment.

2. Pour 30 ml of tap water inside the cup.
3. Weight and record the mass of the cup.
4. Cut square each plastic wrap into sizes that are enough to cover the top of the cup.
5. Wrap the top of the cup with plastic wrap and fasten the wrap with rubber band to prevent any gab presence.
6. Place the cup inside a refrigerator or leave it in an area at room temperature until the set time is reached.
7. Remove the plastic wrap from the cup and weigh the final weight.
8. The final weight is recorded, and the percentage of water loss is calculated.

3.4 Noise Factor and Repetition

The noise factor is an uncontrollable factor presence in an experiment that indirectly influences the performance of result. In this study, the noise factor is considered throughout the experiment which categorized as outer array to minimize bias in result.

In the experiment of Permeability of Plastic Wrap, the selected noise factor is plastic wrap level of stretch during its application that is controlled manually by experimenter. Therefore, there are two repetitions conducted in this experiment.

Table 4: Noise Factor in Permeability of Plastic Wrap Experiment

Factor	Level	
	1	2
The Stretch of Plastic Wrap	Low	High

3.5 Result of Experiment

Table 5: Experiment Result on Percentage of Water Loss (%)

Wrap Stretch	

Run	Type of Plastic Wrap	Temperature	Time	Low		High		
				R1 (%)	R2 (%)	R1 (%)	R2 (%)	
1	x	R	12	6.45	6.45	9.67	9.67	8.06
2	x	F	24	6.67	6.57	12.9	12.9	9.76
3	y	R	24	9.67	9.66	12.67	12.7	11.18
4	y	F	12	6.45	6.45	6.45	6	6.34

Table 5 shows the percentage of water loss measured from the experiment. The value is measured in percentage (%) in order to classified evaporation process, occur by the water in different variables.

3.6 Quality Characteristic

Smaller the Better is the quality characteristic for the experiment of permeability of plastic wrap. The percentage of water loss is better to be low that represented low activated diffusion process of water occur. This is because the purpose of plastic wrap is to prevent the loss of quality of the food being wrapped. The low percentage of water loss proves the ability of plastic wrap in maintaining the quality of wrapped things.

3.7 Signal to Noise (S/N) Ratio

The S/N ratio is used to determine the optimum level of variance with the least variation around the target and the average value closest to the target.

The S/N ratio for permeability of plastic wrap is:

● Trial 1

$$\begin{aligned} \text{MSD} &= (Y_1^2 + Y_2^2 + Y_N^2) / N \\ &= (6.452 + 6.45^2 + 9.67^2 + 9.67^2) / 4 \\ &= 67.5557 \end{aligned}$$

$$\begin{aligned} \text{S/N} &= -10\log_{10} (\text{MSD}) \\ &= -10\log_{10} (67.5557) \\ &= -18.297 \end{aligned}$$

● Trial 2

$$\begin{aligned} \text{MSD} &= (Y_1^2 + Y_2^2 + Y_N^2) / N \\ &= (6.672 + 6.57^2 + 12.9^2 + 12.9^2) / 4 \\ &= 105.11845 \end{aligned}$$

$$\begin{aligned} \text{S/N} &= -10\log_{10} (\text{MSD}) \\ &= -10\log_{10} (105.11845) \\ &= -20.217 \end{aligned}$$

● Trial 3

$$\begin{aligned} \text{MSD} &= (Y_1^2 + Y_2^2 + Y_N^2) / N \\ &= (9.672 + 9.66^2 + 12.67^2 + 12.7^2) / 4 \\ &= 127.16085 \end{aligned}$$

$$\begin{aligned} \text{S/N} &= -10\log_{10} (\text{MSD}) \\ &= -10\log_{10} (127.16085) \\ &= -21.044 \end{aligned}$$

● Trial 4

$$\begin{aligned} \text{MSD} &= (Y_1^2 + Y_2^2 + Y_N^2) / N \\ &= (6.452 + 6.45^2 + 6.45^2 + 6.0^2) / 4 \\ &= 40.201875 \end{aligned}$$

$$\begin{aligned} \text{S/N} &= -10\log_{10}(\text{MSD}) \\ &= -10\log_{10}(40.201875) \\ &= -16.425 \end{aligned}$$

Table 6: S/N Ratio Value

Run	Average	S/N Ratio
1	8.06	-18.297
2	9.76	-20.217
3	11.18	-21.044
4	6.34	-16.425

Run 4 has the best combination with minimum variation with the highest S/N Ratio value. The combination is:

Type of plastic Wrap: Mr DIY Cling Wrap Temperature: Fridge temperature, 5 °C Time: 12 hours.

3.8 Main Plot Effect

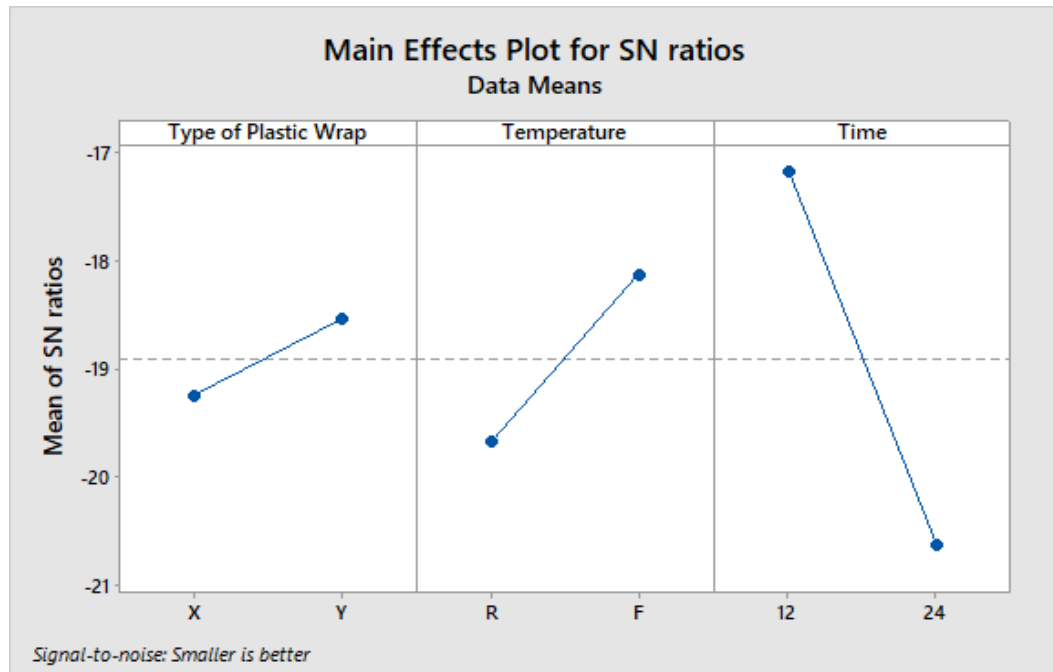


Figure 2: Main Effect Plot for S/N Ratio

With the Quality Characteristic of Smaller the Better, the optimum value produced from the Main Effect Plot is type of plastic wrap, Y (MR DIY Cling Wrap), Temperature of F (Fridge) and Storage time of 12 hours. From this data, it shows that the optimum value is consistent with the optimum value calculated on S/N Ratio. Therefore, the level of factors that can be used to minimize variation are Trial 4, Level 2 for type of plastic wrap, Level 2 for temperature and level 1 for time.

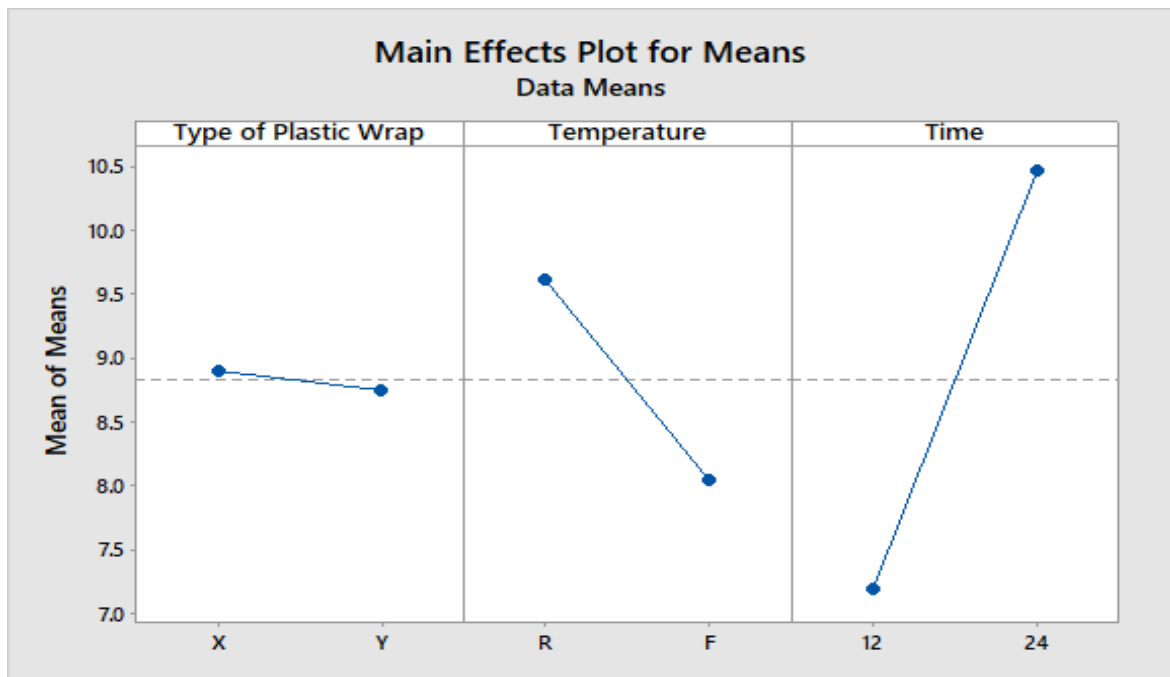


Figure 3: Main Effect Plot for Means

According to Figure 2, each type of factors and level affecting the response of experiment, percentage of water loss. From the Main Effect Plot for Means, plastic wrap Y has the ability to reduce percentage of water loss inside the cup with the low number percentage mean. Meanwhile, the lower the storage temperature, the lower percentage of water loss will be produced. Therefore, fridge on 5 °c able to lower the percent of water loss compared to room temperature. Finally, a short period of sample storage, 12 hours, will help to reduce the water loss compared to the longer period, 24 hours. The factors and levels that can be used to minimize the response are Trial 4, Level 2 for type of plastic wrap, Level 2 for temperature and level 1 for time. Time gives the most impact to the percentage of water loss followed by temperature and type of plastic wrap.

3.9 Analysis of Variance (ANOVA)

Analysis of Variance for Means						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Type of Plastic Wrap	1	0.0236	0.0236	0.0236	*	*
Temperature	1	2.4610	2.4610	2.4610	*	*
Time	1	10.6847	10.6847	10.6847	*	*
Residual Error	0	*	*	*		
Total	3	13.1693				

Figure 4: Analysis for Variance Table (ANOVA)

According to Figure 4, all of the factors did give significant impact to the response because of the asterisk (*) symbol on P-Value. Through ANOVA, the contribution of each factor can be calculated by using the formula of:

$$= \frac{SS}{Total\ SS}$$

Where SS = Sum of Square

Table 7: Factor Contribution

Factors	Contribution	Level
Type of Plastic Wrap	0.0236 / 13.1693 = 0.00179	3
Temperature	2.4610 / 13.1693 = 0.18687	2
Time	10.6847 / 13.1693 = 0.81133	1

From Table 7, Time is the factor that give most contribution to the response, percent of water loss. This can be proved through the calculation of contribution value where time is

the highest making it to level 1, temperature in level 2 and type of plastic wrap in level 3. This result is consistent with the analysis on Main Effect Plot for Means.

4.0 Predicted Value

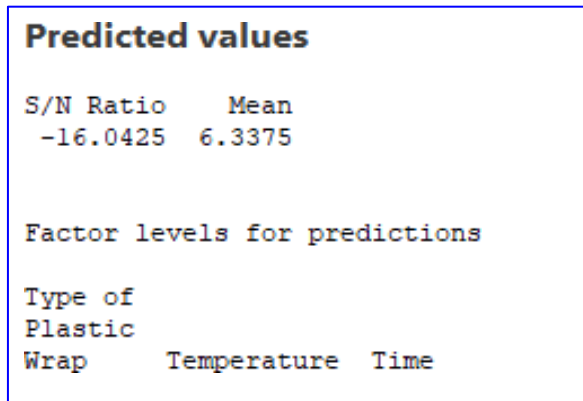


Figure 5: Predicted Value for Percentage of Water Loss

The predicted amount on percentage of water loss under optimum value is produced from Minitab Software. The predicted values are then compared with the actual value to find the result variation from its target.

Table 8: Deviation Measurement

	Predicted Value	Actual Value	Deviation
Mean	6.3375	6.34	6.34 - 6.3375 = 0.0025
S/N Ratio	-16.0425	-16.425	-16.0425 - - 16.425 = 0.3825

From Table 8, the deviation of mean value is less compared to S/N Ratio. The deviation of mean value indicates that the mean is near to achieving its target value while the deviation of S/N ratio shows the data has a widespread on it make it become not precise and accurate.

5.0 Conclusion

In conclusion, this experiment will be able to show or to study about the permeability of plastic wrap in preventing through a different type of factors. The relationship between output and factors of the process also can be determined with the application of the Taguchi methods. The analysis made on the result also produced findings throughout the study that will give benefits to the consumers in selecting the best type of plastic wrap to use in the consumers daily life.

5.1 Significant of Experiment

The purpose of this study is to gain a better knowledge of the usage of natural polymer-based cling films for food packaging, such as protein-based edible films and cellulose and its derivatives. Protein-based edible films provide an alternate packaging source for a variety of food products, reducing moisture loss, limiting oxygen absorption, reducing lipid migration, increasing mechanical handling capabilities, and providing physical protection to food. Cellulose derivatives are a type of natural polymer in which cellulose has been inflated to produce films with increased tensile strength and better water vapor characteristics. However, research is currently focused on blending, stacking, and filling cellulose derivatives with various biopolymers or synthetic polymers to improve the performance.

By this experiment, the consumers should be able to determine which of the materials of plastic wrap that is lease permeable to water vapor or in other words which material is the best to prevent evaporation in different conditions at a different temperature. Next, the consumers also should be able to save time and cost in selecting which plastic wrap to be used at different conditions at a different temperature.

6.0 References

- [1] Science Buddies Staff. (2020, November 20). Polymer Permeability: Which Plastic Wrap Prevents Evaporation Best? Retrieved from https://www.sciencebuddies.org/science-fair-projects/project-ideas/Chem_p032/chemistry/which-plastic-wrap-prevents-evaporation-best
- [2] Siracusa, V. (2012). Food packaging permeability behaviour: A report. *International Journal of Polymer Science*, 2012, 1–11. <https://doi.org/10.1155/2012/302029>
- [3] Siracusa, V., & Ingraio, C. (2017). Correlation amongst gas barrier behaviour, temperature, and thickness in BOPP films for food packaging usage: A lab-scale testing experience. *Polymer Testing*, 59, 277-289.

- [4] Jasse, B., Seuvre, A. M., & Mathlouthi, M. (1994). Permeability and structure in polymeric packaging materials. In *Food packaging and preservation* (pp. 1-22). Springer, Boston, MA.
- [5] Mathlouthi, M. (Ed.). (1994). *Food packaging and preservation*. Springer Science & Business Media.
- [6] Fotie, G., Amoroso, L., Muratore, G., & Piergiovanni, L. (2018). Carbon dioxide diffusion at different relative humidity through coating of cellulose nanocrystals for food packaging applications. *Food Packaging and Shelf Life*, 18, 62-70.
- [7] Ashley, R. J. (1985). Permeability and plastics packaging. In *Polymer permeability* (pp. 269-308). Springer, Dordrecht.
- [8] Houck, L. G., Jenner, J. F., Moreno, D. S., & Mackey, B. E. (1989). Permeability of polymer film wraps for citrus fruit fumigated with hydrogen cyanide to control California red scale. *Journal of the American Society for Horticultural Science*.
- [9] Malhotra, B. H. A. N. U., Keshwani, A., & Kharkwal, H. A. R. S. H. A. (2015). Natural polymer-based cling films for food packaging. *Int. J. Pharm. Pharm. Sci*, 7(4), 10-18.
- [10] Barlow, C. Y., & Morgan, D. C. (2013). Polymer film packaging for food: An environmental assessment. *Resources, Conservation and Recycling*, 78, 74-80