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Assessing packaged food durability using environmental simulation models

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Abstract
The equilibrium moisture content (EMC) of biscuits was determined using the static method at four distinct temperatures (20 °C, 30 °C, 40 °C, and 50 °C) and five varying relative humidity levels (ranging from 20.1% to 93.2%). The results indicated that the equilibrium moisture content of the biscuits ranged from 5.42% to 23.57% (on a dry basis) across the experimental conditions of temperature and relative humidity. Using the developed model, a simulation study was conducted across five selected storage locations in the country: Visakhapatnam, Barmer, Pune, Srinagar, and Leh. These were selected on the basis of climatic conditions. The simulation results showed that the biscuits would remain safe for approximately 50, 54, 60, 70, and 165 days during the rainy season in Visakhapatnam, Barmer, Pune, Srinagar, and Leh, respectively, when packed in 50 µm LDPE film. This model can be a valuable tool for selecting the appropriate packaging material based on varying storage environments.

Keywords: LDPE, EMC, relative humidity, water vapour pressure, permeability

Introduction

The shelf life of packaged foods is a vital consideration in food preservation, affecting both food quality and safety. Environmental factors such as temperature, relative humidity, light, and oxygen availability significantly influence the deterioration processes of food. For instance, increased temperatures can accelerate chemical reactions like oxidation, leading to loss of nutrients, flavor, and texture [1]. Similarly, relative humidity impacts moisture absorption, which in turn can lead to microbial growth or texture changes in food [2]. Therefore, understanding these factors and their interaction with different packaging materials is crucial for optimizing food preservation strategies. Advances in simulation modeling have proven to be an effective tool in predicting the shelf life of packaged foods under varying environmental conditions. Simulation approaches offer the advantage of assessing food stability without the need for extensive and time-consuming real-life experiments. These models consider factors such as temperature fluctuations, humidity levels, and packaging characteristics, providing insights into how they impact food quality [3]. Additionally, the integration of artificial intelligence and machine learning into food packaging simulations has further enhanced the accuracy and applicability of these models [4]. Recent studies have focused on the environmental influence of packaging on the shelf life of specific food categories. For instance, [5] explored how different types of packaging materials, when exposed to variable temperature and humidity levels, affect the shelf life of perishable food products such as fruits and vegetables. Their findings highlighted the importance of choosing the appropriate packaging material to maintain food safety under fluctuating environmental conditions. Similarly, [6] investigated the combined effect of light exposure and temperature on the shelf life of dairy products, demonstrating that these factors can significantly alter product stability over time.

Protein rich biscuits can be prepared from composite flours, such as wheat flour fortified with soy, cottonseed, peanut or corn germ flours [7]. The rancidity of biscuits is accelerated by ultra-violet radiation as well as high temperature, which can be controlled using suitable packaging materials [8]. Biscuits are manufactured in most countries of the world and although Britain led the industrialization of biscuits and also popularized biscuits at least through her former colonies [9]. On an average, Indians eat 0.48 kg every year, while Americans eat 4.02 kg. The annual sales turn-over of a popular biscuit brand is 179.9 million kg. (Reference: Indian Food Industry [10]. It is generally recognized that these products are cereal based and baked to a moisture content of less than 5% [11]. The cereal components is variously increased with two major ingredients, fat and sugar, but there after the possible composition is almost endless Prediction of shelf life of food product stored under different environmental condition is important. Shelf life depends on the large number of factors such as temperature, equilibrium relative humidity, oxygen partial pressure, light, package permeability and package configuration.

Thus a number of factors affect the shelf life of food product. Sometimes, it becomes difficult to study the effect of many factors experimentally. The process becomes expensive and time consuming. Alternatively, a simulation model can be developed which shall be tested with the experimental data. After validation, the developed model can be used for the prediction of shelf life under different storage environmental conditions.

Materials and Methods

A semi permeable film transports water vapour across its thickness by virtue of vapour pressure difference across the film (Fick's and Henry's Laws). The rate of transport of water is given by rearranging the variable.

$$\frac{dw}{dt} = \frac{KwA(P1-P2)}{X} = \quad (1)$$

Where,
W = Weight of water transported across film, g
t = Time, days
Kw = Permeability of film, g mil/m^2 day mm Hg
X = Film thickness, mil
A = Area of film, m^2
P_1 = External water vapour pressure, mm Hg
P_2 = Internal water vapour pressure, mm Hg

Eqn. (1) can be written in terms of moisture in the packages by substituting moisture content for the water transported as follow:

$$m = \frac{W}{Ws} \quad (2)$$

Where,
m = moisture content (g H_2O/g solids)
W = Weight of water transported across the packaging film, g
W_S = Dry weight of enclosed food, g
Hence, Eqn. (1) becomes

$$\left[\frac{dm}{dt} = \left[\frac{Kw}{X}\right]\left[\frac{A}{Ws}\right](P1-P2)\right] \quad (3)$$

Let a_1 and a_2 be external and internal water activity, respectively, Thus

$$a1 = \frac{P1}{Po} \text{ and } a2 = \frac{P2}{Po}$$

Where,
P_0 = Saturation pressure of water vapour at the given temperature, T.
By substituting P_1 and P_2, Eqn. (3) becomes

$$\frac{dm}{dt} = \frac{KwAPo}{(XWs)(a1-a2)} \quad (4)$$

$$\triangle m = \{(KW - A.PO)/(X.Ws)\}(a1 - a2)\triangle t \quad (5)$$

Where,

$$K = (Kw.A.P_0)/(X.W_s) \quad (6)$$

In the Eqn. (5), only known is the internal package water activity, which is a function of material inside the package. The major resistance is in the film and it is assumed that rapidly equilibrates with the food. The internal water activity then is safely determined by water sorption isotherm of the food. Eqn (5) implies that two packages have an identical behaviour as long as the coefficient K remain the same for both packages irrespective of the individual values of the constants.

Computer simulation yields the most cost effective packaging design. Later real time storages studies serve the purpose of legal requirements and conformation of predicted results. Difference between predicted and actual result can be used as indices to check initial assumption for example, poor seals will shorten actual shelf life achieved with an otherwise adequate barrier material. In this example the false assumption is that the material value is equivalent to package permeation. Simulated studies extend beyond the one package/one condition study. Parameters can be changed to affect another study. A survey of potential new packaging material can be accompolished without need to retest the product. Only change is material parameter need to be entered to test performance. To see the effect of storage place on the shelf life of biscuit packed in packaging film, five different places in the country were selected on the basis of their environmental condition. The selected places were Barmer, Visakhapatnam, Leh, Srinagar and Poona. The temperature and relative humidity of selected places are presented in Table.1.

Table 1: Temperature and relative humidity of selected places

Places	Winter		Rainy	
	Temp. (°C)	RH. (%)	Temp. (°C)	RH. (%)
Barmer	17.5	39	34.4	71
Visakhapatnam	22.6	78	30.9	90
Leh	-8.4	38	17.5	62
Srinagar	1.1	64	24.6	85
Poona	21.1	39	29.9	80

Results and Discussion

After validation and the sensitivity analysis of the developed model, the simulation study was carried out. The study was carried out for two extreme weather condition that is winter and the rainy season. The shelf life of product calculated was 50, 54, 60, 70 and 165 days for Visakhapatnam, Barmer, Poona, Srinagar and Leh respectively for the rainy season (Table. 2). It indicates that the present packaging material which is being used by biscuit manufacturer is not suitable for rainy season for most of the cities of the country except Leh. Therefore precaution need to be taken for packaging of biscuit to be distributed in rainy season.

Table 2: Effect of storage place on the moisture content of biscuits packed in 50 µ LDPE film.

Days	Barmer		Visakhapatnam		Leh		Srinagar		Poona	
	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy
0	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
10	1.16	1.70	1.45	1.83	1.03	1.26	1.10	1.55	1.20	1.70
20	1.32	2.53	1.88	2.65	1.06	1.51	1.18	2.08	1.40	2.38
30	1.47	3.28	2.31	3.44	1.08	1.76	1.27	2.61	1.59	3.05
40	1.63	4.01	2.74	4.23	1.10	2.26	1.36	3.13	1.78	3.71
50	1.78	4.74	3.16	5.00	1.12	2.51	1.44	3.65	1.97	4.37
60	1.93	5.02	3.56		1.15	2.75	1.53	4.16	2.16	5.01
70	2.08		4.00		1.17	2.99	1.61	4.67	2.35	
80	2.23		4.41		1.19	3.24	1.70	5.02	2.54	
90	2.30		4.82		1.21	3.48	1.78		2.72	
100	2.39		5.04		1.24	3.72	1.87		2.91	
110	2.54				1.26	3.96	1.95		3.10	
120	2.69				1.28	4.19	2.04		3.28	
130	2.84				1.30	4.43	2.12		3.47	
140	2.98				1.33	4.66	2.22		3.65	
150	3.13				1.35	4.90	2.29		3.83	
160	3.28				1.37	5.01	2.38		4.02	
170	3.43				1.39		2.46		4.20	
180	3.71				1.41		2.54		4.36	
Days*	264	54	95	50	1785	165	466	77	213	60

*No. of days to reach 5% moisture content

Conclusions

The effect of storage conditions on the shelf life of packed materials was studied in various locations across the country, selected based on their environmental factors. During the rainy season, the shortest shelf life observed was 50 days in Visakhapatnam, while Leh recorded a much longer shelf life of 165 days. In contrast, during the winter season, the minimum shelf life for Visakhapatnam increased to 95 days.

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