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Artículos científicos

Determinación de la vida útil de la tortilla de maíz adicionada con aceite esencial de tomillo a través de pruebas de vida acelerada

Determination of Useful Life on Corn Tortilla Added with Thyme Essential Oil Through Accelerated Life Test

Determinação da vida útil de tortilla de milho adicionada com óleo essencial de tomilho por meio de testes de vida acelerada

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Resumen

La tortilla de maíz es uno de los principales componentes en la dieta del mexicano. En el proceso de elaboración, se emplean diferentes conservadores químicos, como el propionato de sodio y algunos acidificantes para incrementar la vida de anaquel de la tortilla de maíz. En México, al no haber una regulación bien definida sobre la adición de conservadores químicos, no existe protección hacia el consumidor. De aquí que esta investigación propone la adición de aceite esencial de tomillo como bioconservador. La metodología utilizada consistió en dos experimentos por separado: uno utilizando una concentración de 0.09 % de aceite esencial de tomillo y otro utilizando propionato de sodio a 0.2 %. Así, usando el modelo de Arrhenius, se calculó la vida útil de la tortilla de maíz adicionada con aceite esencial de tomillo a 21 °C y se encontró que fue de 104.3356 horas, mientras que para la tortilla adicionada con propionato de sodio, bajo las mismas condiciones, se obtuvo una vida de 75.3300 horas. Asimismo, mediante el factor de aceleración, se obtuvo un mejor desempeño del aceite esencial de tomillo como conservador orgánico, en contraste con el propionato de sodio. En suma, no solo mejora la inocuidad alimentaria del producto en cuanto a su vida de anaquel, sino que el aceite esencial de tomillo puede reemplazar a un conservador cancerígeno en la preparación de tortillas de maíz.

Palabras clave: aceite esencial de tomillo, confiabilidad, modelo Arrhenius-Weibull, relación Arrhenius, tortilla de maíz, vida útil.

Abstract

The corn *tortilla* is one of the main components in the Mexican diet. In the manufacturing process, different chemical preservatives are used, such as sodium propionate and some acidifiers to increase the shelf life of the corn *tortilla*. In Mexico, as there is no well-defined regulation on the addition of chemical preservatives, there is no consumer protection. Hence, this research proposes the addition of thyme essential oil as a bioconservative. The methodology used consisted of two separate experiments: one using a concentration of 0.09 % of thyme essential oil and the other using 0.2 % sodium propionate. Thus, using the Arrhenius model, the useful life of the corn tortilla added with thyme essential oil at 21 ° C was calculated and it was found to be 104.3356 hours, while for the tortilla added with sodium propionate, under the Same conditions, a life of 75.3300 hours was obtained. Likewise, through the acceleration factor, a better performance of thyme essential oil was obtained as an organic preservative, in contrast to sodium propionate. In sum, not only does it improve the food safety of the product in terms of its shelf life, but thyme essential oil can replace a carcinogenic preservative in the preparation of corn tortillas.

Keywords: thyme essential oil, reliability, Arrhenius-Weibull model, Arrhenius ratio, corn tortilla, shelf life.

Resumo

A tortilha de milho é um dos principais componentes da dieta mexicana. No processo de fabricação, são utilizados diversos conservantes químicos, como o propionato de sódio e alguns acidificantes, para aumentar a vida útil da tortilha de milho. No México, como não existe uma regulamentação bem definida sobre a adição de conservantes químicos, não há proteção ao consumidor. Assim, esta pesquisa propõe a adição de óleo essencial de tomilho como bioconservador. A metodologia utilizada consistiu em dois experimentos distintos: um utilizando uma concentração de 0,09% de óleo essencial de tomilho e outro utilizando propionato de sódio 0,2%. Assim, usando o modelo de Arrhenius, a vida útil da tortilha de milho adicionada com óleo essencial de tomilho a 21 ° C foi calculada e encontrada em 104,3356 horas, enquanto para a tortilha adicionada com propionato de sódio, nas mesmas condições, uma vida de 75.3300 horas. Da mesma forma, por meio do fator de aceleração, obteve-se um melhor desempenho do óleo essencial de tomilho como conservante orgânico, ao contrário do propionato de sódio. Em suma, além de melhorar a segurança alimentar do produto em termos de prazo de validade, o óleo essencial de tomilho pode substituir um conservante cancerígeno na preparação de tortilhas de milho.

Palavras-chave: óleo essencial de tomilho, confiabilidade, modelo de Arrhenius-Weibull, razão de Arrhenius, tortilha de milho, vida de prateleira.

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Introduction

The corn tortilla is one of the foods most consumed by Mexicans, together with others whose base is also corn, such as totopos (fried corn tortilla triangles, from Nahuatl totopochtli), corn flour and oil and a great variety of fried foods, among others. The National Survey of Household Income and Expenditure (Enigh) estimated that, as of the third quarter of 2018, the annual consumption of corn tortillas per household was 264.7 kg and 74.6 kg per individual (Center for Studies for Sustainable Rural Development and Food Sovereignty [Cedrssa], 2019). The corn tortilla is highly perishable and is affected at a microbiological level by fungi of the genus Aspergillus (which produce aflatoxins, mycotoxins that pose a serious danger to human health) (Wall et al., 2019). For this reason, within the process of making the tortilla, different chemical products are used to improve its appearance, flavor and durability. And in this line, sodium propionate is one of the most used preservatives, whose harmful effects on health (obesity, diabetes, among other diseases) have been recorded in different publications (Darwiche et al., 2001; Hoseinifar, Safari and Dadar, 2017; Türkoğlu, 2008; Zengin, Yüzbaşıoğlu, Unal, Yılmaz and Aksoy, 2011). This is where the interest arises to research, develop and apply a safe, efficient and economical naturally derived food preservative. Likewise, this research aims to disseminate the importance of reliability models so that they are considered in the study plans in higher education institutions, where appropriate, in order to apply them in the analysis of the useful life of various products.

The properties of essential oils derived from plants have been recognized empirically for centuries, but scientifically confirmed only recently. Indeed, it has recently been found that they can be used as antimicrobial and antioxidant agents in food products both to extend their shelf life and to maintain and enhance their quality and organoleptic characteristics (Regnier et al 2012; Smith et al 2001). Today the concern for consuming healthy and natural foods, free of chemical additives and preservatives, has increased. In this research, thyme essential oil was evaluated as a preservative in the corn tortilla to contrast its efficiency with respect to sodium propionate.

Quality is the certainty that a product meets the needs, tastes and preferences of the consumer and reliability is that which guarantees that the product remains in good condition for a certain period of time (in our case, food safety). Inevitably, due to the need to continually update them, the processed food industry has become involved in the dynamics of determining the useful life, best before date and expiration date, among others, of its products, since a poorly estimated date implies wastage or monetary losses (Acuña, 2003). Corradini (2018) indicates that there is a certain time, after having produced the product, in which its sensory and safety properties are maintained, under certain storage conditions. Thus, quality is independent of reliability, that is, knowing whether a product will work over a period of time is a matter of probability.

A reliable product is a product that performs its function at all times, under all operating conditions. It should be noted that the technical definition for reliability differs slightly from the one discussed so far, since it only adds the probability factor: reliability is the probability that a product will not fail under given environmental and functional conditions during a defined period of time (Nelson , 2004). Reliability is assessed by life tests, which are performed in two different ways: standard or accelerated. In the case of the standard mode, the tests are carried out with normal operating parameters and at room temperature; In addition, the current operating time is considered as the test time. In the case of the accelerated mode, parameters such as voltage, temperature, humidity and pressure, among others, are varied above normal values to reduce the test time, or the test could be simply a death test sudden (Zio, 2009).

Theoretical fundament

This section presents the theoretical foundations that support the methodology used in this research. In the introductory section, the most relevant and current information regarding the pertinent frame of reference was reflected.

Model for kinetic degradation

Food spoilage follows zero-order or first-order patterns. These kinetic models are temperature dependent, therefore, the increase in storage temperatures has an accelerating effect on the deterioration of the product (Clancy et al 2016; Haldimann et al., 2013; Peleg, 2019; Van Boekel, nineteen ninety six). The model for the zero order reaction is presented in equation 1.

$$-\frac{dX}{dt} = k \quad (1)$$

Integrating equation 1, we have the equation of a straight line with slope k. It should be noted that here k is the specific reaction constant, the value of which depends on the temperature.

$$X_F = X_0 - k_{tu} \qquad (2)^1$$

Equation 2 mathematically explains the relationship between temperature and the degradation of a food, that is, there is a relationship between the temperature at which a food is stored and how quickly it decomposes.

Arrhenius relationship

According to Peleg et al (2012), the Arrhenius life-stress relationship is widely used as a function of temperature. When faults are accelerated as a result of an increase in temperature, this approach, based on the Arrhenius model (Ebeling, 2010), is used to describe the relationship between the rate of a chemical reaction and temperature. (Rodríguez y Santos, 2008).

$$k = Ae^{\left(\frac{-E_a}{RT}\right)} \qquad (3)$$

In this case, k is the reaction rate constant, R is the ideal gas constant, 8.314472 $\frac{J}{mol \cdot K}$, E_a is the activation energy in $\frac{J}{mol}$, T is the absolute temperature in degrees Kelvin, A is the characteristic pre-exponential factor of the failure mechanism of the product whose units are equal to that of the rate constant. Thus, the nominal failure time τ (vida) it is inversely proportional to the failure rate (Pascual, 2009). This produces the Arrhenius life relation.

$$\tau = Aexp[E_a/(RT)] \qquad (4)$$

The equation of the straight line is obtained by applying the logarithm to the equation 3:

$$lnk = lnA - \frac{E_a}{R} \cdot \frac{1}{T} \qquad (5)$$

The Arrhenius relationship is widely used to explain and calculate the rate at which any product loses functionality when it is "stressed". In reliability engineering, stress is understood as the action of subjecting a product to conditions that are known in advance to

[1] X_0 ordenada al origen.

be adverse, that is, if it is affected by temperature, humidity, vibration, amperage, voltage, to name a few examples. It then uses that variable to accelerate its wear and tear, its failure. In other words, you don't have to wait, for one more example, for a food to spoil in 20 days; if it is “stressed” with a high temperature, in a short period of time (hours), it can cause its decomposition and, through these mathematical approaches, the moment of its actual failure can then be predicted.

Arrhenius-Weibull model

Continuing with the explanation of the previous paragraph, to carry out this failure forecast, it is primarily required to know what is the probability distribution that the useful life data follow, that is, the data obtained from the different samples when they were subjected to extreme conditions (stressful) of operation. In this case, the shelf life of the corn tortilla is affected by the storage temperature, and according to the observed data, the estimated probability distribution corresponds to the Weibull. The mathematical treatment for this case is shown below.

Dahlquist et al. (2016) and Ahmadini and Coolen (2019) mention that the useful life of a product can be described with a Weibull distribution. The assumptions of the Arrhenius-Weibull model are:

- At an absolute temperature T_a, product life has Weibull distribution; the natural logarithm of life has a distribution of extreme values.
- The shape parameter β is a constant independent of temperature; the extreme value distribution of the natural logarithm of life has a constant scale parameter $\delta = {}^{1}/_{\beta}$.
- The natural logarithm of life in Weibull is a linear function of the inverse of temperature.

$$\ln[\alpha(T)] = \gamma_0 + \left({}^{\gamma_1^{'}}/_{T}\right) \quad (6)$$

Parameters $\gamma_0, \gamma_1^{'}$ y β are characteristic of the product $\alpha(T)$ It is expressed as a straight line in the Arrhenius relationship and Weibull percentile lines shown in equation 6.

The reliability of a device is defined as the probability that that device performs its function for at least a certain time under certain conditions (Yin et al 2017). The Arrhenius-adjusted probability density function is expressed in equation 7:

$$f(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{7}$$

Acceleration factor

The acceleration factor refers to the life relationship between the level of use and a higher stress level (stress temperature), as shown by equation 8 (Pina et al 2015).

$$A_f = e^{\left[\left(\frac{E_a}{R}\right)\left(\frac{1}{T}-\frac{1}{T'}\right)\right]} \tag{8}$$

The acceleration factor methodology (A_f) It is an alternative to estimate the number of times that a product survives with respect to its normal operating range, between one reference and another, for example, at room temperature and at a much higher temperature.

Method

Nixtamalized commercial corn flour was used (corn nixtamalization is a pre-Columbian process that consists of cooking the corn kernel in an alkaline solution using calcium hydroxide [Castillo et al, 2009]), thyme essential oil and purified water (water free of impurities to an imperceptible degree). The dough was made by mixing 100 g of corn flour with 160 ml of purified water and adding essential oil (for every 100 grams of flour, 90 microliters of essential oil were added). The mixture was kneaded until no lumps were observed in the dough.

Following the methodology of the Martínez et al (1996) patent, dough discs were made with the following characteristics and approximate conditions (input or independent variables): 45 g of dough for each disc, which were pressed in a manual press, and tortillas with dimensions of a diameter of 15 cm and a thickness of 2 mm were obtained, which are the standard measurements in the local market. The tortillas were cooked on a hot plate at a temperature of 200 ° C. Each tortilla was cooked for 25 seconds on one side and 26 seconds on the other side until inflated and formed the blister on the first side, indicative of the good cooking of the tortilla and its quality. Subsequently, the tortillas were cooled at room temperature for 31 min and packed in polyethylene bags. The tortillas were stored at 25ºC, 30ºC, 35ºC and 40ºC. The shelf life of the tortillas was calculated according to the procedure used by Islam et al (1984) and Martínez et al (2004). For these authors the reference is the time in which the tortillas are kept without showing apparent traces of fungus (output variable of the process). A control was prepared without adding additives to the dough. In addition, tortillas added with 0.2% sodium propionate were prepared to contrast the efficiency. The tortillas obtained were packed and stored under the same conditions as the tortillas with thyme essential oil.

Results

Stress tests were performed at different storage temperatures using Hertherm model 50125590 automatic incubation equipment. The life times of the corn tortilla added with thyme essential oil at 0.09% (output parameter or measurable shelf life in hours) are shown in table 1. Minitab version 17 software was used for the management and analysis of the information. A unifactorial arrangement was used in four levels: 25 ºC, 30 ºC, 35 ºC and 40 ° C, with ten replications at each level.

Tabla 1. Datos de vida de la tortilla de maíz adicionada con aceite esencial de tomillo sometida a diferentes temperaturas

	Temperatura			
	25 °C	30 °C	35 °C	40 °C
Vida (horas)	84	78	60	36
	72	60	48	48
	84	78	66	40
	78	72	60	44
	78	54	66	44
	90	72	60	44
	84	72	60	36
	90	78	48	40
	84	78	60	44
	84	60	54	36

Fuente: Elaboración propia

After performing the normality test on the data shown in table 1 and submitting them to the Kolmogorov-Smirnov test, a p-value of 0.053 was obtained, which indicates that the data statistically show normal behavior.

In addition to the above, a one-factor analysis of variance (Anova) was performed; here the answer is the life in hours of the tortilla until it shows a visible presence of fungus and the factor is the temperature in four levels (25 ° C, 30 ° C, 35 ° C and 40 ° C). The results of the Anova are shown in table 2.

Tabla 2. Análisis de varianza de un solo factor para tortillas de maíz estresada a diferentes temperaturas

Fuente	GL	SC ajust.	MC ajust.	Valor *F*	Valor *p*
Temperatura (°C)	3	9421	3140.40	74.26	0.000
Error	36	1522	42.29		
Total	39	10944			

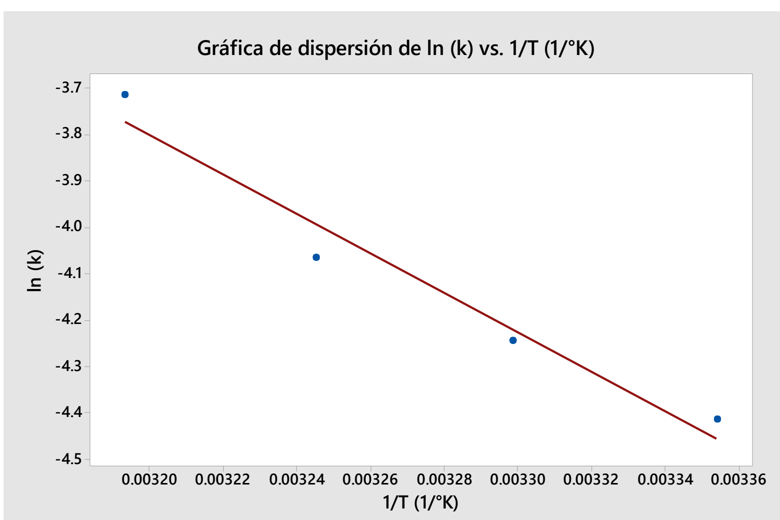
Fuente: Elaboración propia

The calculated p-value is less than 0.05, which indicates that the temperature is significant with respect to the lifetime of the tortilla. With a coefficient of determination R^2 of 86.09 % and R^2 adjusted of 84.93%, it can be said that it has a good linear fit.

Since the reaction rate constant is a function of temperature, this dependence is described by the Arrhenius life relationship. Applying the logarithms, we obtain the equation of a straight line with slope E_a/R, in addition to the values of β_0 and β_1.

For the four stress temperatures, the Arrhenius model was applied, as expressed in equation 3, applying logarithms to both sides of the equation, thanks to which figure 1 was obtained (Minitab) of *ln(k)* based on *1/T*.

Figura 1. Gráfico del *ln(k)* en función de *1/T*



Fuente: Elaboración propia

The simple linear regression equation that is obtained allows estimating the useful life of the corn tortilla added with thyme essential oil for different storage temperatures, expressed in equation 9:

$$\ln(k) = 9.7848 - 4245.3\ 1/T\ (1/°K) \quad (9)$$

With a coefficient of determination R^2 de 95.90 % and R^2 adjusted of 93.86%, it can be said that there is a good linear fit. Activation energy is the minimum energy required for a chemical reaction to occur. Theoretical data reported by Vega et al (2006) suggest that, for corn flour, there is an average activation energy of 8.2480 kcal / mol. In our case, since $E_a/R = \beta_1$, and ln (A) = β_0:

$$E_a = (4245.3)\ (1.987x10^{-3}) = 8.4354 \text{ kcal/mol}$$

If we consider that the reference corresponds to a study reported in Brazil, the results are acceptably similar. Next we have to:

$$A = e^{-9.7848} = 5.630090x10^{-5}$$

Substituting values in equation 4, the half-life a is obtained 21 °C.

$$k = 5.630090x10^{-5}e^{\left(\frac{8.4354}{(1.987x10^{-3})(294.15)}\right)} = 104.3356\ horas$$

The predicted life time for the corn tortilla added with thyme essential oil at 0.09% at a temperature of 21 ° C is 104 hours.

On the other hand, performing the same analysis for the tortillas added with sodium propionate, considering that $E_a/R = \beta_1$, and ln (A) = β_0, we have the following:

$$E_a = (3216.4)\ (1.987x10^{-3}) = 6.3910 \text{ kcal/mol}$$

$$A = e^{-6.6127} = 1.3432x10^{-3}$$

Substituting values in the equation, the half-life is obtained at 21 ° C.

$$k = 1.3432x10^{-3}e^{\left(\frac{6.3910}{(1.987x10^{-3})(294.15)}\right)} = 75.33\ horas$$

Hence, 73 hours is the predicted life time for the corn tortilla added with 0.2% sodium propionate at a temperature of 21 ° C.

The acceleration factor (how many times the product lasts longer at 21 ºC than at 40 ºC) is also estimated for tortillas with thyme essential oil:

$$A_f = e^{\left[\left(\frac{E_a}{R}\right)\left(\frac{1}{T}-\frac{1}{T'}\right)\right]} = e^{\left[\left(\frac{8.4354}{1.987x10^{-3}}\right)\left(\frac{1}{21+273.15}-\frac{1}{40+273.15}\right)\right]} = 2.40048$$

Thus, a corn tortilla remains without visible fungus growth 2.4 times longer at 21 ° C than at 40 ° C. In other words, if a tortilla shows a visible presence of fungus after one hour at 40 ° C, the shelf life of the tortilla will be 2.4 hours at 21 ° C. Similarly, if a tortilla shows no visible fungus in one hour at 40 ° C, the tortilla will survive 2.4 hours at 21 ° C.

Likewise, the useful life of the tortilla added with sodium propionate at 0.2% was calculated and it was stressed under the same conditions as the tortilla added with essential oil of thyme at 0.09%, comparing the useful life times of the added tortillas with thyme essential oil and sodium propionate at different storage temperatures shown in table 3.

Tabla 3. Predicción del tiempo de vida útil de la tortilla de maíz adicionada con aceite esencial de tomillo a 0.09 % y tortilla de maíz adicionada con propionato de sodio a 0.2 %

	Aceite esencial de tomillo a 0.09 %	Propionato de sodio a 0.2 %
Temperatura (°C)	Tiempo de vida útil (horas)	Tiempo de vida útil (horas)
15	140.9142	115.2023
20	109.6029	94.5926
25	85.9706	78.1940
28	74.6015	69.9686
30	67.9762	65.0524
35	54.1594	52.4488

Fuente: Elaboración propia

It is important to note that the industry uses chemical preservatives for three reasons. First, there is no clear regulation regarding the maximum amount to be used in manufactured products. The Mexican standard leaves everything to "good manufacturing practices", despite the vast literature that identifies these conservatives as carcinogens. Second, these chemical preservatives, such as sodium propionate, are very cheap, which invites their indiscriminate use. Finally, few studies propose the use of bioconservatives, such as essential oils. Especially, in corn tortillas there is no literature where essential oils are applied as preservatives.

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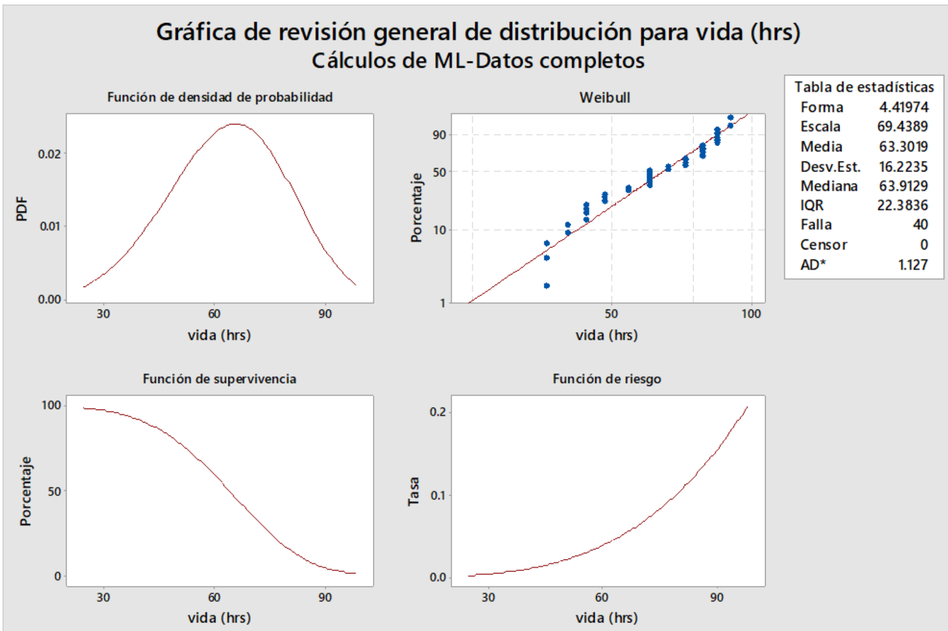
Arrhenius-Weibull model

With the life data in hours obtained and with the Minitab software, the general distribution graph shown in Figure 2 was obtained.

Figura 2. Revisión general de distribución para la vida en horas de la tortilla de maíz adicionada con aceite esencial de tomillo a 0.09 % estresada a diferentes temperaturas



Fuente: Elaboración propia

β is the shape parameter with a value of 4.41974. Thus, substituting the values in equation 7 and taking as an example the probability that the tortilla lasts three days at 21 ° C, the following result is obtained:

$$f(falla\ a\ 72hrs) = \frac{4.41974}{104.3356}\left(\frac{72}{104.3356}\right)^{4.41974-1} e^{-\left(\frac{72}{104.3356}\right)^{4.41974}}$$

$$f(falla\ a\ 72hrs) = 9.81197x10^{-3}$$

That is, the probability that the product fails at 72 hours is 9.81197 x 10^{-3}. The cumulative failure function is also calculated, as shown in equations 7 and 10, together with the shape parameter obtained from figure 2, that the product lives less than 72 hours at 21 °C.

$$F(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{10}$$

Substituting values:

$$F(72\,hrs) = 1 - e^{-\left(\frac{72}{104.3356}\right)^{4.41974}} = 0.1764$$

The probability that the product satisfactorily fulfills the function for which it was designed is calculated with the reliability function as follows.

$$R(t) = e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \quad (11)$$

Substituting data:

$$R(72\,hrs) = e^{-\left(\frac{72}{104.3356}\right)^{4.41974}} = 0.8235$$

It is known that the minimum and maximum room air conditioning temperature in supermarkets is 21 ° C to 26 ° C. Table 4 shows the probability of failure calculated for different temperatures, as well as the cumulative failure function and the reliability function.

Tabla 4. *F(t) y R(t)* a diferentes temperaturas para la tortilla de maíz adicionada con aceite esencial de tomillo a 0.09 %

Temperatura °C	Días	*F(t)*	*R(t)*
21	3	0.17636	0.82363
	4	0.49938	0.50061
	5	0.84356	0.15643
23	3	0.25840	0.74159
	4	0.65564	0.34435
	5	0.94263	0.05736
26	3	0.43197	0.56802
	4	0.86693	0.13306
	5	0.99551	0.00448

Fuente: Elaboración propia

As can be seen in table 4, the lower the time and temperature, the lower the probability of failure, while the reliability function decreases as time and elevated temperatures are higher.

Estimation of failure times

The model for the accelerated test fits the data adequately, allowing a good estimate of the distribution of failure times of a corn tortilla added with thyme essential oil exposed to 21 ° C. Table 5 shows the estimated quantiles of this distribution.

Tabla 5. Estimación de los tiempos de fallo con intervalos de confianza de 95 %

Porcentaje	Duración estimada (horas)	Intervalo de confianza	
		Inferior	Superior
0.1	73.4212	65.5828	82.1964
0.5	77.8448	70.1155	86.4262
1	80.0853	72.4007	88.5855
5	86.5395	78.9198	94.8948
10	90.1902	82.5502	98.5372
20	100.8176	87.0761	103.247
50	108.342	96.0747	113.321
80	114.824	105.449	125.032
90	120.715	110.489	131.887
95	125.807	114.730	137.954
99	135.946	122.902	150.376

Fuente: Elaboración propia

If it is desired to estimate the life at a temperature of 21 ° C, the duration is approximately 104,324 hours. In real situations, it is necessary to estimate a quantile that provides a guarantee to consumers, for example, 90, 95 or 99. In this case, for the 95 quantile the duration would be approximately 125,807 hours, which means that there is a probability of 0.95 that the tortilla shows a visible presence of fungus (failure).

Discussion

For centuries, essential oils have been used for their antimicrobial and antioxidant potential against a wide variety of food products. However, its application is a recent and growing trend that reflects consumer interest in acquiring products with a high nutritional level, a good way to prevent diseases, and towards prolonging the shelf life of food.

Of French origin, Thymus vulgaris, or better known as thyme, is a subshrub of the Lamiaceae family that is perennial and aromatic, rich in essential oil, whose main component is thymol; It is marketed mainly for its leaves and essential oil. The essential oil consists mainly of monoterpenic phenols, such as thymol, carvacrol, p-cymene, gamma-terpinene, limonene, borneol and linalool. However, it must be taken into account that the composition of the essential oil varies according to the time and place of harvest (Borugă et al, 2014).

Thyme essential oil has an antiseptic and antifungal effect superior to that of phenol and hydrogen peroxide. In fact, in the 19th century and the first half of the 20th, when antibiotics were still unknown, thyme was considered an effective disinfectant.

In this research, a design was developed for accelerated life tests and reliability analysis to corn tortillas added with thyme oil in order to establish convenient warranty times when selling the product to customers and impact on warranty expenses and offer a product free of chemical additives. One way to speed up the life of a product is by increasing the temperature in which it is usually found. To extrapolate the results of accelerated life tests at nominal temperature, the most widely used model is the Arrhenius model. Thus, a graph of ln (k) as a function of 1 / T was constructed; the Arrhenius graph yields a straight line from which both the activation energy and the pre-exponential factor can be determined. The activation energy predicted by the Arrhenius equation is 8.43 kcal / mol. The estimated shelf life of corn tortilla added with thyme essential oil at 15 ° C, 25 ° C, 30 ° C and 35 ° C is 140 days, 85 days, 67 days and 54 days, respectively.

With the times and temperatures studied, a general equation was obtained to estimate the useful life of this product for different storage temperatures. The established shelf life equation allows predicting the behavior of the product at the different temperature conditions that can be found in different regions of the country. The importance of using reliability models is that they provide the basis for selecting the experimental strategy that allows obtaining the required information at the minimum cost, as well as the evaluation of the experimental results in the selection of the best option that offers more reliability to the conclusions.

Conclusions

The estimated useful life of the corn tortilla added with thyme essential oil at 0.09% concentration as a preservative at 21 ° C is 104.3 hours, approximately. The life span is relatively shorter by adding 0.2% sodium propionate. It should be noted that, according to NOM-187-SSA1 / SCFI-2002, there is no maximum limit when adding sodium propionate to corn tortillas, it is left to the consideration of the entrepreneur's good manufacturing practices. There is no absolute certainty of the amount of sodium propionate in commercial tortillas.

With life times obtained at different temperatures, the general equation was obtained to estimate the useful life of the corn tortilla added with thyme essential oil at 0.09% for different storage temperatures, which is described by the equation:

$$k = 5.630090x10^{-5}e^{\left(\frac{8.4354}{(1.987x10^{-3})(T)}\right)}$$

The cumulative probability that the product lives less than 72 hours at 21 ° C is F (t) = 0.1764 and the probability that the product satisfactorily fulfills the function for which it was designed for 72 hours at 21 ° C is R (t) = 0.8235. For non-perishable products, such as electronic, mechanical, structural equipment, among others, a reliability of 80% is considered acceptable, according to the reliability engineering literature, so a level of reliability of 82.35% in a perishable product such as the corn tortilla is very acceptable.

On the other hand, the predicted shelf life at a high temperature is short, which is why it is necessary that some packaging technology be used in addition to preserve the life of the corn tortillas. Like many other food products, a cooling system is unavoidable, like a household refrigerator for example, however it is clear that this cooling, by itself, has a minimal positive effect on the preservation of the product.

Future lines of research

In this section some of the findings found in the development of this research are documented so that they serve as a guideline for future research.

Even though it is not the purpose of this research, a strong lack of program content has been found, at the bachelor's and master's level, of the concept and application of reliability engineering, so it is necessary to disseminate the potential of these tools among the academic and professional community, as it is a very effective means of developing new knowledge.

In this research, only the temperature variable was used as the stressful medium to accelerate life tests, however, it is important, for future research, to consider other variables such as light, humidity, pH, etc., so that the degrading operation is more comprehensive.

In the same way, other materials derived from corn should be considered, such as chips, toasted tortillas, prepared flours, etc.

An element that may be important to consider, despite the fact that a perceptible flavor to thyme oil was not found, is a sensory analysis, mainly if these results are extrapolated to other essential oils, such as lemongrass, cloves, etc. .

Although they were not formally included, a priori sensory tests were carried out in which it was found that the taste of thyme is practically imperceptible.

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