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Technological Surveillance and Technology Life Cycle Analysis – Application in Food Drying

Samuel Yepes G (1), Mariana Martínez (2), Samuel Restrepo L (3),), Juan C. Palacio (4), Andrés F Ríos (5), Jhon W. Zartha (6).

[1-6]Pontifical Bolivarian University. School of Engineering, Faculty of Agroindustrial Engineering, Circular 1a. 70-01 Medellín, Colombia.

(Corresponding Author)

Abstract:

This article presents an analysis for the life cycle of technology through S-curves, as well as an exercise on technological surveillance applied to food drying. 13 nonlinear regression models were applied, inflection points for each model were calculated, and models were validated through T and P value calculations. Adjusted R^2 value and Durbin Watson were also assessed. Best adjustment models were determined with a T value higher than 2 or lower than -2, and with a P value lower than 0.005. The models with best adjustment in articles were sigmoidal, logistic and Gompertz, which showed inflection point between the years 2009 and 2012. On the other hand, models with best adjustment on patents were sigmoidal and logistic, which resulted in inflection points in the year 2007. From an article and patent viewpoint, it can be said that food-drying technology is at a maturity stage. Inflection points obtained provide a methodology for academics, researchers and entrepreneurs interested in food-drying technology. This allows them to identify the current state of technology, make better decisions regarding monitoring and investment strategies, and identify whether it is an appropriate time to exercise technological law mechanisms and intellectual property, such as patenting, software registration, and others. The sigmoidal model was a winning model in both articles and patents. This coincides with results obtained in two previous investigations on food-drying. It also agrees with results obtained in other S-curve studies regarding other technologies applied on food, where the sigmoidal model was reported as one of the winners.

Keywords. S-Curve; Technological surveillance; Technology life cycle; Inflection points; Food drying

INTRODUCTION

This article comprehends the application of a methodology to calculate the inflection point of food-drying technology. Concepts regarding food drying and S-curves, materials and methods used are presented emphasizing the need to align mathematical procedures with S-curves applications throughout technology's life cycle. Databases used are mentioned, as well as search strategies for patents and scientific articles on Scopus. Applied mathematical models, procedures to assess inflection points and possible decision-making strategies regarding the state of analyzed technology are also shown. Finally, the results and discussion are presented, establishing conclusions and references.

Drying is an operation that consists of applying a method that separates liquid from solid —that is: the separation of moisture, or occasionally liquids, from a solid [1] Drying technology relates to the separation of a solvent from a solid mixture (sometimes a liquid), in which a product with a lower percentage of moisture is obtained[2][3][4][5] Drying is used in different production processes in the food industry, *i.e.* cocoa [6], maltodextrin, coffee, tea, mate, vitamins, enzymes, antibiotics, liver extract and gums, starches, gluten, protein, soy milk, and carbohydrates (7) It has also been used in fruits, cereals such as corn and sorghum, sugar, animal concentrates, oil seed cakes, milk powder, and other products.

A technology can be analyzed through its performance parameters, for instance, patents and scientific articles published in specialized journals. These parameters accumulated overtime result in an S-shaped graph showing the phases or stages of technology's life cycle, as is shown in Figure 1 [8] [9].

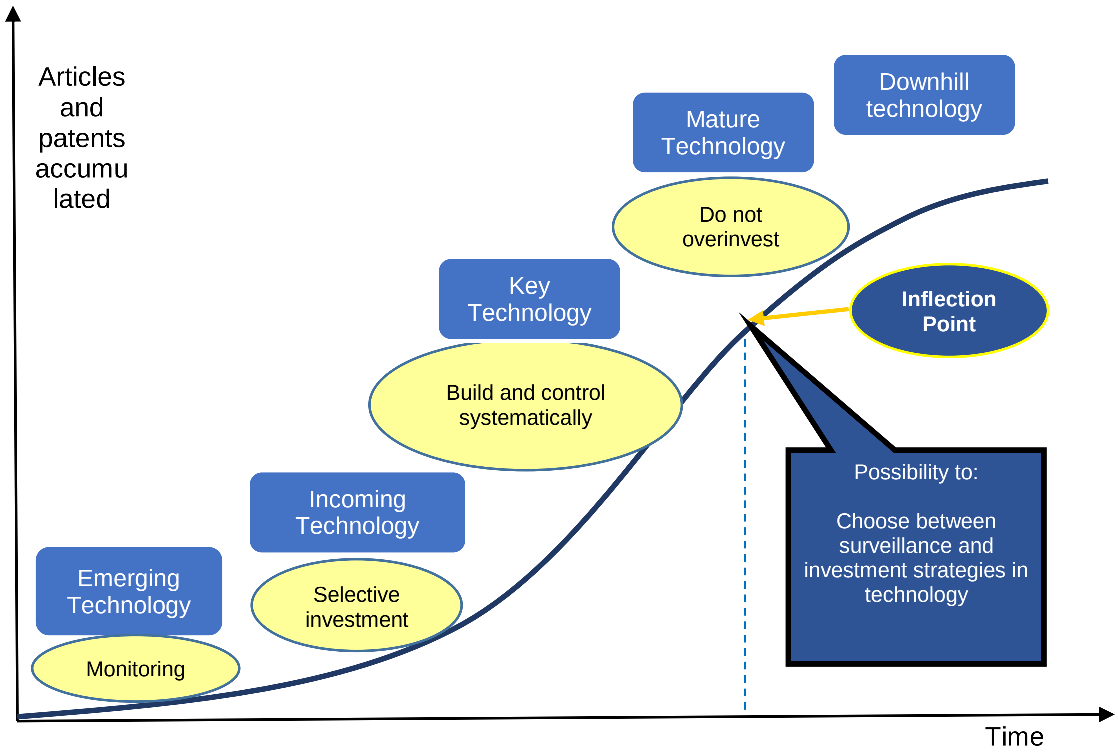

Figure 1. State of technology

Source: Adapted from Ortiz & Pedroza [9].

The previous graph shows how technology can be in an emerging, incoming, key, mature or declining phase. These moments can be analyzed through the calculation for inflection points.

S-curves have been applied in diverse fields of knowledge, but mostly they are used to represent technological trajectories. At a qualitative level, S-curves have been applied in technologies and innovations and have proven useful when approximations to technology's life cycle are to be made, as well as to adequate timing to create technological rights mechanisms and intellectual property [10] and the possibility of applying strategies [9] [11].

In terms of S-curves and their usefulness for innovation analysis, previous studies explain that innovations "are associated to a series of market, commerce and technological uncertainties, which increase with the demand of information and knowledge about variables that intervene in the launching of new products and the improvement of existing ones [12] [13] [14] [15] [11].

Schiling & Esmundo [16] make contributions regarding alternative energy sources, considering a qualitative vantage point. [17] [15] and Zartha, [18] [19] [11] study different applications in the agricultural business, financial sector, chemistry, biodegradable packaging, biotechnology, among other sectors.

S-curve uses can be multiple, since they allow the study of product life cycle. They facilitate analysis that indicate convenient timing to protect or negotiate a technology, as well as establish the appropriate moment to invest radically or incrementally. The state of maturity for technology can be seen in Figure 2 [10].

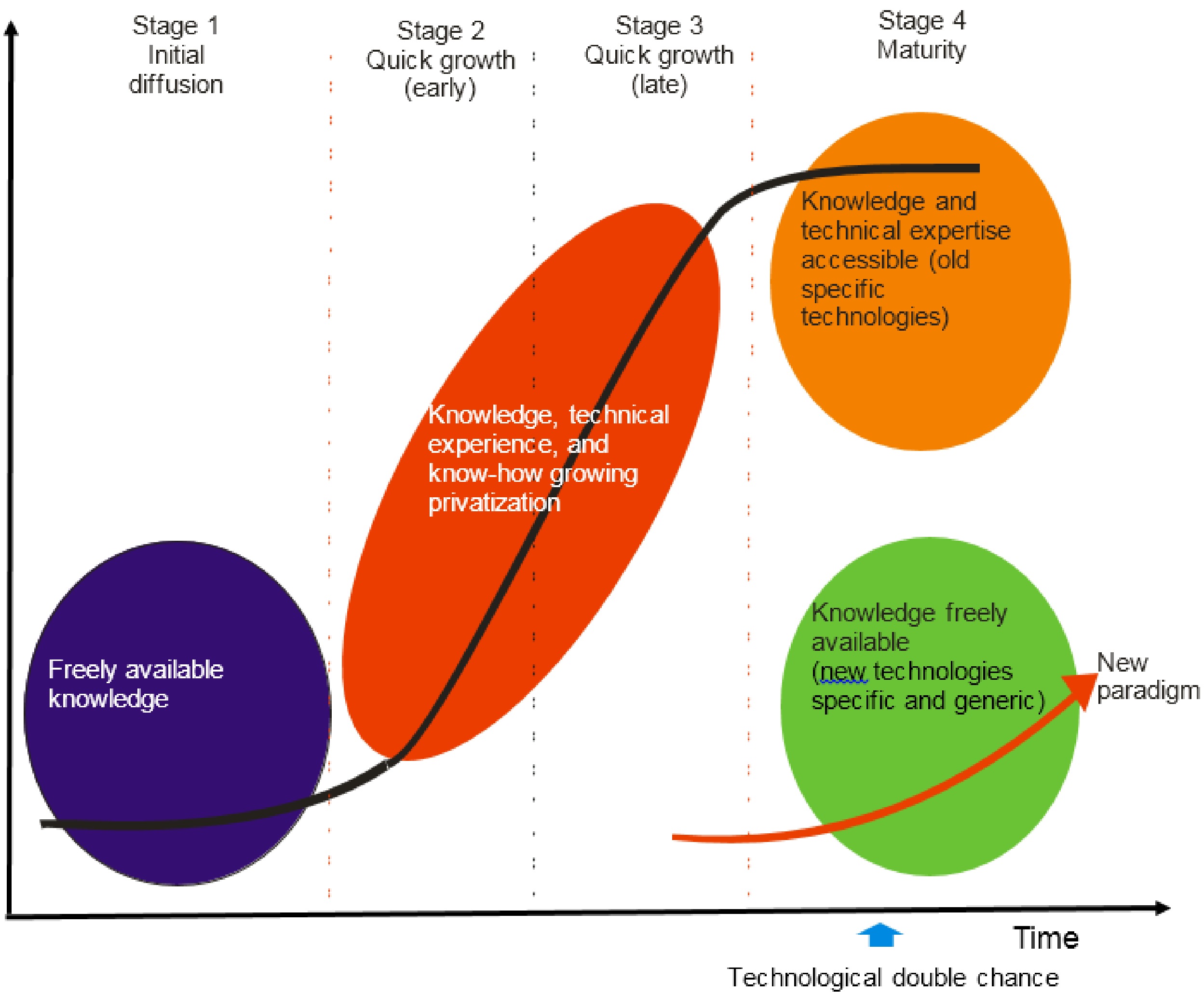

Figure 2. S-Curve stages. Maturity level.

Source: Adapted from Pérez [10]

MATERIALS AND METHODS:

Methodology was developed in the following stages:

Stage 1: Selection of accumulated data. Search equations or strategies were established in the Scopus database, both for articles and patents, using key terms or critical surveillance factors. A time series was organized with accumulated patents and articles from obtained documents.

Stage 2: S-curve model application. Accumulated data obtained in articles and patents were run through the free version of the Sigmaplot software. All 13 preset models were applied: sigmoidal 3, 4 and 5 parameters, logistic 3 and 4 parameters, Weibull 4 and 5 parameters, Gompertz 3 and 4 parameters, Hill 3 and 4 parameters, and Chapman 4 and 4 parameters. Inflection point was calculated through nonlinear regression, in patents and articles, according to each of these models.

Stage 3: Selection of the model with better adjustment. Once results for each of the 13 models were obtained, inflection points and all parameters were validated with T and P values. Models (and their parameters) with values of -2 <T> 2 and P < 0.005 were considered valid —*i.e.*, those with better adjustment. Other indicators such as adjusted R^2 value and Durbin Watson were also taken into account as a complement of validation.

Stage 4a. Technological surveillance elements. A new search equation was created with the same surveillance critical factors or food drying key words. Emphasis was placed in the last five years. The purpose was to analyze aspects such as: article scope, amount of publications per country, authors and institutions related to these works.

Stage 4b. Decision making. Based on results for inflection points on best-adjusted models, contributions were made in terms of the current phase in drying technology's life cycle, adequate timing to exercise technological rights mechanism and intellectual property, as well as recommendations on strategies for monitoring and investment.

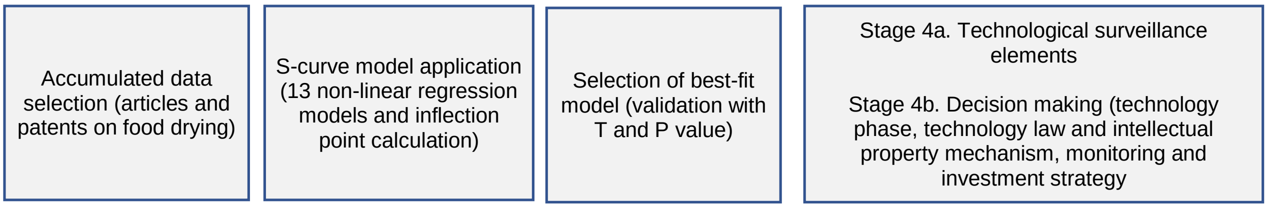

Figure 3. Methodology Stages

Source. Own elaboration.

RESULTS AND DISCUSSION

Here forth, results and data analysis found with article and patent search equations are shown in the table 1.

Table 1. Equation for article search.

Search equation on Scopus for articles about food-drying technology
DOCTYPE (ar) PUBYEAR > 2011 SUBJAREA (agri AND NOT chem AND NOT bioc AND NOT medi AND NOT ceng AND NOT immu AND NOT nurs AND NOT phar AND NOT vete) TITLEABS-KEY ((food OR meals) "drying proces" OR "drying technic" OR "pump dry" OR "dryin technology" OR wipe OR dehydration OR evaporation OR "refractive window drying" OR "dryin tunnel" AND NOT freezer AND NOT cooler AND NOT fridge AND NOT refrigerator)

Source: Own elaboration.

Based on the general search equation, 1,445 total articles were obtained from 1978 to 2017, the time series is shown in the table 2.

Table 2. Time series for general search equation.

Year.	**No. Articles per year.**	**Acummulated.**	**Year.**	**No. Articles per year.**	**Acummulated.**
1978	10	19	1998	26	234
1979	9	28	1999	22	256
1980	7	35	2000	23	279
1981	4	39	2001	47	326
1982	3	42	2002	53	379
1983	3	45	2003	54	433
1984	4	49	2004	85	518
1985	5	54	2005	69	587
1986	3	57	2006	86	673
1987	4	61	2007	96	769
1988	6	67	2008	77	846
1989	14	81	2009	62	908
1990	6	87	2010	53	961
1991	7	94	2011	71	1032

Year.	No. Articles per year.	Acummulated.	Year.	No. Articles per year.	Acummulated.
1992	8	102	2012	57	1089
1993	12	114	2013	79	1168
1994	16	130	2014	92	1260
1995	15	145	2015	97	1357
1996	23	168	2016	77	1434
1997	40	208	2017	11	1445

Source: Own elaboration.

Data obtained with article search equation was plotted in SigmaPlot software with 13 models. Table 3 summarizes the results obtained with the 5 models that met T and P value ranges:

Table 3. S-Curve model application in accumulated articles.

Articles								
	Inflection point	R^2	P		T			
Sigmoidal, 3 parameter	2010	0.9977	Si	0.0001	si	24.2096	0.3064	Meets
			Si	0.0001	si	32.8447		
			Si	0.0001	si	3550.6403		
Sigmoidal, 4 parameter	2009	0.9985	Si	0.0001	si	27.887	0.487	Meets
			Si	0.0001	si	27.2423		
			Si	0.0001	si	4895.1419		
			Si	0.0001	si	4.3601		
Logistic, 3 parameter	2010	0.9978	Si	0.0001	si	22.8831	0.3033	Meets
			Si	0.0001	Si	-40.4914		
			Si	0.0001	si	2043.1664		
Logistic, 4 parameter	2009	0.9985	Si	0.0001	si	27.7013	0.4868	Meets
			Si	0.0001	Si	-27.2497		
			Si	0.0001	si	4846.5248		
			Si	0.0001	si	4.4343		
Gompertz, 4 parameter	2012	0.9982	Si	0.0001	si	11.2659	0.3454	Meets
			Si	0.0001	si	14.9094		
			Si	0.0001	si	1659.3377		
			Si	0.0001	si	8.3796		

Source: Own elaboration.

The models that converge were: sigmoidal 3 parameters, sigmoidal 4 parameters, logistic 3 parameters, sigmoidal 4 parameters, and gompertz 4 parameters.

Models show that the inflection point took place between the years 2009 and 2012. Therefore, according to parameter performance in scientific articles, it can be considered a mature technology (since the inflection point occurred before the time of analysis). The adequate strategy in monitoring and investment would be non-investment, and the strategy on mechanisms of technological law and intellectual property would be that the right moment to exercise these mechanisms was before the turning point (2009-2012). The Figures 4 and 5 show some of the graphics related to the lower adjustment models:

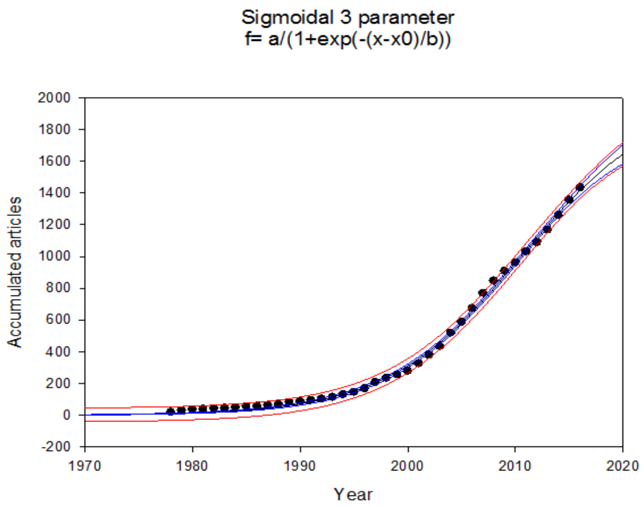

Figure 4. Sigmoidal 3 parameter

Source: Own elaboration

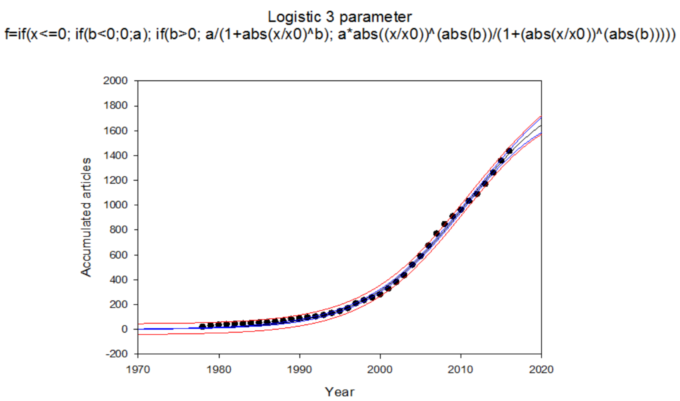

Figure 5. Logistic 3 parameter.

Source: Own elaboration

Patents.

The search equation in Scopus for patents is shown in the table 4.

Table 4. Equation for patent search.

Search equation in Scopus for patents related to food-drying technology
TTL/meals drying OR fruit drying proces AND drying proces ANDNOT (metal AND qhimestry AND textil AND medi).

Source: Own elaboration

Table 5 contains the results that were obtained using said equation:

Table 5. Patent time series.

Year	Amount of patents	Accumulated patents
1997	6	6
1998	15	21
1999	10	31
2000	9	40
2001	12	52
2002	24	76
2003	15	91
2004	20	111
2005	16	127
2006	14	141
2007	15	156
2008	9	165
2009	8	173
2010	10	183
2011	10	193
2012	13	206
2013	17	223
2014	21	244
2015	22	266
2016	11	277
2017	1	278

Source: Own elaboration

Time series obtained with patent search equation were run in Sigmaplot software's free web version. Thirteen preloaded models were applied on these series. Table 6 shows the results for the two models adjusted according to T and P values:

Table 6. Results from the application of S-curve models in accumulated patents.

Patents								
	Inflection point	R^2	P		T		Durbin W	
Sigmoidal, 3 parameter	2007	0.9813	Si	0.0001	si	16.1908	0.2877	Meets
			Si	0.0001	si	10.096		
			Si	0.0001	si	2668.6313		
Logistic, 3 parameter	2007	0.9813	Si	0.0001	si	16.1908	0.2883	Meets
			Si	0.0001	si	10.096		
			Si	0.0001	si	2668.6313		

Source: Own elaboration

The converging models were: Sigmoidal 3 parameters and Logistic 3 parameters.

Both models show the inflection point in 2007. Therefore, according to the performance parameter patent it can be considered a mature technology, the same as with scientific articles, (except in this case the inflection point occurred before, in the year 2007). The adequate strategy in monitoring and investment would be non-investment, and the strategy on mechanisms of technological law and intellectual property would be that the right moment to exercise these mechanisms was before the turning point (2007). The Figures 6-8 show some graphs related to the lower adjustment models:

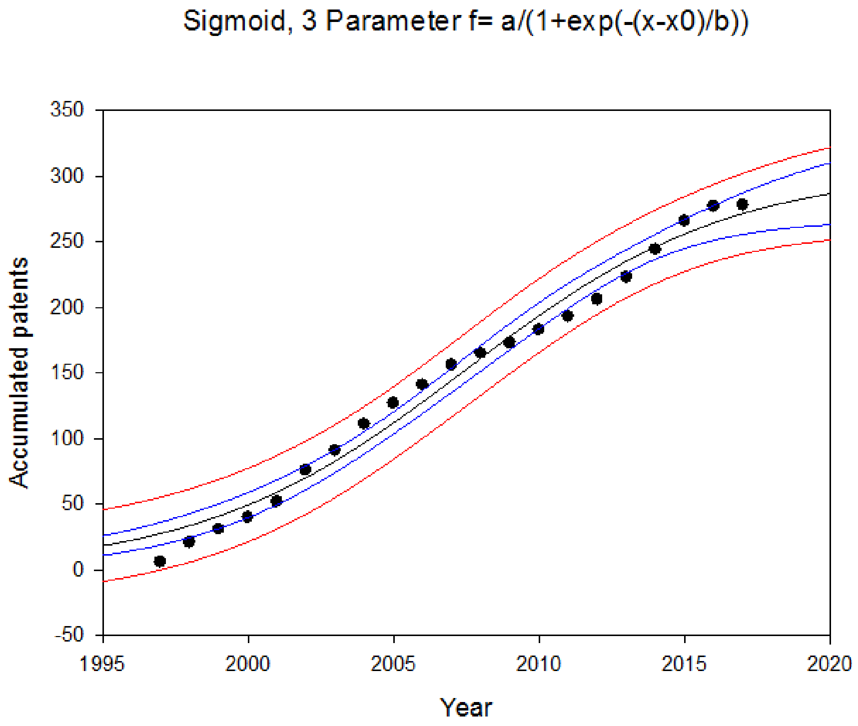

Figure 6. Sigmoidal 3 parameter.

Source: Own elaboration

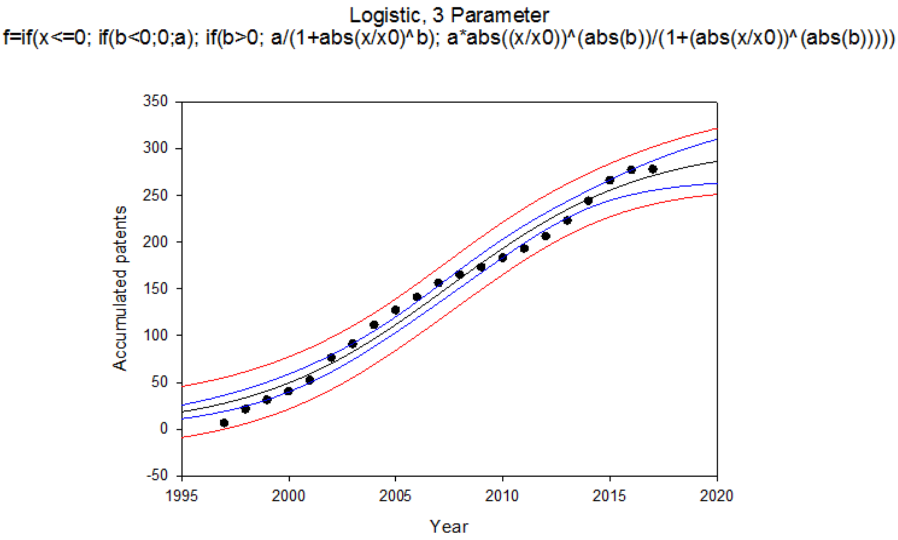

Figure 7. Logistic 3 parameter

Source: Own elaboration

A consolidated analysis shows that the winning models in articles were sigmoidal, logistic, and Gompertz, while on patents the sigmoidal and logistic models were preferred. This coincides with results obtained in previous research about the same drying technology. In the study performed by Zartha [20] the winning model for patents of continuous drying was sigmoidal, and in another study by Zartha, [21] about food-drying technology also resulted in Sigmoidal as the winning model. This model was reported as the winning model in food technologies such as emulsification, sedimentation, centrifugation, cold plasma and high pressures.

The following picture illustrates the phases of food-drying technology's life cycle and possible strategies (input for decision making on this technology) for better understanding:

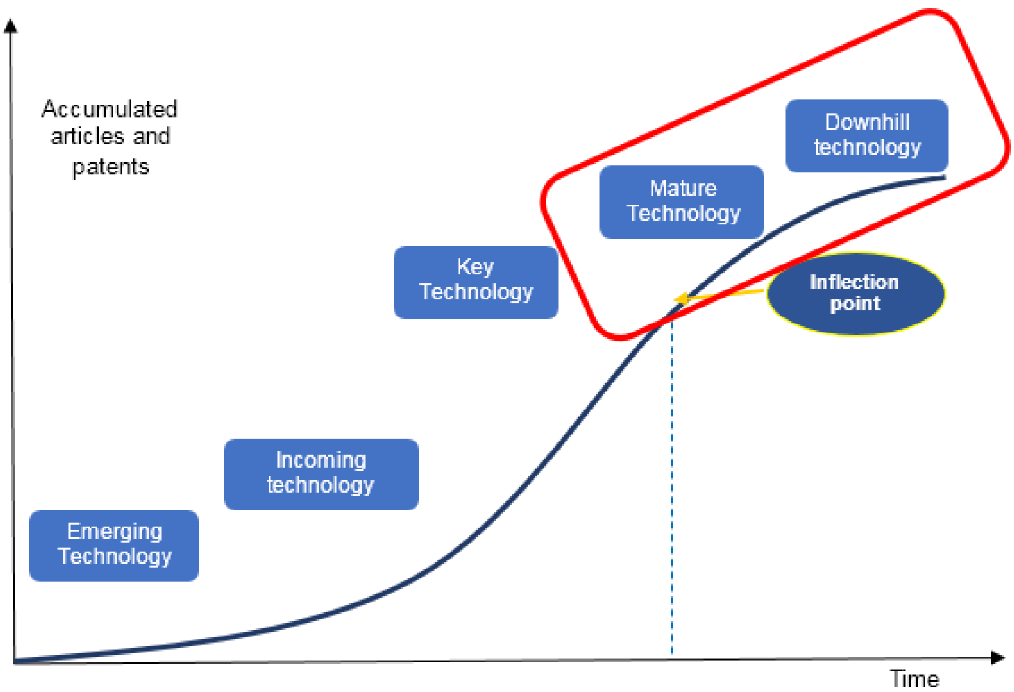

Figure 8. Technology life cycle – food drying

(Source: Own elaboration)

Additionally, documents published in the last 5 years were analyzed, as well as a presentation of their authors, journal impact, publishing year, and a brief summary on their main contributions, consolidated information is on the table 7:

Table 7. Equation for article search – last 5 years

Search equation for articles related to unitary drying operation from the last 5 years.
DOCTYPE (ar) PUBYEAR > 2011 SUBJAREA (agri AND NOT chem AND NOT bioc AND NOT medi AND NOT ceng AND NOT immu AND NOT nurs AND NOT phar AND NOT vete) TITLEABS-KEY ((food OR meals) "drying proces" OR "drying technic" OR "pump dry" OR "dryin technology" OR wipe OR dehydration OR evaporation OR "refractive window drying" OR "dryin tunnel" AND NOT freezer AND NOT cooler AND NOT fridge AND NOT refrigerator)

Source: Own elaboration

As stated in Table 8, 576 articles were obtained and classified by subject area. Later, an emphasis was placed on articles regarding food drying in the Agricultural and Biological Science area.

Table 8. Amount of documents per subject area in the last 5 years.

SUBJECT AREA	***DOCUMENTS***
Agricultural and Biological Sciences	408
Engineering	94
Environmental Science	45
Earth and Planetary Sciences	19
Energy	5
Computer Science	2
Business, Management and Accounting	1
Decision Sciences	1
Materials Science	1

Source: Own elaboration

Figure 9 illustrates the number of articles obtained by country or region in 11 of the 70 countries from whence these articles come. The largest number of articles, 92 documents, come from China, followed by India and the United States with 48 documents, Brazil with 35, 22 from Australia, 21 from Spain, 18 from France, 16 from Italy, 14 from Thailand, 13 from Germany, and 4 articles come from Colombia.

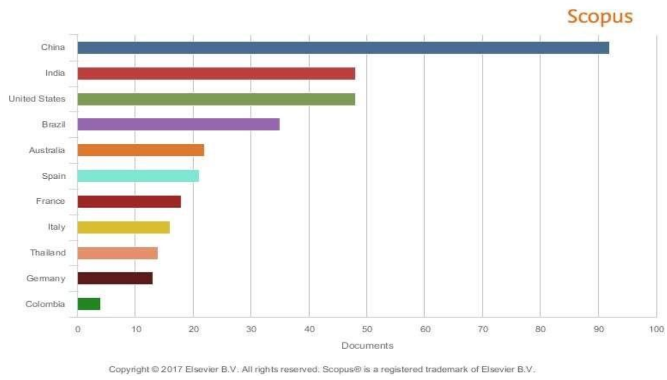

Figure 9. Documents per country/territory. Source: Own elaboration

Moreover, Figure 10 shows 11 out of the 160 associations or institutions from whence the documents obtained come. There are 12 articles from China Agricultural University, 9 from Central Food Technological Research Institute India, 8 from Kasetsart University, 6 from Wageningen University and Research Center, Universitat Politècnica de València, Chinese Academy of Agricultural Sciences, Federal University of Ceara and Ministry of Agriculture Of the People, 5 from Aristotle University of Thessaloniki, State University of Campinas, and 3 articles from the National University of Colombia.

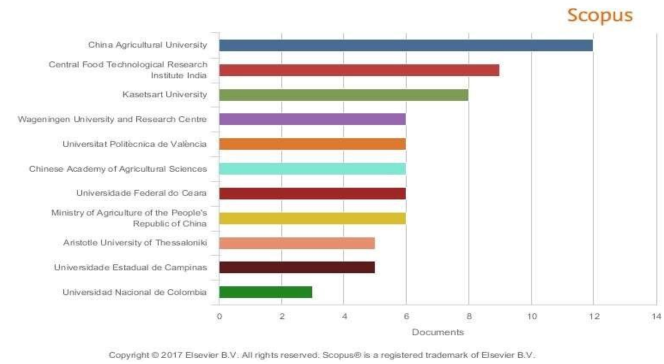

Figure 10. Documents per association or institution. Source: Own elaboration

Journal articles on food drying yielded: 45 articles from *Journal of Food Science and Technology*, 38 from *Journal of Food Engineering*, 32 from *International Journal of Food Science and Technology*, 24 from N*ongye Gongcheng Xuebao Transactions Of The Chinese Society Of Agricultural Engineering* and 19 articles were published in *Lwt Food Science And Technology*. All of these were published between the years 2012 and 2017.

Citation score – CiteScore – among these five journals in the 2011-2015 period was highest for the *Journal of Food Engineering* and Lwt *Food Science And Technology*.

The following Table 9 covers an analysis of sampled articles since 2015, emphasizing their authors, work title, and publishing journal. The sample was obtained according to journal impact.

Table 9. Analysis of sampled articles published between 2015 and 2017 regarding food drying.

SOURCE TITLE	*AUTHORS*	*TITTLE*	*YEAR*	*ABSTRACT*
Journal Of Food Science And Technology	Elik, A., Yanık, D.K., Maskan, M., Göğüş, F.	Influence of three different concentration techniques on evaporation rate, color and phenolics content of blueberry juice	2016	The study was undertaken to assess the effects of three different concentration processes (open-pan, rotary vacuum evaporator and microwave heating) on evaporation rate, color and phenolics content of blueberry juice. Total phenolics loss during concentration was highest in open-pan technique (36.54 %) and lowest in microwave heating at 200 W (34.20 %). Thus, the use of microwave technique could be advantageous in food industry because of production of blueberry juice.
	van Koerten, K.N., Schutyser, M.A.I., Somsen, D., Boom, R.M.	Cross-flow deep fat frying and its effect on fry quality distribution and mobility	2016	Studies the fluidization of rectangular potato chips during frying was characterized with a modified Ergun equation. The mix was visualized by using two colored layers of fries and quantified in terms of entropy mixture. Smaller fries were quickly mixed during frying, while longer fries showed much less mixing, which was attributed to the higher minimum fluidization velocity and slower dehydration for longer fries. The cross-flow velocity found an important parameter for the homogeneity of the moisture content of fries.
	Ilango, S., Pandey, R., Antony, U.	Functional characterization and microencapsulation of probiotic bacteria from koozh	2016	Authors encapsulated several skim milk powder probiotic isolates according to two different drying techniques: lyophilization and spray drying. The encapsulated probiotic isolates survived both in simulated gastric fluid and simulated intestinal fluid with high cell viability (98-99 %). Storage for 16 weeks at room temperature (27 °C), resulted in 2 log reduction, but better survival with only 1 log reduction was observed at 4 °C and was best at -20 °C. Survival of isolates was similar in both spray and freeze dried products.
	Verma, M., Singh, J., Kaur, D., Mishra, V., Rai, G.K.	Effect of various dehydration methods and storage on physicochemical properties of guava powder	2015	The study aimed at evaluating the effect of various dehydration techniques like freeze drying, tunnel drying, sun drying and vacuum drying, about the physiochemical and nutritional properties of guava powder. A higher concentration of ascorbic acid was found in freeze-drying and vacuum techniques. Guava powder dried through lyophilization showed fewer losses due to nutrient oxidation while in storage, as well as maximum mineral content, such as potassium, calcium, phosphorus and iron.
	Horuz, E., Maskan, M.	Hot air and microwave drying of pomegranate (Punica granatum L.) arils	2015	Drying behavior, shrinkage, rehydration, bulk density and color changes of the products in Hicaz type grenades were investigated by means of hot air and microwave drying techniques. The former was carried out at three different temperatures (50, 60 and 70 °C) at 1.0 m/s air

				velocity. For the later, three microwave power levels (210, 350, and 490 W) were studied. It was observed that shrinkage of air dried samples was higher than microwave dried sample. Rate of rehydration of microwave dried aril samples was relatively faster than air dried samples. However, bulk density of air dried samples was higher than those of microwave dried sample.
	Vega-Gálvez, A., Zura-Bravo, L., Lemus-Mondaca, R., Martinez-Monzó, J., Quispe-Fuentes, I., Puente, L., Di Scala, K.	Influence of drying temperature on dietary fiber, rehydration properties, texture and microstructure of Cape gooseberry (Physalis peruviana L.)	2015	The study focused on the effects of air-drying temperature on dietary fiber, texture and microstructure of the Cape gooseberry fruits in the range of 50–90 ºC. At 50-ºC, tissue structure damage was evidenced leading to the maximum water holding capacity and the lowest rehydration ratio. Changes in microstructure tissue were also observed at the studied drying temperatures. Hot air drying technology leads not only to fruit preservation but also increases and adds value to Cape gooseberry.
	Sengupta, A., Gupta, S.S., Nandi, I., Ghosh, M.	Conjugated linolenic acid nanoparticles inhibit hypercholesterolemia induced by feeding a high-fat diet in male albino rats	2015	The study was designed to clarify the effects of two types of CLnA rich oil nanocapsules on hypercholesterolemia induced by feeding a high-fat diet in male albino rats. CLnA rich oil nanocapsules were prepared by the ultrasonication method and the freeze-drying technique. Results showed that CLnA rich oil nanocapsules reduced the blood lipids, tissue lipids and plasma viscosity significantly. This paper is the first report of the lipid-lowering effects of CLnA rich oil nanocapsules suggesting that the CLnA rich oil nanocapsules could be used for the treatment of hypercholesterolemia.
International Journal Of Food Science And Technology	Sette, P., Franceschinis, L., Schebor, C., Salvatori, D.	Fruit snacks from raspberries: influence of drying parameters on color degradation and bioactive potential	2017	Raspberries were dehydrated using air and freeze-drying with wet and dry sugar infusion pretreatments. Product quality factors such as color, bioactive compounds, antioxidant capacity and sensorial characteristics were analyzed. Freeze-dried raspberries presented a higher retention of bioactive compounds and a lower content of polymeric compounds than air-dried ones. Dried samples without pretreatment (control) showed the highest retention of total phenolic content (freeze-dried ≈82% and air-dried ≈37% retention), but the lowest sensory acceptability. Although sugar infusion pretreatments caused an important loss of bioactive compounds (9–18% of TPC retention), a higher sensorial acceptability was obtained. Pretreatments with bisulphite and acid allowed obtaining the best quality attributes in terms of anthocyanin and polyphenol content, antiradical activity and color retention. Polyphenol intake through pretreated dried raspberries (115–299 mg gallic ac./100 g intake) would be higher in some cases than that of usually consumed foods as vegetables, cereals and several fresh fruits.

Journal Of Food Engineering	Alves, N.N., Messaoud, G.B., Desobry, S., Costa, J.M.C., Rodrigues, S.	Effect of drying technique and feed flow rate on bacterial survival and physicochemical properties of a non-dairy fermented probiotic juice powder	2016	The study evaluates the influence of spray and spouted bed drying and feed flow rate on the microorganism survival and physicochemical properties of probiotic orange juice powder. The spouted bed drying at low feed flow rates using maltodextrin as drying agent were the best parameters to produce powder fermented probiotic orange juice.
	Udomkun, P., Nagle, M., Argyropoulos, D., Mahayothee, B., Müller, J.	Multi-sensor approach to improve optical monitoring of papaya shrinkage during drying	2016	This study aimed to assess the feasibility of a multi-sensor approach for predicting shrinkage of papaya during drying using computer vision methods in combination with optical scattering analysis of light at 650 nm. Multivariate correlations of computer vision parameters and optical scattering properties showed the enhanced performance for shrinkage prediction. This multi-sensor approach could possibly be applied as a fast, accurate and non-invasive technique for in-line quality control to monitor shrinkage in the production of dried fruits.
	Karunasena, H.C.P., Brown, R.J., Gu, Y.T., Senadeera, W.	Application of meshfree methods to numerically simulate microscale deformations of different plant food materials during drying	2015	In this work, meshfree methods are applied to numerically simulate microscale morphological changes of several food materials during drying. The model involves Smoothed Particle Hydrodynamics (SPH) and Discrete Element Method (DEM) to represent fluid and solid phases of the cellular structure. Simulation was conducted on apple, potato, carrot and grape tissues and the results are qualitatively and quantitatively compared and related with experimental findings obtained from the literature. The findings highlighted the potential applicability of the meshfree approach to model large deformations of the plant tissue microstructure during drying, providing a distinct advantage over the state of the art grid-based approaches.
	Franco, T.S., Perussello, C.A., Ellendersen, L.D.S.N., Masson, M.L.	Foam mat drying of yacon juice: Experimental analysis and computer simulation	2015	The foam mat drying of yacon juice (YJ) and concentrate yacon juice (CYJ) was conducted under various conditions of thickness of product (0.5, 1.0 and 1.5 cm) and air temperature (50, 60 and 70 °C). Layer thickness and air temperature influenced statistically ($p > 0.5$) drying time, moisture content and water activity (Aw) of the product. The process was modeled in terms of heat and mass transfer and then simulated by a finite element method software. It was able to predict the process satisfactorily and the foam drying technique allowed to obtain yacon powder of good quality, which can be inserted in various food formulations.
	Quist-Jensen, C.A., Macedonio, F., Conidi, C., Cassano, A., Aljlil, S., Alharbi, O.A., Drioli, E.	Direct contact membrane distillation for the concentration of clarified orange juice	2016	Multi-stage vacuum evaporation is a conventional unit operation in the industrial production of concentrated fruit juices. Membrane processes, such as direct contact membrane distillation (DCMD) and osmotic distillation (OD), offer

				several advantages over the traditional thermal evaporation, since they operate at a lower temperature thus preserving the nutritional and organoleptic properties of the fresh juice.
Lwt Food Science And Technology	Zhao, Y., Takhar, P.S.	Micro X-ray computed tomography and image analysis of frozen potatoes subjected to freeze-thaw cycles	2017	The study focuses on frozen products that are subjected to freeze-thaw cycles during storage and shipping. The objective was to investigate the effect of temperature fluctuations on ice crystal growth/decay in frozen potatoes. X-ray micro-computed tomography (CT) was used to observe the microstructure of frozen potatoes. The total number of pores was reduced with increases in amplitude and duration of freeze-thaw cycles. These results demonstrate that micro-CT and image analysis can be used to analyze the microstructure of frozen materials and obtain valuable information for designing the freezing process.
	Zhao, G., Zhang, R., Liu, L., Deng, Y., Wei, Z., Zhang, Y., Ma, Y., Zhang, M.	Different thermal drying methods affect the phenolic profiles, their bioaccessibility and antioxidant activity in Rhodomyrtus tomentosa (Ait.) Hassk berries	2017	The effects of three thermal drying methods (hot air drying (HD), microwave drying (MD) and combined microwave-hot-air-drying (CD)) on phenolic profiles, their bioaccessibility and antioxidant activity in *Rhodomyrtus tomentosa* berries were estimated. The total phenolics, flavonoids and anthocyanins contents of CD-berries were significantly higher. Conversely, the bioaccessibility of phenolics in HD-berries was remarkably higher than that of MD- and CD-ones, although the latter 2 provided more bioaccessible phenolics than the former after *in vitro* gastrointestinal digestion. Thus, combined microwave-hot-air-drying (CD) is a more suitable drying technique for *Rhodomyrtus tomentosa* berries to maintain their phenolics and antioxidant activity.
	Sogi, D.S., Siddiq, M., Dolan, K.D.	Total phenolics, carotenoids and antioxidant properties of Tommy Atkin mango cubes as affected by drying techniques	2015	Mango cubes were dehydrated using different techniques; lyophilization or freeze-drying, cabinet (hot-air), vacuum and Infra-red (FD, CD, VD, IRD, respectively). Total phenolics, carotenoids, ascorbic acid contents and antioxidant properties of mango powder were determined. Freeze–dried powder had the highest antioxidant properties than those from other drying techniques. Freeze dried powders had the lower bulk density than samples from other drying techniques. Physicochemical characteristics of the freeze- and cabinet-dried mango powders offer potential application in food products.
Critical Reviews In Food Science And Nutrition	Joardder, M.U.H., Kumar, C., Karim, M.A.	Food structure: Its formation and relationships with other properties	2017	This review critically assesses the factors that influence the modification of microstructure in the course of drying of fruits and vegetables. The effect of simultaneous heat and mass transfer on microstructure in various drying methods is investigated. Effects of changes in microstructure on other functional properties of dried foods are discussed. After an extensive review of the

				literature, it is found that development of food structure significantly depends on fresh food properties and process parameters. An enhanced understanding of the relationships between food microstructure, drying process parameters and final product quality will facilitate the energy efficient optimum design of the food processor in order to achieve high-quality food.
	Zhang, M., Chen, H., Mujumdar, A.S., Tang, J., Miao, S., Wang, Y.	Recent developments in high-quality drying of vegetables, fruits, and aquatic products	2017	This paper reviews some new drying technologies developed for dehydration of vegetables, fruits, and aquatic products, which are microwave drying, radio frequency drying, and electrohydrodynamic.
	Ertekin, C., Firat, M.Z.	A comprehensive review of thin-layer drying models used in agricultural products	2017	This study gives a comprehensive review of more than 100 different semitheoretical and empirical thin-layer drying models used in agricultural products and evaluates the statistical criteria for the determination of appropriate model. Many models have been used to describe the drying process for different agricultural products. These models are used to estimate drying time of several products under different drying conditions, and how to increase the drying process efficiency and also to generalize drying curves, for the design and operation of dryers.
	Kamiloglu, S., Toydemir, G., Boyacioglu, D., Beekwilder, J., Hall, R.D., Capanoglu, E.	A Review on the Effect of Drying on Antioxidant Potential of Fruits and Vegetables	2016	Air, freeze, microwave and sun-drying are among the most thoroughly studied drying methods. This review provides an overview of recent findings on the effects of different drying techniques on major antioxidants of fruits and vegetables.
	Pereira, M.C., Hill, L.E., Zambiazi, R.C., Mertens-Talcott, S., Talcott, S., Gomes, C.L.	Nanoencapsulation of hydrophobic phytochemicals using poly (dl-lactide-co-glycolide) (PLGA) for antioxidant and antimicrobial delivery applications: Guabiroba fruit (Campomanesia xanthocarpa O. Berg) study	2015	Poly (dl-lactide-co-glycolide) (PLGA) nanoparticles with entrapped GE were synthesized using the emulsion-evaporation method with different lactide to glycolide (50:50 and 65:35) ratios to determine the dependency of polymer composition on nanoparticles antioxidant and antimicrobial activities. Controlled release experiments showed an initial burst followed by a slower release rate of carotenoids inside PLGA matrix. Both nanoparticles showed *Listeria innocua* growth inhibition within the concentration range tested (<1200 μg/mL), that was not observed by the free extract. These nanoparticles could be used with other extracts containing carotenoids and other functional lipids as delivery systems for enhanced biological activity.
	Dianawati, D., Mishra, V., Shah, N.P.	Survival of Microencapsulated Probiotic Bacteria after Processing and during Storage: A Review	2016	Two common drying methods commonly used for microencapsulation are freeze drying and spray drying. In spite of their benefits, both methods have adverse effects on cell membrane integrity and protein structures resulting in decrease in bacterial viability.
	Tao, Y., Sun, D.-W.	Enhancement of Food Processes by	2015	This review is focused on the use of ultrasound to enhance various food processes, including

		Ultrasound: A Review		extraction, freezing, thawing, brining, oxidation, filtration, and drying/dehydration.
	Nayak, B., Liu, R.H., Tang, J.	Effect of Processing on Phenolic Antioxidants of Fruits, Vegetables, and Grains—A Review	2015	This review aims to provide concise information on the influence of various thermal and nonthermal food-processing operations on the stability and kinetics of health beneficial phenolic antioxidants of fruits, vegetables, and grains.
Food Research International	Barba, F.J., Parniakov, O., Pereira, S.A., Wiktor, A., Grimi, N., Boussetta, N., Saraiva, J.A., Raso, J., Martin-Belloso, O., Witrowa-Rajchert, D., Lebovka, N., Vorobiev, E.	Current applications and new opportunities for the use of pulsed electric fields in food science and industry	2015	This review focused on some of the most renowned traditional and emerging PEF applications for improvement of osmotic dehydration, extraction by solvent diffusion, or by pressing, as well as drying and freezing processes. The impact of PEF on different products of biological origin including plant tissues, suspension of cells, by-products and wastes will be analyzed in detail. In addition, recent examples of PEF-assisted biorefinery application will be presented, and finally, the main aspects of PEF-assisted cold pasteurization of liquid foods will also be described.

Source: Own elaboration

This Table 9 summarizes some of the main articles published on food-drying technology since 2015. It was found that a great number of them compare the nutritional and organoleptic characteristics of food along with their energy efficiencies and drying times. Food industry is oriented towards the search for cleaner and more efficient technologies, which may retain the desired nutritional and organoleptic characteristics, similar to those of fresh produce.

Drying is a mature technology, though fluidized bed, microwave, spray drying and refractive window appear to be increasingly strengthened by their advantages with traditional convective drying. Other drying applications are radiofrequency, electrohydrodynamic drying, various relations with nanotechnology (nanoparticles, nanoencapsulation), and semi-theoretical and empirical models of thin layer drying.

CONCLUSIONS

Food-drying technology was considered in a mature stage from an article and patent point of view. This can be helpful for decision-making and monitoring investment strategies for those interested in this topic. Furthermore, it can help identify whether it is an appropriate time to exercise technological law mechanisms and intellectual property rights, such as patenting, software registration, among others.

There are several winning models in both articles (sigmoidal, logistic and Gompertz) and patents (sigmoidal and logistic). However, sigmoidal model appearance patterns are starting to show in drying studies from the last few years, even in other food technologies.

According to search equations used, the dynamics or patenting rate on food drying has decreased since 2007. Those interested in such technologies should take this into account, since they could choose technological surveillance strategies on free patents before investing, or even choose other technology mechanisms and intellectual property.

Inflection points on articles took place between 2009 and 2012. This indicated that publishing dynamics on food drying has decreased since then. Academics and researchers in this area have to analyze the reasons behind this, identify the causes, and propose new strategies to maintain investigations in this area, or remain open to new proposals or technologies that may replace or complement drying technology.

LIMITATIONS AND POSSIBLE FUTURE RESEARCH:

Performance parameters of articles and patents accumulated over time were analyzed on this article. It is suggested for further investigation on these technologies to consider other performance parameters such as citation numbers, or parameters of drying technology efficiency within manufacturing companies, or based on data taken from different drying equipment providers.

Sub-types or subcategories within food-drying technology could be taken into account and their appearance in a specific period of time in new research. This information aligned to the S-curve and its inflection point may help get a better idea on food drying trajectory.

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