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Patent-based network analysis to understand technological innovation pathways and trends

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1. Introduction

A major challenge for researchers and investors is to know which research projects and technologies are the most promising to achieve the strategic objectives of the organization's R&D&I (Research, Development and Innovation) area. Due to the high level of market competition in intensive technology sectors, technological prospective activity has been widely explored. For this reason, multiple techniques have been developed in the search for more consistent alternatives, some with better results than others [1].

Over the last few years, some of the methods most frequently used by researchers in technology forecasting have been the Delphi analysis [2–5] text mining on patents and scientific publications [6–9], ARM [10], the AHP [11], the scenario analysis [12], and agent-based simulation [13]. Most of these techniques use information from patent databases that may come from numerous patent authorities, scientific publications and company data on sales growth, to cross-reference information and extrapolate future trends [14].

The patents sources stand out because, in addition to containing large volumes of data, they are a mixture of invention and industrial application. Moreover, considering the cost of generating and maintaining a patent, it is inferred that the assignee expects to develop his invention into a product or process, even if this is not the main reason for patenting. Other favourable issues are the volume of published patents and the ease of access to this information that is at the technological frontier. It is estimated that in some subjects, approximately 70% of the information about innovation is contained only in these kind of documents [15,16].

Considering situations where the information concerning technological development is not clear and there is the need for researchers to interconnect these patents through its citations, it is important and possible to obtain, with relative accuracy, a path of technology development [17,18]. The value of generating a patent information panel lies in its ability to consistently reflect the evolution of a given technology. This allows us to identify from which knowledge a patent has emerged and forecast its developments, making it possible to visualize which technological trends are the most promising. Thus, the construction of a patent's chain through its respective citations creates the critical path of a technology, which can be understood as a "technological route". In this case, those routes that are longer, more quoted, and central tend to gather more disruptive technologies.

The technological routes (TR) methodology can be useful from a managerial viewpoint because it allows R&D managers to simultaneously analyse a very large patent dataset, which may comprise thousands of documents, to identify the trends within this universe of information. Additionally, it is possible to generate an analysis focused on the strategic topics which are of interest to the company. Thus, according to the demand for technological information, the proposed methodology can be adjusted to better contribute to the competitive intelligence of firms.

Having said that, the objective of the present paper is to demonstrate the technological routes method, which is based on the application of social network analysis (SNA) in patent data. For the research question, this study aims to answer how the TR approach can be used to identify technological opportunities from a set of business demands for technological forecasting in real world scenarios. In other words, it proposes to prove how TR can assist companies in their technological planning. This method has already proven to be robust by other authors [19,20]. However, this research has an innovative approach because it starts from the needs of a company. Therefore, to validate the method, the trends associated with tocopherols were used as a principal subject; it was chosen because it is a core product for many biotechnology companies. The study had the participation of a Brazilian biotechnology company, which listed its demands regarding tocopherol concentration or isolation which were incorporated into the evaluation of the relevance of the results achieved.

2. Review

The relevance of patents as an information source is associated with them being classified in a logical and structured manner with a uniform content structure; they have a wide area of knowledge coverage and contain unique technical or scientific data, since they must follow the novelty criterion [21]. The earlier studies in this field focused on

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technology development identification via bibliometric data [22], which could depend on the analysis of the growth curves of the number of citations [23], or the more complex normalized Google distance, which focuses on the co-citation of specific terms in a text [24]. Later, studies focused on core technology identification among specific technological areas [25].

Recently, in an analysis of trends in the field of environment-related technologies, the term and overall concept of "technological routes" was proposed, which supported the development of this research [26]. The definition of technological routes can be expanded to the technology development path or even as a technology strand based on patent citations. When a researcher visualizes the route, he or she pictures a representation of a transitory stage of technology development. Therefore, technological routes are dependent on the elements captured at the time of the study and can be updated or complemented through the integration with other databases that influence the chosen themes or by interactions with other related routes that interfere in the development of the route that is under analysis [26]. One of the advantages of the use of technological routes is that it is not necessary for the researcher to have a previous list of possible development candidates, which greatly diminishes the selection bias of the researcher.

In an SNA, the network is non-linear, decentralized and flexible; has a dynamic structure with no defined limits; and is self-organizing and established by horizontal cooperation relations [27,28]. Although initially developed for sociology studies, SNA indicators and techniques are extremely suitable for analysing the structural characteristics of the interactive relationships of an innovation system [29]. Solla Price [30] realized several decades ago that technology transfer can be mapped through an analysis of publication citations. Recently, several papers have adopted patent citations and SNA to investigate promising technologies related to the most diverse topics, such as energy cells [25], telecommunication technologies [31], and promising green technologies [24], among others. This research objective reinforces that an SNA is an adequate technique for research and that, combined with a method such as TR, it can support technological prospecting with quantitative and qualitative characteristics, allowing an analysis of technological diffusion in different areas. The SNA allows us to analyse the connections and the linkages of technological evolution that econometric analyses do not consider. Thus, an SNA enables technological prospecting to be performed to understand the development of a technology through the analysis of the backward citations.

When searching for a better way to identify technological routes from patent data, it was found that the use of networks constructed from backward citations stands out from the analysis performed by simply using the number of forward citations. The adoption of backward citations makes the analysis more coherent as it preserves the prominent position of recent technologies, which is fundamental for a future trend analysis. On the other hand, an analysis based on forward citations needs to artificially create punctuation parameters to level the number of citations of newer and older technologies from different technological branches [32].

The TR used in this paper is based on the methodologies proposed by Hummon and Dereian [22], which were implemented by Verspagen [25] and Fontana, Nuvolari and Verspagen [33]. The methodology is based on the analysis of the most relevant connections, search path link count (SPLC) and search path node pair (SPNP). From a listing of all the possible network paths, the SPLC algorithm measures the frequency of patents that are located in different paths; then, the paths that have more connections may represent the main technology route. The key concept is that the more routes a patent connects to, the more important it is to the network as a whole. The SPLC technique weights the assignment for each connection (citation) based on the position of the general structure, which in turn is based on the existence of different paths in the network. Therefore, a path is a sequence of citations that extends from the most recent patent to the oldest one through the intermediate patents. This path represents the knowledge flow of this technology. The greater the number of paths that pass through a link is, the greater the weight is that is assigned in the SPLC algorithm, and therefore, the more important that link will be classified as.

As for the SPNP algorithm, it is used to trace all the network paths and to check how many times an "i" node is present in these paths to determine the count, n_i. Then, the same is done for a node connected to i, which can be called "j", with a count of n_j. The SPNP value is the multiplication of n_i by n_j [25]. Because of the multiplication operation, such an analysis increases the central patent relevance of the network [22]. Since, the results of both analyses are largely similar, it is up to the researcher to choose which statistics to use. Both techniques require that the network does not have any circular connections because this phenomenon generates networks that close in on themselves. Therefore, when seeking to map technology routes, the data must be processed to prevent the citations of previous patents citing later ones.

According to TR theory, a TR, which uses an SNA as a technique to provide the results, is not intended to explain more about innovation than other methods, but it is used as a method to investigate the relationships between patents based on their citations. It also uses functionalities to identify central positions and more relevant links in the network.

3. Data and methodology

The research began with semi-structured interviews with the executive board of a start-up firm that operates in the biotechnology sector in Brazil, mainly in the R&D of new solutions. The partners are researchers with several years of experience in their field of activity who develop technological projects in partnerships with large international companies. This company was selected because it is part of a strategic field study in Brazil for food biotechnology, and because of the partners' strong innovation mindset. Their participation in this study increased their accessibility to new technology forecast approaches and assured their cooperation in the interview phases.

In the initial interview phase (step 1), the technological area of interest (IPC target) of the company was identified (Fig. 1). At this stage, the firm executives indicated the priority patents for their business: US5371245, US5487817 and US5512691, which are related to technologies involving tocopherol (vitamin E) for food use; the subgroup refers to the CPI ″C07D 311/72, which has the following

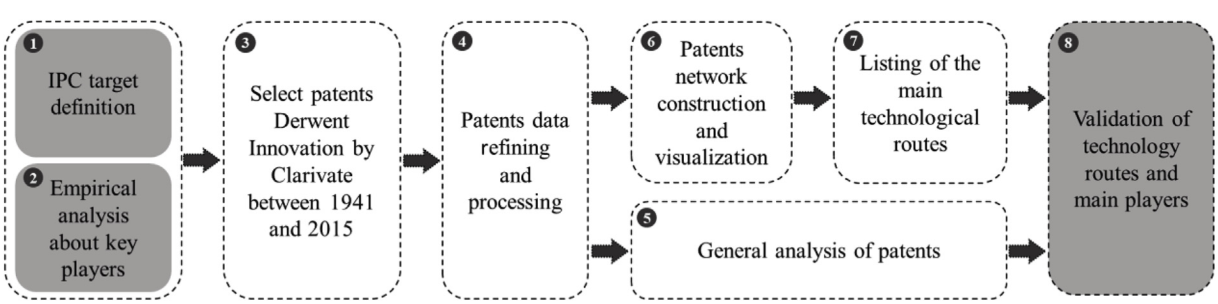

Fig. 1. Methodology overview.

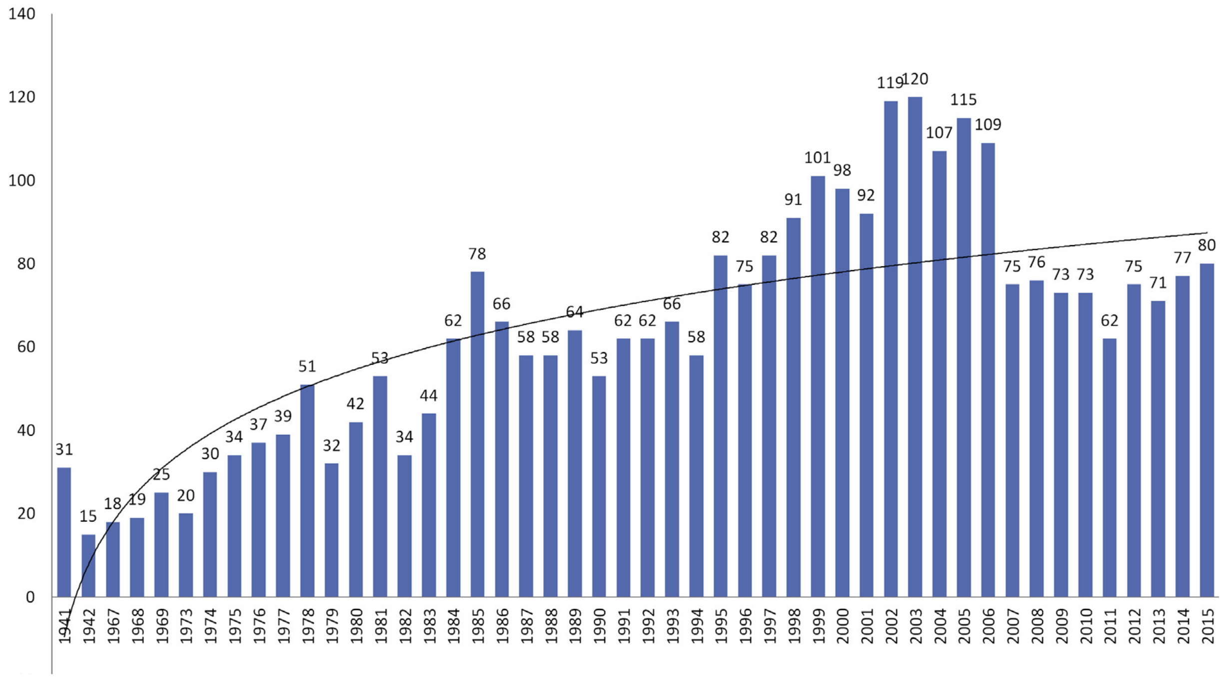

Fig. 2. Tocopherols patents published evolution.

description: heterocyclic compounds containing six-membered rings having one oxygen atom as the only hetero atom, condensed with other rings; ortho- or peri-condensed with carbocyclic rings or ring systems; benzo [b] pyrans, not hydrogenated in the carbocyclic ring; other than with oxygen or sulphur atoms in position 2 or 4; with two hydrocarbon radicals attached in position 2 and elements other than carbon and hydrogen in position 6; 3,4-dihydro derivatives having in position 2 at least one methyl radical and in position 6 one oxygen atom, e.g., tocopherols [34].

The next step (2) was to verify the company's perception, at that time, about the top developers of tocopherol-related technologies based on its scientific and market knowledge. To that end, the executives were asked which companies or research groups were considered the most relevant in this area, and according to their perception, the main players in new technology development were Cargill, ADM, Basf and Danisco. Later, this empirical information was compared with the data obtained by analysing the patents related to tocopherol.

Step 3 consisted of collecting the patent data from Derwent Innovation by Clarivate. The patent search was built to extract those patents with a relevant IPC according to the company's point of view. Thus, we selected patents classified with IPC ″C07D 311/72″ and application dates from 1941 to 2015. The query used was: "(ICR = (C07D 311/72)) AND (AY > = (1941) AND AY < = (2015))", where ICR is the IPC current field and AY refers to the patent application year. Only the earliest patent of each INPADOC (patent families) was recovered to avoid redundant data about countries where there were deposits for same invention. The following patent data were extracted: publication number, title, application date, IPC code, standardized assignee, cited references (backward citations), number of cited references (patents), number of assignees, address.

In the patent data cleaning step (4), the data were exported and organized using Microsoft Excel so that the source and target nodes were aligned. Additionally, the names, dates, and codes were standardized to avoid any further analysis distortions, with the aid of the OpenRefine tool [35]. The circular patent citations were identified and manually removed by observing the patent deposit year and their citations. Step 5 refers to the extraction of general statistics on the patents collected, which are readily available in the Derwent Innovation application and may be complemented manually in the spreadsheet.

In step 6, The Gephi free software was used to build a relationship network of tocopherol-related [36] patents. The patents were structured and grouped into a spreadsheet and loaded into Gephi. In this spreadsheet, one of the columns refers to the publication number, and the other column refers to the backward citations. Thus, already imported into SNA software, the nodes are identified as patents, and the links are identified as cited patents. Initially, the network appeared to be disordered, and it was necessary to run a visualization algorithm to obtain a better understanding of the network and the patent relationships. In this case, the OpenOrd visualization algorithm was used. Afterwards it was possible to identify clusters using modularity statistics [37] and an analysis of centrality statistics [38].

In addition, in step 7, a developed Java plug-in (compatible with the Gephi software version 0.8.2) was applied to calculate the SPLC values in the network and thus to obtain the main technological routes on the subject. This was possible because the algorithm was written to follow the steps described by Hummon and Dereian [22]. In step 8, the technological routes and the main players were validated by executives of start-up company, which made it possible to check the feasibility and consistency of the results in terms of technological prospection and the feasibility of using them as strategic information in firm strategic planning.

4. Results and discussions

Considering the choice of tocopherol-related technologies, all the patents were sought between the 1941 and 2015 period. A long period was chosen because tocopherol-related technologies have been developed for many decades, and the understanding of the whole technological path was strategic for the company. An exponential growth trend of patent publications was observed in the first few decades, and then there was an apparent trend of stabilization in the later stages. It should be noted that due to a period of legal secrecy, no information is available (Fig. 2).

It was found that some assignees (Fig. 3) stood out in the patenting in this field, if only during restricted periods. For instance, the Eastman Kodak Co. was a very active company between 1950 and 1976 and had a few innovations in 1997; it later proceeded to leave this technological area. The Nissin Flour Mill developed its inventions between 1976 and

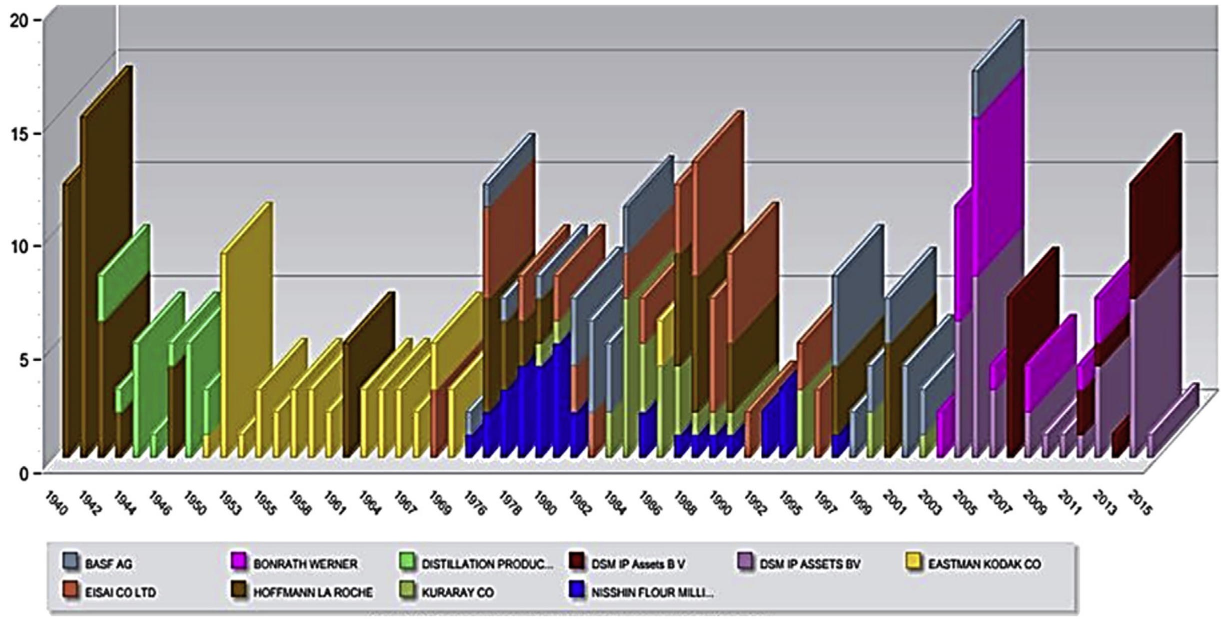

Fig. 3. Top 10 patents assignees.

1998 and later abandoned this area. Hoffmann La Roche developed technologies at different times between 1940 and 2001, with a behaviour that oscillated greatly. It also has not presented any technology recently.

DSM IP Assets BV has been innovating in this field since 2005 and has maintained a constant level of new developments and protection with a total of 70 patents. It should be noted that due to different spellings in patent documents, the same company is represented in two different ways, as shown in Fig. 3 (DSM IP Assets B V and DSM IP ASSETS BV). Another company that also stood out recently, although less prominently, was Bonrath (15 patents). This shows a tendency for companies developing this technology to maintain their patenting leadership for limited periods of time and to be later surpassed by other organizations or to change the strategic direction of their R&D projects portfolio.

In analysing the technology origin-countries (the countries where the patents were filed) (Fig. 4-a), it was found that company protection efforts are concentrated in Japan and China, since PCTs have not yet entered the national phase. Due to the Chinese government's incentive policies, it is possible to observe the representativeness of China's applications after 1995 (Fig. 4-b). In addition, in the last 20 years, there has also been an increase in PCT applications.

5. Technological routes

From the construction of the patent citation network using the SPLC criterion, the most important technological routes were mapped, which could potentially help the company in its technological and strategic planning. The patent data were imported into the Gephi software, and a citation network was constructed with 1942 technologies (nodes) connected by 1995 citations (edges). The large component had 1190 nodes, and the modularity coefficients and eigenvector centrality were calculated and are represented by colour and node sizes, respectively, proportional to their relevance in the network. The large component of the tocopherol-related patent co-citation network (Fig. 5) has four main communities (or clusters) obtained by the Gephi modularity algorithm, which demonstrates the thematic clusters, as indicated by the blue arrows. It is also noted that no high concentration has arisen around any single community.

To determine the topics addressed in each of the four most relevant communities, the most important patents in each community were highlighted. Table 1 shows some details of approximately 5 main nodes (patents) for each community as cluster identification, patent number, patent subject summary, company name (assignee) and publication date. Another outstanding value is the patent eigenvalue centrality,

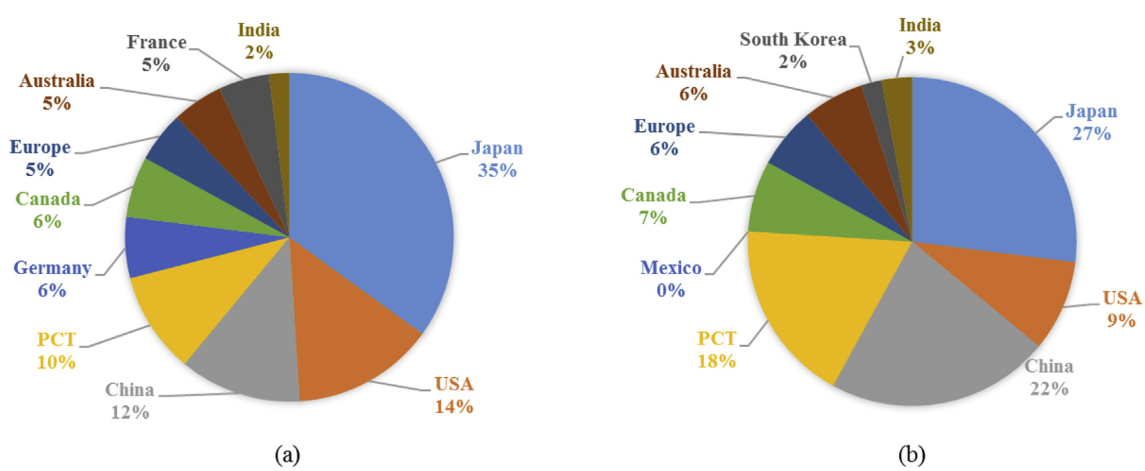

Fig. 4. Priority application countries: (a) from 1940 to 2015; (b) from 1995 to 2015.

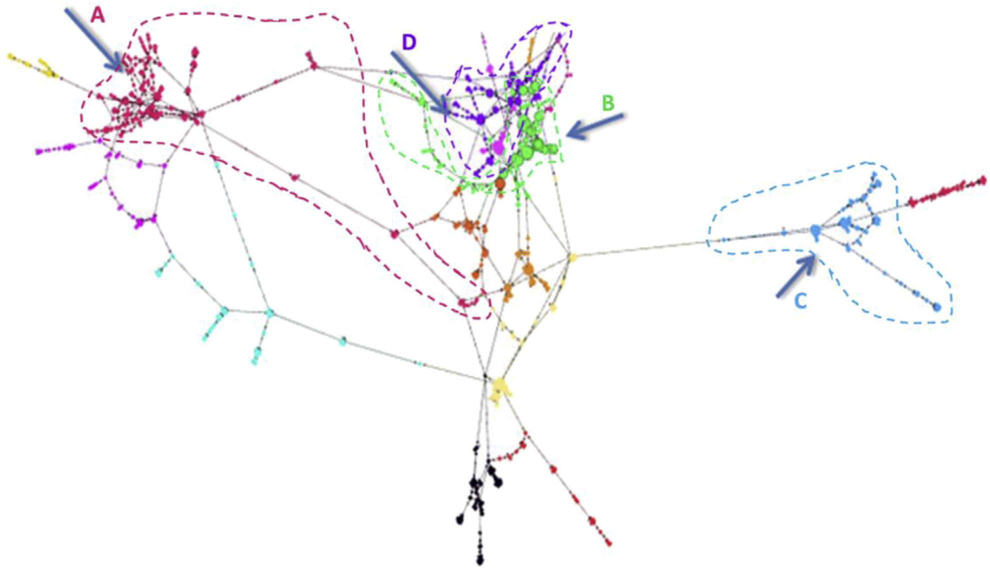

Fig. 5. Major tocopherols patent communities.

which was considerably high since the median eigenvector degree of the network is 0.0071. The criterion for the selection of the main nodes (technologies) was the number of citations received for each patent that was obtained within the community in which they are found. Therefore, patents with a larger number of selected citations tend to better represent the main theme of that cluster.

It is possible to note that the largest network community, community A, identified by red nodes, is focused on technologies involved in the development of condensation techniques for tocopherols. This network consists of patents whose assignees are mainly Japanese and European firms which have fewer central patents in their development line. Although the group influence is significant, there is not yet a very strong influence of specific patents. In contrast, community B (green nodes) could be defined by its anion exchange technologies for tocopherol isolation (Table 1). This community had patents with the highest degree of centrality in the network, perhaps because the average age of patents was higher, which increases their chances of receiving citations. In any case, the citations received and consequently their centrality indicate that the patents of this community serve as the basis for many other patents. Community C, represented by technologies used in the epidermis as sunscreens, bleach and anti-allergy (light blue nodes), stood out from all the others because it dealt with a different aspect of tocopherol extraction, which was the use of tocopherols in health applications in cooperation with firms in the pharmaceutical and cosmetics sectors. The last relevant network cluster is community D (purple nodes), which covered technologies for extracting tocopherols from plants by means of esterification and was intimately linked to community B (anion exchange technologies for tocopherols). The profile of most recent patents indicates that it may be a successor of the technologies focused on the extraction of tocopherols.

When analysing the technological routes, TR1 and TR2 were identified as having the most relevance (Fig. 6). It is important to emphasize that only the second most important route, TR2, includes one of the patents prioritized by the company, US5371245 (saponification and use of zinc halide). This indicates that although the company has good insight about which technology has high relevance in the field of tocopherols, the most relevant technological route was not on the company's technological roadmap. In this way, the TR methodology allowed the company to analyse trends that are relevant to its target market in a way that could not be identified by conventional means.

In terms of the first most relevant route (TR1), it presents the patent WO2005026142A2 as the most recent, according to the SPLC criterion (Fig. 6). This patent protects a technology for the synthesis of a precursor of alpha-tocopherol alkenoates and was granted in 2005 to the DSM company, which has its headquarters in Amsterdam (Netherlands). This company focuses on technologies that link life sciences and materials sciences in the fields of health, nutrition and materials. The company has a sales revenue of approximately 10 billion euros and 25,000 employees [39].

The second route with the most relevance (TR2) presents two patents as the most recent. EP1083174A1, which addresses a method of tocotrienol purification and tocopherol use using liquid chromatography, which is not protected in the company's country of operation. It was published in 2005 by TechniKrom Inc., which in 2009, changed its name to Hygeia Industries. The company is headquartered in Glenview, Illinois (USA) and focuses on the extraction, purification, and blending of natural compounds for nutritional and pharmaceutical use. Despite being a small company with 10 employees, it earns $ 1.8 million in sales [40]. EP1689353A2 relates to the purification from tocopherols/tocotrienols, carotenoids, and sterols by means of a transesterification and distillation process. This patent was granted in 2006 to Carotech and is protected in the country of the assignee (Malaysia). This company was a subsidiary of Hovid Berhad and had been operating since 1995, having the first and largest factory in the world to extract the tocotrienol complex. Carotech's core strategy was to supply the market with phytonutrients and other inputs, exporting to 30 countries, and having 400 employees. However, in 2010, due to financial problems, Hovid Berhad divested itself of its stocks, and in 2015, Carotech changed its name to ExcelVite [41,42].

Still worth mentioning are the following patents that integrate the principal technological routes (Fig. 6):

WO2004063182A1 (Process for the manufacture of α-tocopherol acetate) - owned by DSM, granted in 2004 and protected in Brazil.

WO1998021197A2 (Manufacturing process of d, L-α-tocopherol) - Hoffman La Roche, granted in 1998 and not protected in Brazil.

WO1999038860A1 - (Method for separating tocotrienol from mixtures containing tocol)- Eastman Co., granted in 1999 and protected in Brazil.

US5660691A (Process to produce concentrated tocotrienol / tocopherol blend) - Eastman Co., granted in 1997 and not protected in Brazil.

Next, the positioning of the other patents that had been indicated as

Table 1
Major tocopherol patents.

Cluster	Patent Number (Publication Year)	Patent Summary	Centrality	Assignee
A (Red nodes)	EP1134218A1 (2001)	Preparation of (all-rac-)-alpha-tocopherol as an active member of vitamin E comprises use of tris (perfluoroalkanesulfonyl or pentafluorobenzenesulfonyl) methane as a catalyst in a condensation reaction.	0,0953	Hoffman La Roche
A (Red nodes)	EP658552A1 (1995)	Preparation of alpha-tocopherol derivatives of formula comprises reacting a trimethylhydroquinone of formula with an allyl alcohol derivative of formula or an alkenyl alcohol deriv. of formula in the presence of a fluorosulphonate of formula.	0,0823	Esai
A (Red nodes)	JP59190987A (1984)	High purity DL-alpha-tocopherol preparation by catalytic condensation of 2,3,5-tri:methyl hydroquinone with iso:phytol or phytol.	0,0492	Mitsui Toatsu Chemicals
A (Red nodes)	JP48072167A (1973)	Dl-alpha tocopherol preparation from condensation of trimethylhydroquinone and (iso) phytol.	0,2094	Kuraray
A (Red nodes)	US2411969A (1946)	Process for the preparation of synthetic dl-tocopherols.	0,2635	Hoffmann La Roche
B (Green nodes)	US4480108A (1984)	Separation of acylated tocopherol homologue mixtures by reaction with saturated cyclic amine(s), esp. pyrrolidine.	0,0558	Eastman Kodak
B (Green nodes)	US3819657A (1974)	Methylation of tocopherols (1972).	0,1102	Gen Mills Chen
B (Green nodes)	US3402182A (1968)	Isolating tocopherol homologues with an anion exchanger.	0,1634	Eisai
B (Green nodes)	US3122565A (1964)	Concentrating tocopherol by abs on anion exchange resin.	0,6282	Eisai
B (Green nodes)	US3153055A (1964)	Process for separating tocopherols and sterols from deodorizer sludge and the like.	0,4345	Eastman Kodak
C (Light Blue nodes)	US20050065099A1 (2005)	Treating or ameliorating mitochondrial disorder e.g. Alzheimer's disease, Parkinson's disease, comprises administering chroman derivatives.	0,0142	Bodupalli S, Et al.
C (Light Blue nodes)	US5217992A (1993)	Tocotrienol(s) and their pro-drugs used in treatment of hypercholesterolemia hyperlipidemia and thromboembolic disorders.	0,0142	Squibb Bristol Myers
C (Light Blue nodes)	EP445735A1 (1991)	6-Hydroxy:chroman deriv. as skin whitening agent in melanogenesis inhibiting endermic preparation for external use.	0,0284	Sansho Seiyaku
C (Light Blue nodes)	US4321270A (1982)	-Piperidinyl-di:hydro-benzopyran derivatives especially useful as antiallergy and antihypertensive agents.	0,0279	Squibb and Sons
C (Light Blue nodes)	US4144325A (1979)	Preventing erythema of the skin dye to UV absorption by application of sunscreen composition containing tocopherol compounds and carrier.	0,0142	Voyt Walter
D (Purple nodes)	US5660691A (1997)	Tocotrienol-tocopherol blend concentrate production from vegetable oil by-product by thermal esterification and multi-stage distillation, used for production of pure vitamin E.	0,1378	Eastman Chem
D (Purple nodes)	WO1997021697A1 (1997)	Recovery of tocopherol derivatives from e.g. distillates of vegetable oils, tall oil or products from paper-making processes.	0,0421	Henkel Corp
D (Purple nodes)	US5512691A (1996)	Production of tocopherol concentrates from vegetable oil by-products by esterification and multistage distillation.	0,3042	Eastman Chem
D (Purple nodes)	EP610742A1 (1994)	Separation of tocopherol and sterol from, e.g. sunflower oil distillates including a step involving esterification of the sterols with fatty acids present in the distillates.	0,0421	Hoffmann La Roche
D (Purple nodes)	EP333472A2 (1989)	Production of tocopherols and tocotrienols from palm oil by-products Production of tocopherol(s) and tocotrienol(s) from palm oil by-products.	0,0758	Palm Oil R&D Board

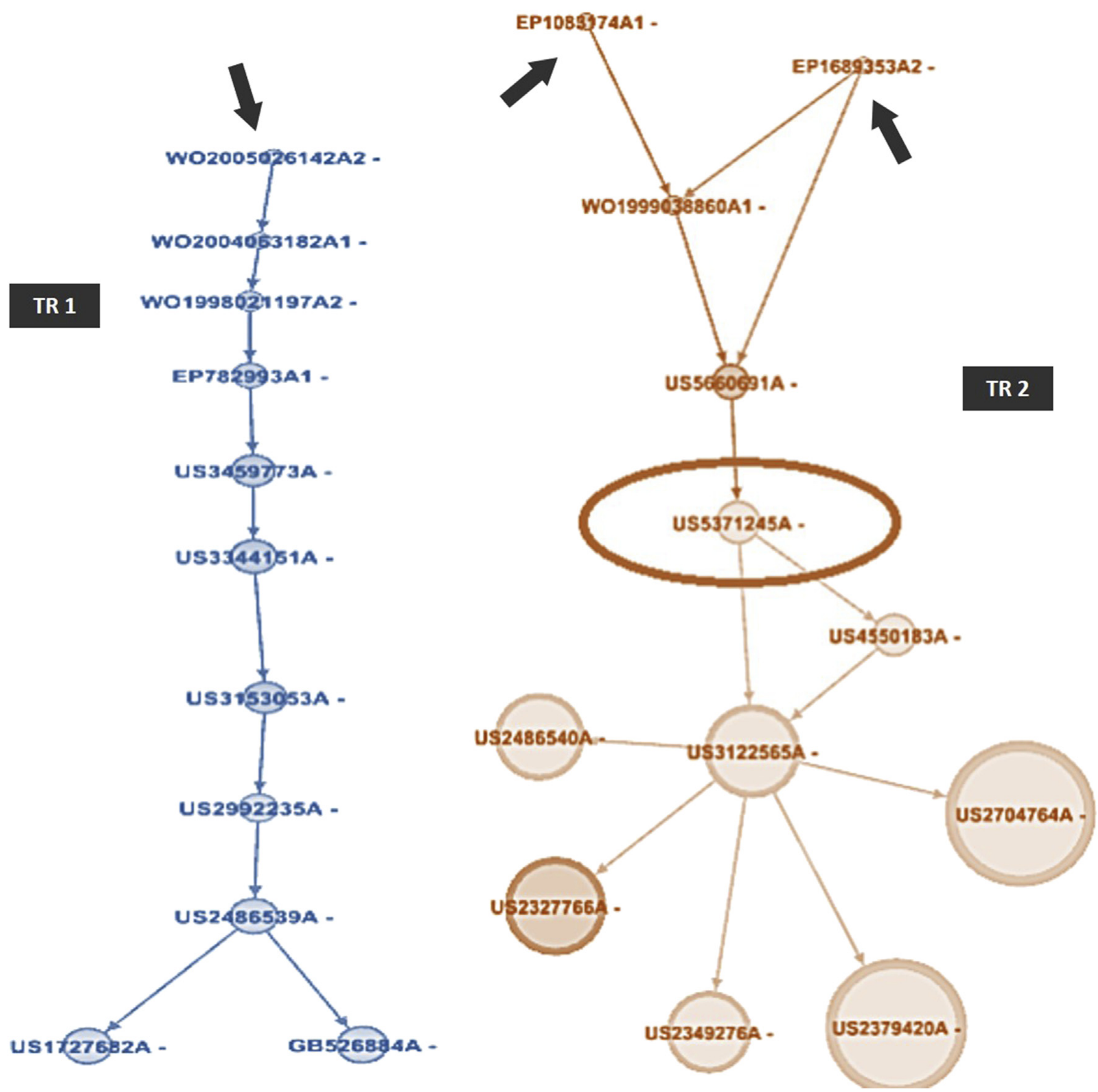

Fig 6. Most relevant patent of Technological Routes: TR1→WO2005026142A2 and TR2→EP1083174A1/EP1689353A2.

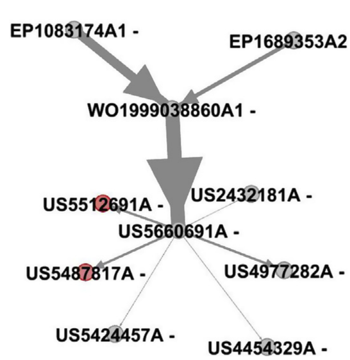

Fig. 7. Technological route including patents US5512691A and US5487817A indicated by the company.

strategic by the company was identified in the RT (Fig. 7). These patents, US5512691A and US5487817A (green nodes) were in the network attached to IPC C07D 311/72. These were in a much lower position in terms of network scoring impact according to the SPLC criterion and occupied the 62nd place in the TR.

It is interesting to note that within the technological route in Fig. 7, there were some patents (EP1083174A1 and EP1689353A2) that had already been described in TR1 (Fig. 6), which is justified because the patents were chosen to have strong thematic proximity, something indicated by the modularity analysis. This reinforces the importance of the patents described in the top SPLC value routes in the network, since they persist in paths well below the initial positions of the SPLC classification. Furthermore, this demonstrates that the strategic relevance perception of the company was not completely off the mark.

Another important issue is that although patent US5512691A (red nodes in Fig. 7) has a greater eigenvector centrality, when one examines the importance of the route development, it was observed that another patent, US5371245 (patent marked by a circle in the middle of Fig. 6), has been placed in a higher position in the final SPLC report. Such an event reinforces that the SPLC method is not only based on the number or value of the citations that a patent receives but mostly based on the of patents related to the route development.

6. Conclusions

The objective of this paper was to verify the feasibility of a technological prospecting method, TR, based on the use of network analysis techniques. Consequently, to identify and analyse technological routes in real situations, with the initial information intentionally restricted to be based on the information that companies usually have access to in a real environment. From the patents considered as strategic for the company studied, it was possible to build a TR on the theme, identify the thematic clusters based on a modularity analysis, find the patents of greater centrality in the network, and generate a technological route whose path indicates the main developments. With these data, information such as the leading companies and the researchers and countries that research on tocopherols became evident, and the TR also presented the most relevant technologies and latest trends. This information may change the company's strategic planning, and some observations and recommendations are made below.

Regarding the knowledge about competitors, a large difference was noted between the companies that were expected to be relevant in the sector (Cargill, ADM, BASF, Danisco) and the assignees with the greatest impact on the network. In this latter group, the strong influence of Japanese companies on new technology development was visible. It is interesting to note that the only company mentioned by the studied firm that was present among the 10 main assignees in the theme has not protected any invention in this topic since 2007. This is an indication of a great need to update the databases used in the professional environment. These elements provide evidence that the studied company, while claiming to follow technical advances in the investigated field, did not know many of its competitors or possible partners because they did not have a managerial method that would allow a mapping of the global scenario of technological development in their field of activity. This was provided by the use of TR and confirmed by the entrepreneurs. A possible explanation for this contradiction may be that the analysed company assumed that the major producers/distributors of tocopherols were the same companies that invented technologies in this area, which would unfortunately prevent it from making alliances or even tracking the correct companies in regard to technological development. In addition, the search tool normally used by the studied company, and by many others, is Google Patents. This tool, despite having quick and simple access, may not be the most appropriate for patents submitted in other languages, and adjustments should be made when the company wishes to seek patents from countries whose official language is not English. In fact, Google Patents, despite being an interesting tool for data collection, is not qualified to be classified as a technological forecasting tool. A key point here is that without robust technology prospecting methods, such as RT, companies are no longer aware of the technological trends relevant to their business.

Another relevant point to highlight is that the richness of the theme generated parallel lines of research, indicating that searches should be performed according to competitors in groups using similar techniques, thus facilitating the monitoring of these companies. Despite the age of the subject, which has been published since 1940, the absence of nodes with very different sizes from others may be an indication of the non-concentration of the technologies used in the execution of these studies, thus making room for future developments. The publication trend line per year indicates that the theme is currently slightly decelerating but is not yet in decline. In addition, the agglutination index from the modularity coefficient indicates a low probability of monopolies, which facilitates the entry of new competitors. The most recent patents present in the higher-ranking technological routes based on the SPLC criteria focused on topics such as the use of catalysts for precursor synthesis of alpha-tocopherol alkenoates, as well as purification techniques based on reverse phase separation of liquid chromatography and transesterification and distillation process medium. These patents were published in the years 2005 and 2006, indicating that the techniques for the consolidation processes in this sector are developing slowly, which explains the absence of new patents on the main routes. An additional interpretation of the routes can be realized by observing that the tocopherol purification/separation route not only has branches but also the participation of other modularity clusters, which indicates whether it is a topic with greater numbers of methods due to greater interest in the theme or if there is a certain amount of feasibility/openness to generate innovations.

Based on these results, a set of recommendations was listed, and the following recommendations were made for the studied company: (i) monitor and/or contact the Asian companies that still conduct research on this topic, to explore opportunities for research, contracts, or business representations; (ii) check other development routes for opportunities, as well as other thematic groupings; (iii) the information in the study may be useful for acquiring financing (as it indicates market know-how), or as leverage in negotiations; (iv) monitor the strongest companies in recent years, for example, Dsm Ip Assets and Bernrath Werner; (v) check the patents that are not protected in Brazil, in particular EP1083174A1, that have prominence in the route; and (vi) along with the technical staff, analyse the methods and results of the most recent patents that have been highlighted in the selection made by the SPLC methodology so that it is possible to advance the sector.

Regarding the company feedback, it showed a high level of satisfaction with the information presented and was keen to immediately implement some of the recommendations made in this study. In addition, the company requested that further analyses be conducted on other topics or on the technological development routes of specific competitors. A company recommendation for future studies was to identify thematic communities by modularity to carry out an analyses of the different technological routes within them.

In terms of theory, this paper points out two contributions. First, the results indicated that the technological route can be used as a relevant method to understand technology knowledge flow and technology trends, in addition to identifying the main players that can be partners or competitors according to the company-targeted market. The tests performed in the market environment proved that TR can be useful from a managerial viewpoint and allows industrial experts to identify patterns that can be followed and adopted by scientists and the market in a simplified way. Additionally, it increases the possibility of generating technological knowledge for organizations that previously did not have either the methodological ability or the financial resources to obtain it. Second, although it recognizes in a recurring way the potential use of TR for technological prospection, it ultimately relied on the interpretation of market specialists in the field of the patent documents, which increased the validity of the results. In this way, this research concludes that one of the best ways to improve the science and technology position of a company is by providing the methods and tools that allow entrepreneurs to investigate the best innovation alternatives and opportunities. This kind of approach avoids wasting resources and time, both of which are highly valuable in the generation of new technologies. For the future, the opportunity to use this methodology in other industries, technologies or countries can expand and validate the results of this research.

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References

[1] S. Mishra, S.G. Deshmukh, P. Vrat, Matching of technological forecasting technique to a technology, Technol. Forecast. Soc. Change 69 (1) (2002) 1–27.
[2] B.E. Ribeiro, M.A. Quintanilla, Transitions in biofuel technologies: an appraisal of the social impacts of cellulosic ethanol using the Delphi method, Technol. Forecast. Soc. Change 92 (2015) 53–68.
[3] P. Meesapawong, Y. Rezgui, H. Li, Planning innovation orientation in public research and development organizations: using a combined Delphi and Analytic Hierarchy Process approach, Technol. Forecast. Soc. Change 87 (2014) 245–256.
[4] B. Förster, H. von der Gracht, Assessing Delphi panel composition for strategic foresight - a comparison of panels based on company-internal and external participants, Technol. Forecast. Soc. Change 84 (2014) 215–229.
[5] J. Keller, A. Heiko, The influence of information and communication technology

(ICT) on future foresight processes - results from a Delphi survey, Technol. Forecast. Soc. Change 85 (2014) 81–92.
[6] J. Choi, Y.S. Hwang, Patent keyword network analysis for improving technology development efficiency, Technol. Forecast. Soc. Change 83 (2014) 170–182.
[7] C. Lee, B. Kang, J. Shin, Novelty-focused patent mapping for technology opportunity analysis, Technol. Forecast. Soc. Change 90 (2015) 355–365.
[8] M.Y. Wang, S.C. Fang, Y.H. Chang, Exploring technological opportunities by mining the gaps between science and technology: microalgal biofuels, Technol. Forecast. Soc. Change 92 (2015) 182–195.
[9] B. Yoon, I. Park, B.Y. Coh, Exploring technological opportunities by linking technology and products: application of morphology analysis and text mining, Technol. Forecast. Soc. Change 86 (2014) 287–303.
[10] Y. Geum, H. Lee, Y. Lee, Y. Park, Development of data-driven technology roadmap considering dependency: an ARM-based technology roadmapping, Technol. Forecast. Soc. Change 91 (2015) 264–279.
[11] N. Somsuk, T. Laosirihongthong, A fuzzy AHP to prioritize enabling factors for strategic management of university business incubators: resource-based view, Technol. Forecast. Soc. Change 85 (2014) 198–210.
[12] P. Fortes, A. Alvarenga, J. Seixas, S. Rodrigues, Long-term energy scenarios: bridging the gap between socio-economic storylines and energy modeling, Technol. Forecast. Soc. Change 91 (2015) 161–178.
[13] M. Rixen, J. Weigand, Agent-based simulation of policy induced diffusion of smart meters, Technol. Forecast. Soc. Change 85 (2014) 153–167.
[14] E. Geisler, The metrics of technology evaluation: where we stand and where we should go from here, Int. J. Technol. Manag. 24 (4) (2002) 341–374.
[15] M. Blackman, Provision of patent information: a national patent office perspective, World Patent Inf. 17 (2) (1995) 115–123.
[16] WIPO, World Intellectual Property Organization, International treaties and conventions on intellectual property, WIPO Intellectual Property Handbook: Policy, Law and Use, WIPO, Geneva, 2013, pp. 237–264 chap. 5.
[17] M.P. Carpenter, F. Narin, P. Woolf, Citation rates to technologically important patents, World Patent Inf. 3 (4) (1981) 160–163.
[18] J. Michel, B. Bettels, Patent citation analysis. A closer look at the basic input data from patent search reports, Scientometrics 51 (1) (2001) 185–201.
[19] C.G. Pereira, et al., Patent mining and landscaping of emerging recombinant factor VIII through network analysis, Nat. Biotechnol. 36 (7) (2018) 585–590.
[20] A.F. De Paulo, G.S. Porto, Evolution of collaborative networks of solar energy applied technologies, J. Clean. Prod. 204 (2018) 310–320.
[21] G.S. Porto, Gestão da inovação e empreendedorismo, 1 ed., Elsevier/Campus, Rio de Janeiro, 2013.
[22] N.P. Hummon, P. Dereian, Connectivity in a citation network: the development of DNA theory, Soc. Network. 11 (1) (1989) 39–63.
[23] T.U. Daim, G.R. Rueda, H.T. Martin, Technology forecasting using bibliometric analysis and system dynamics, A Unifying Discipline for Melting the Boundaries Technology Management, IEEE, 2005, pp. 112–122.
[24] W.L. Woon, S. Madnick, Asymmetric information distances for automated taxonomy construction, Knowl. Inf. Syst. 21 (1) (2009) 91–111.
[25] B. Verspagen, Mapping technological trajectories as patent citation networks: a study on the history of fuel cell research, Adv. Complex Syst. 10 (01) (2007) 93–115.
[26] G. Porto, S. Kannebley, J. Baroni, A. Romano, Rotas Tecnológicas e Sistemas de Inovação (Relatório Final), Economia de Baixo Carbono: Avaliação de Impactos de Restrições e Perspectivas Tecnológicas. Ribeirão Preto-SP, 2012.
[27] S.P. Borgatti, D.S. Halgin, On network theory, Organ. Sci. 22 (5) (2011) 1168–1181.
[28] M.I. Tomaél, A.R. Alcará, I.G. Di Chiara, Das redes sociais à inovação, Ciência da informação, Brasília, vol. 34, 2005, pp. 93–104 (2).
[29] H.Y. Shih, T.L.S. Chang, International diffusion of embodied and disembodied technology: a network analysis approach, Technol. Forecast. Soc. Change 76 (6) (2009) 821–834.
[30] D.J. Solla Price, The pattern of bibliographic references indicates the nature of the scientific research front, Soc. Network.: Crit. Conc. Sociol. 4 (2002) 328.
[31] H. Lee, C. Kim, H. Cho, Y. Park, An ANP-based technology network for identification of core technologies: a case of telecommunication technologies, Expert Syst. Appl. 36 (1) (2009) 894–908.
[32] B.H. Hall, A.B. Jaffe, M. Trajtenberg, The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools (No. W8498), National Bureau of Economic Research, 2001.
[33] R. Fontana, A. Nuvolari, B. Verspagen, Mapping technological trajectories as patent citation networks. An application to data communication standards, Econ. Innovat. N. Technol. 18 (4) (2009) 311–336.
[34] WIPO, World Intellectual Property Organization, international patent classification. Section C – chemistry and metallurgy, 2016. Available in: ftp://ftp.wipo.int/pub/itos4ipc/ITSupport_and_download_area/20170101/pdf/scheme/full_ipc/en/ipc_en_c_full_ipc_20170101.pdf, (2016) Access in: 12/03/2016.
[35] R. Verborgh, M. De Wilde, Using OpenRefine, Packt Publishing Ltd, 2013.
[36] M. Bastian, S. Heymann, M. Jacomy, Gephi: an open source software for exploring and manipulating networks, ICWSM 8 (2009) 361–362.
[37] V.D. Blondel, J.L. Guillaume, R. Lambiotte, E. Lefebvre, Fast unfolding of communities in large networks, J. Stat. Mech. Theory Exp. 2008 (10) (2008) P10008.
[38] M.O. Jackson, Social and Economic Networks vol. 3, Princeton university press, Princeton, 2008.
[39] DSM, About, Available in: http://www.dsm.com/corporate/about.html, (2015) Access in 12/11/2015.
[40] Hoovers, Company Size for Hygeia Industries, Inc., 2015 Available in: http://www.hoovers.com/company-information/cs/marketing-lists.hygeia_industries_inc.5d4020a33ae33277.html Access in 12/11/2015.
[41] Flexnews Malaysia, Hovid Berhad announces disposal of shares in Carotech, Available in: http://www.flex-news-food.com/console/PageViewer.aspx?page=31891, (2010) Access in 12/11/2015.
[42] Excelvite, About Us, (2015) Available in: http://www.excelvite.com/about-us/ Access in 12/11/2015.