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Contribution to a sustainable industrial ecology: Valorization of agro-food waste

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Abstract: In the early 1990s, Industrial Ecology emerged as a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies. It aims to optimize the use of all natural resources and limit environmental impacts. It is inspired by the functioning of natural ecosystems to recreate on the scale of the industrial system an organization characterized by optimal use of resources and a high rate of recycling of matter and energy. On the other hand, industry (especially agro-food), regulatory authorities and consumers are all interested in authenticating raw materials and food products in order to ensure food quality and safety requirements. In this context, it can be said that the implementation of an integrated green analytical approach is essential to create viable production and consumption conditions in the industrial sector. This new method is based on infrared Fourier transform spectroscopy applied to agro-food waste. In the light of the obtained results, it has been proved that the proposed approach can be used, with success, in food industry for the reliable, cheap and fast quality control. Thus, presents a contribution for the implementation of an industrial ecology in the agro-food sector.
Keywords: Agro-food waste, Green analytical approach, Industrial ecology, sustainability, valorization.

I. INTRODUCTION

1.1. Industrial ecology: Principles and objectives

Industrial ecology views industry as a human-made ecosystem that functions in the same way as natural ecosystems. Thus, wastes or by-products from one process are used as an input into another process (no waste would leave the industrial system or negatively impact natural systems). And subsequently, the industrial ecology interacts with natural ecosystems and tries to move from a linear system of consumption and exhaustion to a cyclical or closed-loop system of recovery and reuse. And like natural ecosystems, industrial ecology is constantly evolving [1], [2], [3], [4].

Finally, the challenge of industrial ecology is to make the industrial system evolve towards a viable long-term mode of operation, compatible with the biosphere.

1.2. Operational axes of industrial ecology

To achieve its global objective, industrial ecology, has an operational strategy that has four main axes [5], [6], [7], [8], [9], [10], [11]:

(1)- Valorize the waste and by-products: Like food chains in natural ecosystems, it is imperative to create networks of resource and waste use in industrial ecosystems, so that any residue becomes a resource for another company or economic activity.

(2)- Minimize losses by dissipation: In fact, consumption and use often pollutes more than manufacturing. Thus, there are as many products totally or partially dissipated into the environment during their normal use. And subsequently, new products and new services must be designed to minimize or make this dissipation harmless for humans and their environment.

(3)- Dematerialize the economy: The total flows of material and energy must be minimized while providing at least equivalent services. In fact, technical progress ensures that more services are obtained with a smaller quantity of material, in particular by manufacturing lighter objects. Other, one of the best ways to dematerialize the economy is to optimize the use, i.e. sell the use instead of the object.

(4)- Decarbonize energy: Fossil carbon is the source of many environmental problems identified recently: increase in the greenhouse effect, oil spills, acid rain ... Therefore, it is essential to make the consumption of hydrocarbons less damaging and promote the transition to another source of energy less rich in fossil carbon (use of renewable energies).Industrial ecology and sustainable development

Sustainable development has been defined by the United Nations World Commission on Environment and Development as "meeting the needs of the present generation without sacrificing the needs of future generations". The major principles of sustainable development include: the sustainable use of resources, the preservation of ecological and human health (i.e. maintaining the structure and functioning of ecosystems) and the promotion of environmental equity, both inter-generational and inter-societal [12], [13], [14].

Industrial ecology aims to promote sustainable development at three levels global, regional and local. In fact, according to Makov (2014) it is the science behind sustainability [15].

1.3. Industrial ecology in Morocco

In recent decades, Morocco has suffered significant environmental threats that are generally due to human activity, which has made this topic a social concern and which has created international, national and regional debates.

Waste production in Morocco increased by 7,486 thousand tons in 2000 to reach 6.2 million tons in 2020 according to estimates by the supervisory ministry, this growth force is mainly linked to the acceleration of the urbanization process, the improvement of the standard of living of the inhabitants and the extension of tourist and industrial activities, etc.

In terms of space, waste production is highly concentrated in the regions of Rabat and Casablanca. This is mainly due to their high demographic concentration (21% of the national urban population), and to the location of the main industrial activities (more than 50% of the total industrial production figure) ... Almost 70% of municipal waste is produced in the urban environment, i.e. the equivalent of 4.5 million tones / year. This amount corresponds to an average per capita of around 0.85 kg / day [16].

In fact, Morocco has always been concerned about the protection of its environment. Taking into consideration the state of degradation of its natural resources, Morocco has adopted an environmental policy based essentially on the concept of sustainable development. It intends to make environmental protection a factor in the country's economic and social development [17].

1.4. Problematic and proposed solution

Regardless of which concepts treated above, industrial ecology is concerned with the evolution of the industrial system as a whole and in the long term. Environmental problems are therefore only one aspect, among others, of industrial ecology, which works for the advent of a more "elegant" and "intelligent" industrial system, i.e. capable of generating wealth and well-being with fewer resources and less impact on the Biosphere.

In this context, at the industrial sector (specifically the agro-food sector), the problematic that arises is:

- How to automate control for green industrial use?
- How to ensure the traceability of the raw material?
- How to install a quality control technique: reliable, fast, economical, non-polluting and smart?

To reply to these requirements, while respecting the principles and objectives of industrial ecology, our research team proposed a developed analysis and control technique. This technique is based on infrared spectroscopic analysis of food product waste combined with multivariate analysis to establish a mathematical model of prediction of the quality of the products in question.

At the end, in the remainder of the present paper, you will find the description of the new developed technique. Then, the results of its application with discussion were presented. And finally, a conclusion explains the interest and efficiency of its implementation for an ecological and sustainable agro-food industry.

II. MATERIAL AND METHODS

2.1. Scientific procedure

To automate the control for a green and ecological industrial use, we adopted the following approach (Fig. 1).

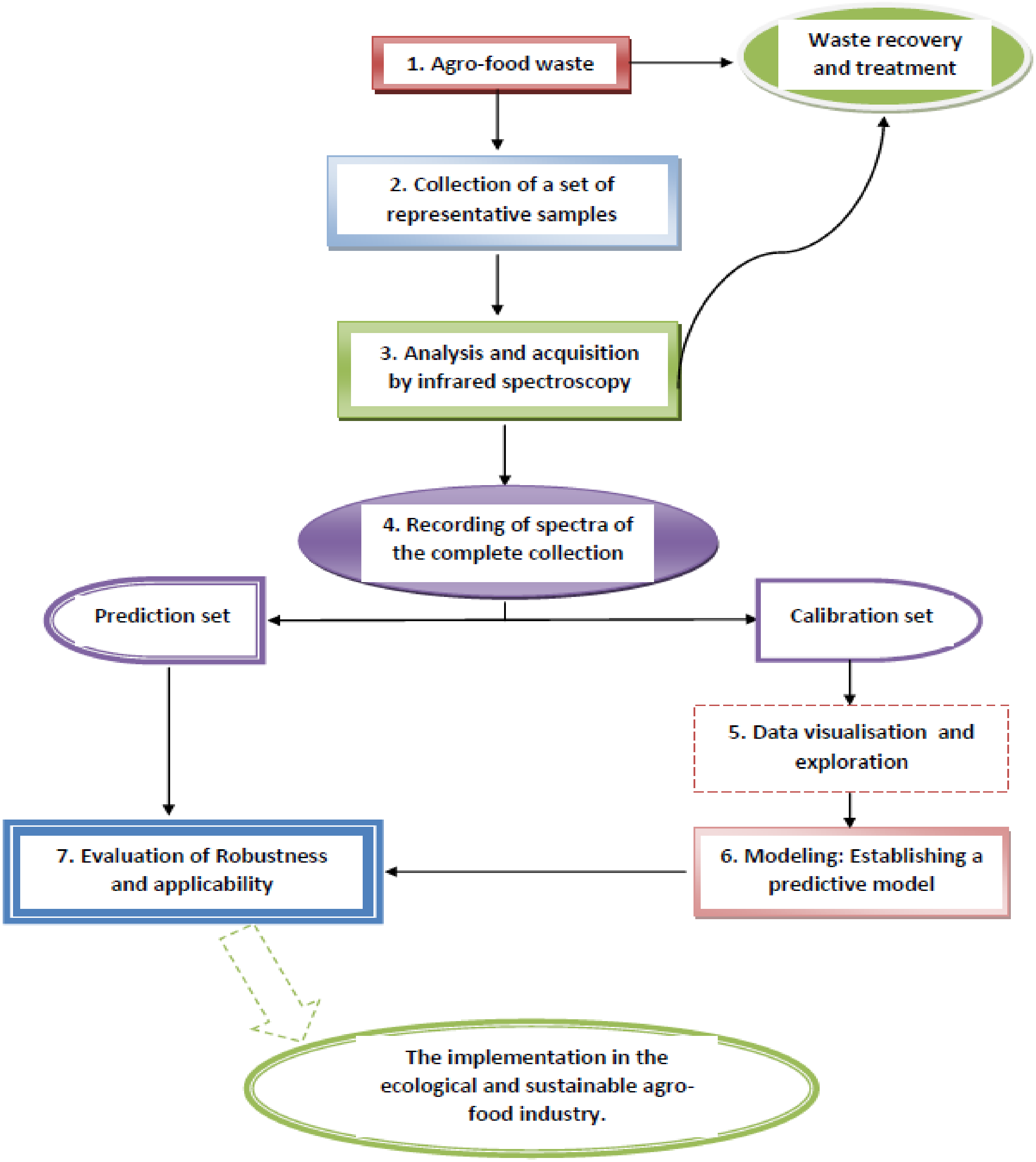

Figure 1: The main stages of the scientific process.

2.2. Sampling

The proposed analytical technique for quality control by guarantying traceability in the ecological and sustainable agro-food industries, its validity is tested by its application on a set of samples of green pea pods (firstly) and date seeds (secondly).

According to Figure 1, we have created two different sample collections:

- For green pea pods, samples were taken from three very close areas called Aine (A), Ksiba (K) and Tassemit (T). A series of 113 samples was selected to constitute the prediction model (calibration set). And 39 samples were used as an external validation set (prediction set).

- For date seeds, samples were taken from three varieties named Boufegousse (BF), Bouslikhen (BK) and Mejhoul (MJ). A series of 45 samples was selected for the calibration set. While 18 samples for prediction set.

2.3. Analysis and processing tools

2.3.1. Analysis by infrared spectroscopy

In the present research work, infrared spectroscopy analysis was chosen due to its multiple advantages and benefits (Fig. 2) [18], [19], [20].

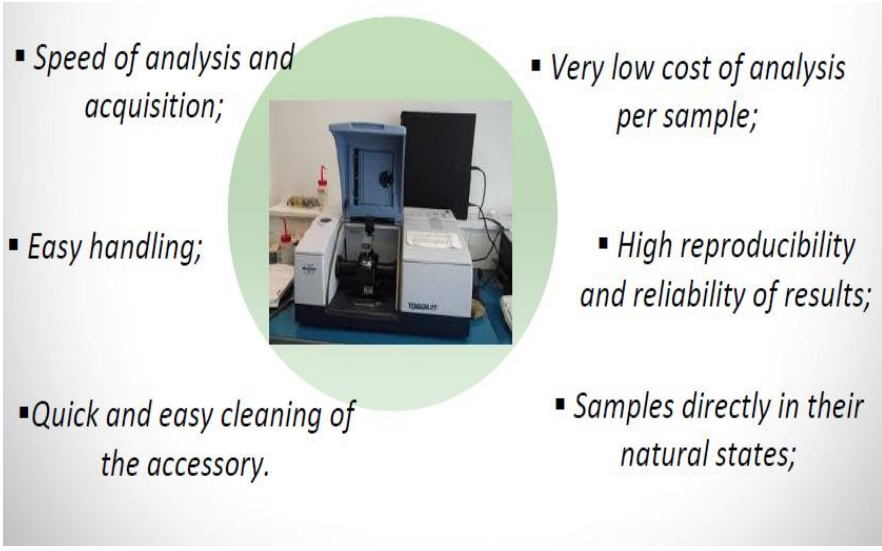

Figure 2: The advantages of infrared spectroscopic analysis.

In practice, spectroscopic measurements were taken from studied samples at ambient temperature of 25 ° C. The specters were obtained using a Vector 22 Bruker FTIR Spectrophotometer equipped with an attenuated total reflectance accessory (ATR single reflexion, Diamond, incident angle 45°, Pike Miracle, Pike Technologies, Madison, USA) with DTGS detector, Globar (MIR) Source and KBr Germanium separator, with a resolution of 4 cm^{-1} at 90 scans. Spectra were scanned in the absorbance mode from 4000 to 600cm^{-1} and the data were handled with OPUS logiciel.

For modeling step, the specters (analytical data) are converted into a numerical table by using "Unscrambler X" software version 10.2.

2.3.2. Algorithms of processing and modeling

To visualize, explore and model the analytical data, the various mathematical tools and algorithms offered by the "Unscrambler X" software were used. In this work, mainly, principal component analysis (PCA) and cluster analysis (CA) have been used for visualization. While, to establish the prediction model the linear discriminant analysis (LDA) was used. In fact, these tools have been applied due to their proven success in various research works [21], [22], [23], [24], [25].

III. RESULTS AND DISCUSSION

3.1. Spectroscopic measurements of Agro-food waste samples

For green pea pods, the infrared (IR) spectra of 113 samples from each of the three studied classes at the region of 4000–600 cm^{-1} were recorded in triplicate and a mean spectrum was calculated for each class. The resultant mean spectra of three classes are presented in Fig.3 (a). While, the IR spectra of the studied samples of date seeds were shown in Fig. 3 (b).

In general, according to Fig.3, it wasn't any clear difference between the three studied classes by visual inspection.

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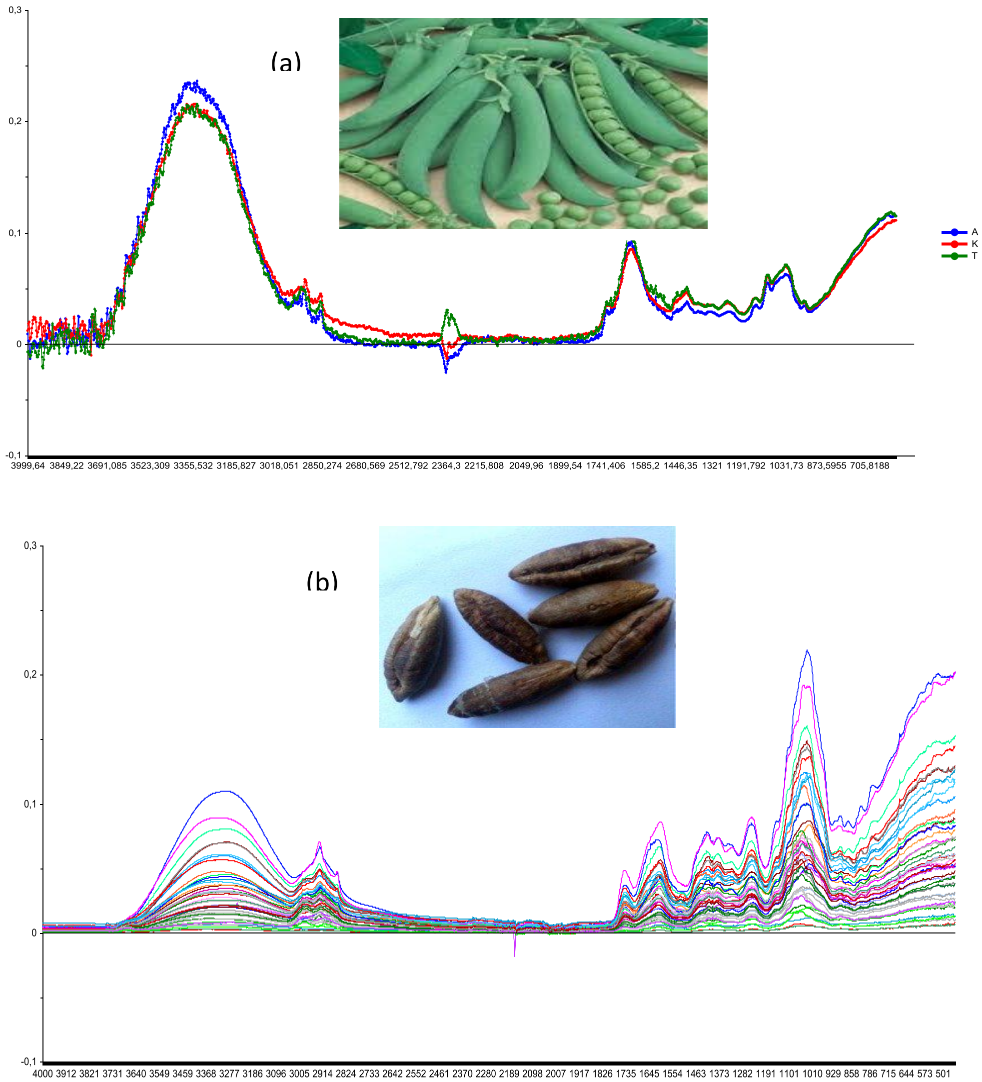

Figure 3: ATR-FTIR spectra at frequency region of 4000–450cm^{-1}: (a) The average spectrum calculated for each class of green pea pods: Aine (A), Ksiba (K) and Tassemit (T);
(b) Spectra of samples of date seed from 3 varieties: Boufegousse (BF), Bouslikhen (BK) and Mejhoul (MJ).

3.2. Data visualization

In order to extract non specific analytical information from the full spectra and anticipate the possibility of distinguishing between the three studied classes, CA and PCA were applied (Fig.4). For green pea pods, the results were reported in the form of dendrogram, shown in Fig.4 (a). On the basis of the connecting distances three distinctive clusters were defined. While, all date seed samples were separated into three groups according to the variety. This result was presented in the score plot of PCA (Fig. 4 (b)).

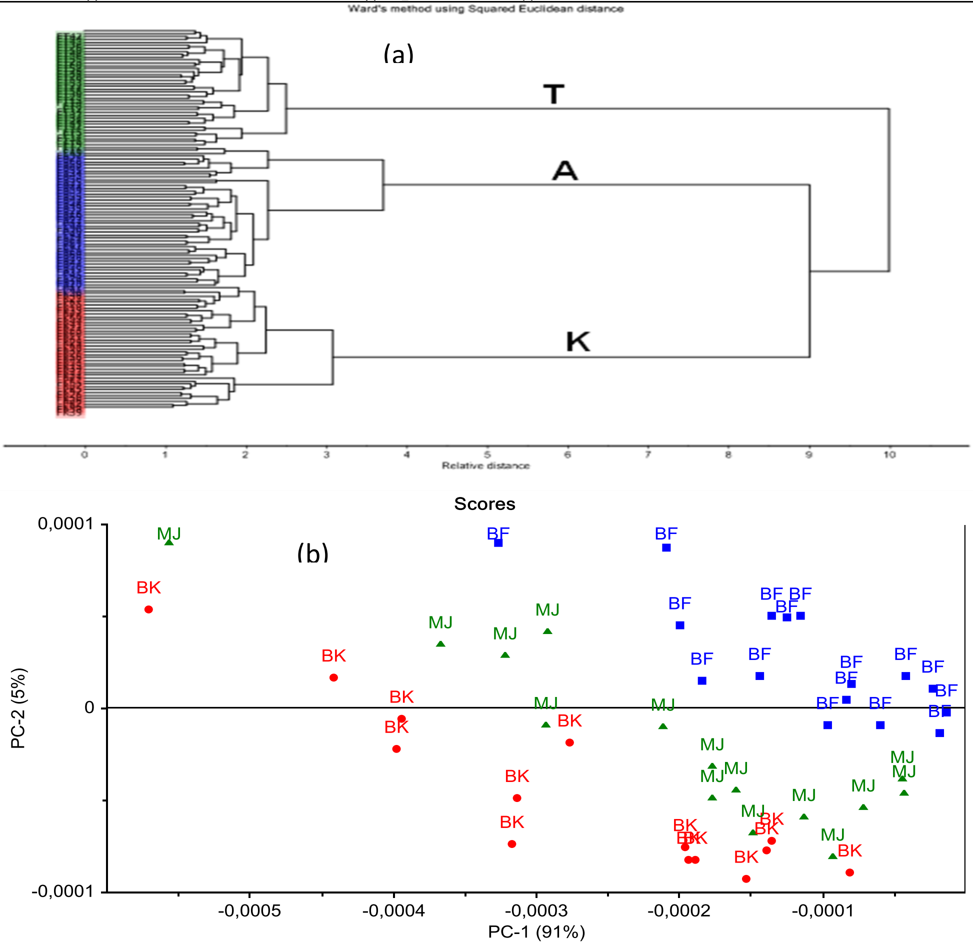

Figure 4 : (a) Dendrogram obtained by C.A for studied green pea pods;
(b) 2D score plot of the PCA discrimination results for the studied date seeds.

3.3. Modeling

At this stage, a mathematical prediction model was established by LDA. In Fig. 5 (a), a net grouping of green pea pod samples according to geographic origin was shown. Each sample is located near other samples of the same provenance on the bi-plot. Likewise, all date seed samples were grouped according to variety into three classes, except two samples (Fig.5 (b).

Generally, according to score plot in Fig. (5), the obtained LDA model was able to discriminate all samples with a correct classification of 97.78 to 100%. Which appears sufficient and acceptable to consider this model.

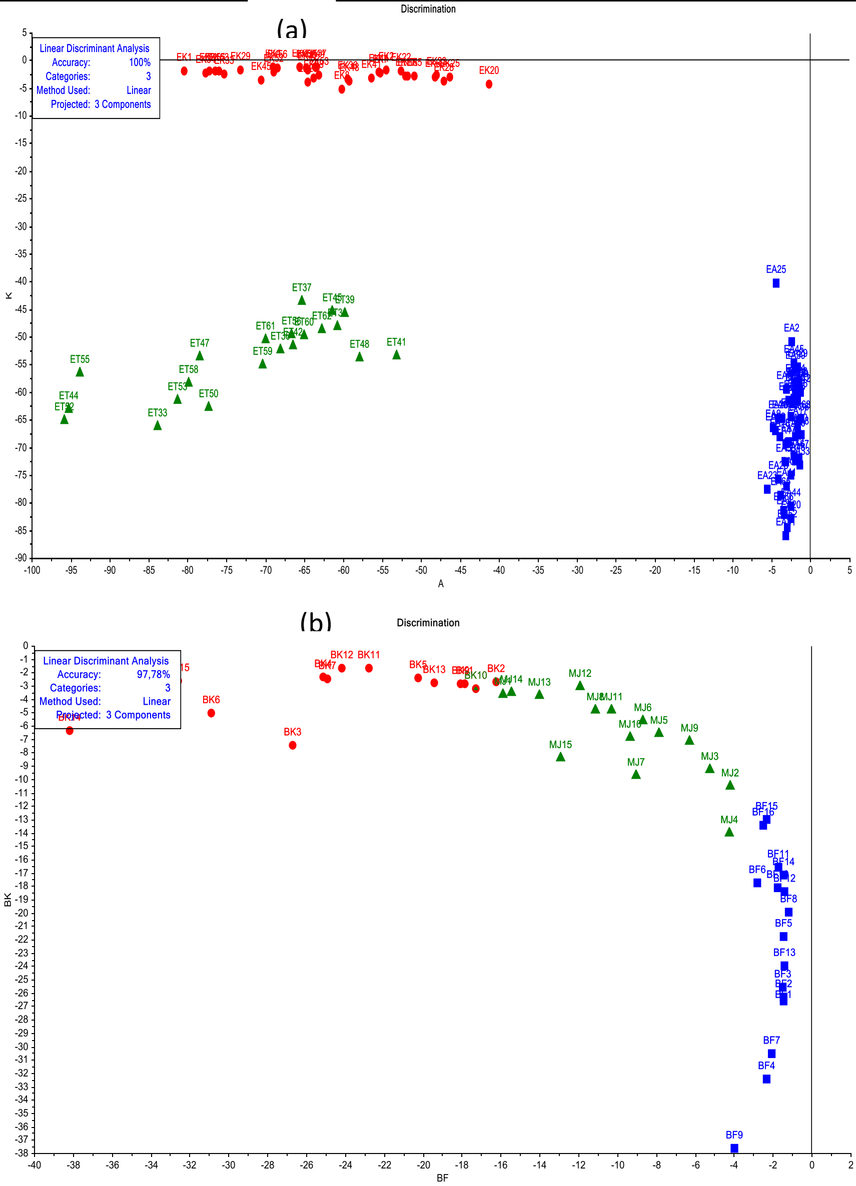

Figure 5: 2D score plot of the classification results by LDA for the studied, (a) green pea pods; (b) date seeds.

3.4. Applicability test of established model

At this last stage, the model established by LDA was tested to verify its ability to detect each studied sample and ensure its authenticity. So an external validation process was carried out. In this process, the final LDA model was applied to the prediction samples, to classify them in the three previously established classes (Tables 1 and 2). According to the obtained results, it was proved that the proposed approach allows correct prediction and detection of the geographical or varietal origin. The LDA model made from infrared spectra gave a good classification rate of 100%.

Table.1. Prediction matrix from application of the LDA model on the test set of green pea pods

Val. Samples	**A**	**K**	**T**	**Prediction**
A1	-3.158874	-50.84052	-74.68506	A
A2	-4.101234	-67.1871	-84.7058	A
A3	-1.687999	-59.35314	-70.3778	A
A4	-1.190466	-66.69976	-74.74252	A
A5	-2.185573	-67.08732	-86.3427	A
A6	-1.315456	-72.19382	-77.67012	A
A7	-1.506472	-69.54567	-77.80459	A
A8	-1.358198	-58.30017	-69.63013	A
A9	-1.908075	-67.1737	-74.87966	A
A10	-2.593512	-62.3767	-65.92429	A
A11	-1.960508	-55.40334	-63.06521	A
A12	-2.793671	-70.09133	-77.22839	A
A13	-1.134691	-65.91769	-72.12811	A
A14	-2.68093	-80.06209	-69.07406	A
A15	-1.758588	-60.67843	-58.71832	A
K1	-57.42326	-1.417984	-47.96061	K
K2	-43.5301	-3.374485	-45.64589	K
K3	-80.50932	-6.14508	-33.51978	K
K4	-52.00443	-2.088511	-45.02376	K
K5	-57.3997	-1.38269	-51.40598	K
K6	-72.29573	-1.828321	-58.94814	K
K7	-62.56615	-1.951521	-52.77494	K
K8	-77.1734	-2.049581	-66.50121	K
K9	-66.147	-2.261976	-64.99434	K
K10	-65.61007	-1.555146	-52.68943	K
K11	-61.35155	-1.872738	-41.31849	K
K12	-74.39681	-1.400173	-55.85326	K

K13	-61.70991	-2.139587	-65.06322	K
K14	-68.19442	-1.179674	-56.24524	K
K15	-95.0842	-4.182551	-72.19393	K
T1	-76.56245	-47.3916	-1.781111	T

Table.1. (Continued).

T2	-54.5568	-35.47198	-3.427937	T
T3	-60.83017	-46.27092	-2.236708	T
T4	-75.08875	-58.77942	-3.410845	T
T5	-87.13584	-49.05946	-2.709015	T
T6	-64.22703	-46.77996	-2.290959	T
T7	-73.98074	-59.14059	-1.311663	T
T8	-78.07673	-47.30912	-1.788351	T
T9	-57.96758	-45.07384	-2.320819	T

Table.2. Prediction matrix from application of the LDA model on the test set of date seeds.

Val. Samples	BF	BK	MJ	Prediction
BF1	-1.731771	-18.15029	-6.578182	BF
BF2	-1.381163	-18.43539	-6.373425	BF
BF3	-1.438119	-26.34145	-11.4107	BF
BF4	-2.30029	-32.4577	-15.54798	BF
BF5	-1.44493	-17.16254	-5.680613	BF
BF6	-2.782592	-17.76814	7.13701	BF
BK1	-24.18576	-1.670009	-7.814801	BK
BK2	-38.17123	-6.370128	-18.8017	BK
BK3	-16.22474	-2.70391	-3.603048	BK
BK4	-25.10872	-2.366943	-6.319353	BK
BK5	-30.87604	-5.025789	-10.28248	BK
BK6	-24.90357	-2.458194	-5.982384	BK
MJ1	-8.672007	-5.659779	-1.132034	MJ
MJ2	-4.254069	-	-	MJ

		14.01096	3.712273	
MJ3	-12.89882	-8.417456	-5.768194	MJ
MJ4	-11.92987	-3.090985	-1.73257	MJ
MJ5	-9.333789	-6.872722	-1.73257	MJ
MJ6	-4.206968	-10.49938	-2.88742	MJ

IV. CONCLUSION

Industrial processes, from the extraction of raw materials to the disposal of products, have a negative impact on the environment. Industrial ecology aims to reduce environmental stress forward by industry while encouraging innovation and efficient use of resources. Certainly, industrial ecology recognizes that the industry will continue to function and develop. But it supports an environmentally conscious industry, which reacts as part of a larger ecology rather than as an external and solitary entity.

The present research work, presents a systematic and innovative analytical methodology for a sustainable process, combining the principles of industrial ecology with the requirements (in terms of quality) of the authority and the consumers. In fact, this new method offers the possibility of determining the traceability of a food product by a simple analysis of the waste of its raw material.

Additionally, in light of the obtained results, we can say that,

- The developed analytical approach from IR combined with multivariate analysis presents an operational strategy for the implementation of industrial ecology;

- It is a practical, easy, economical, non-polluting and effective tool to guarantee quality and authenticity in the sustainable food industry.

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