From food processing leftovers to bioplastic: a Design of Experiments approach in a circular economy perspective

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The continuous population growth all over the world highlights the need of more sustainable materials and processes for cultivation and food waste valorization (Sadowski and Baer-Nawrocka, 2018). In particular, the reduction of petroleum derived plastic, actually employed in over 60 million tons, is one of the critical issues that arises from European Union Council, thereafter research in this field is attracting more and more interest (European Commission, 2018).

In a circular economy perspective, the aim of this study is to obtain bioplastic suitable for agricultural purpose (e.g. mulch film or pot) derived from food waste and agricultural leftover processing. Therefore, at least two beneficial effects are expected, the first concerning the reduction of organic waste volume derived from food processing and the second related to a restrained employment of petroleum derived plastic. The key point of this conversion is the employment of a particular insect, black soldier fly (*Hermetia illucens*), well-known in literature as safe biodigester for a wide type of waste and able to act, in its prepupae stage, as source of macronutrients such as protein and lipids, useful for several application (e.g. feed, biofuel) (Barragan-Fonseca et al., 2019). Consequently, the present work can be divided in two parts, the first concerning the optimization of black soldier fly diets and the second about the bioplastic formulation based on insect's fraction.

Design of experiments (Montgomery, 2012) was applied to insect's diets and bioplastic formulation correlating in this way waste (type and amount) into the insect's diet with its prepupae (P) rearing performance (days, weigh, number) and black soldier fly nutritional composition (lipids and proteins), and thereafter with its capability to act as source of nutrients interesting for bioplastic formulation. A total of 14 different diets were examined. For each diet 3 repetitions were performed, and the average value of the responses have been considered for mathematical model calculation. All the other rearing parameters were kept as constant (27 ± 0.5 °C, 60–70% RH). A control diet (CNT), composed of 50% wheat bran, 30% alfalfa meal and 20% corn meal was also considered for comparison (Sheppard et al., 2002). Lipidic and proteic fractions from prepupae were obtained as reported in Caligiani et al., 2018. In Table 1 ranges of factors and responses obtained have been reported in comparison with the control diet.

Table 1. Diets and Black Soldier Fly rearing performances.

				RESPONSES				
	Legume wt %	Corn wt %	Pomace wt %	P Weight (g)	P Number	Days	Lipids (%)	Proteins (%)
Min	0	0	0	0.1111	62.3	12.0	4.94	14.76
Max	100	100	100	0.2268	100	47.0	11.97	18.46
CNT	/	/	/	0.1667	97.33	20.2	7.86	16.81

In order to obtain bioplastic, proteins fraction from BSF was exploited, thanks to theirs more similar chemical bonding with plastic, and employed to partially substitute LDPE in plastic formulation, through hot melting and pressing. In Table 2 factors and responses ranges have been indicated including all the 22 different combination of factors considered.

Table 2. Bioplastic formulation and mechanical properties.

				RESPONSES		
	Protein wt%	Temperature (°C)	Time (min)	Tensile stress (MPa)	Tensile strain (%)	Young Modulus (MPa)
Min	10	130	3	2.41	1.60	67
Max	30	170	8	6.17	21.71	211

Results (Figure 1a) indicate that a well-tailored mixture of food processing leftovers is able to improve the BSF growth performance very close to the control diet, thus overcoming the negative effects of nutritionally unbalanced substrates. In particular, a wide range of this type of leftovers are able to optimize (orange color into the graph) the rearing performance obtaining, thereafter, an improved efficiency in macronutrients availability.

Proteins extracted are able to be mixed with petroleum derived plastic, LDPE, decreasing the negative effects on the environment but also decreasing the mechanical properties (Figure 1b). It is relevant to note that mechanical properties are not fundamental for plastic to be employed in mulching film or pot. At the same time, from the Design of Experiments calculation, temperature and time of processing resulted to have a restrained impact of the mechanical properties of the plastic.

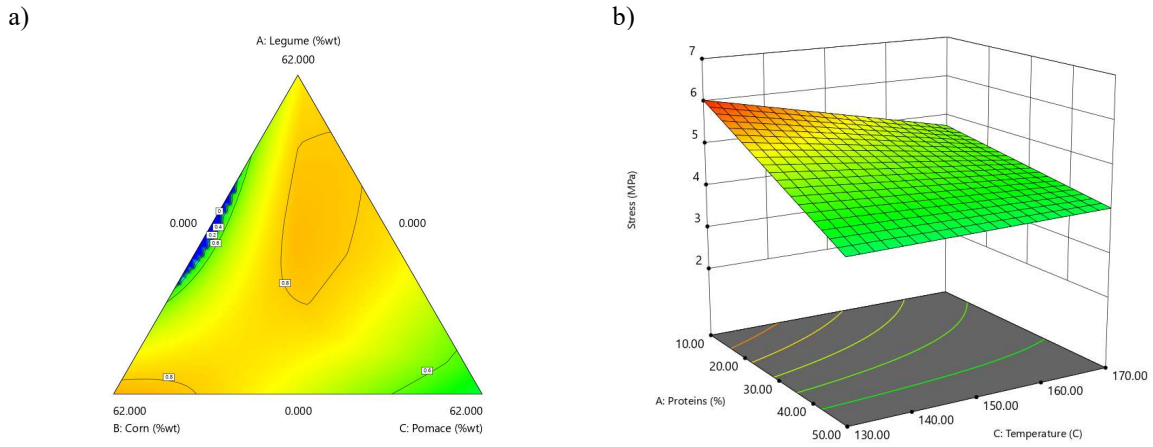

Figure 1 – Results from Design of Experiments modelling: a) Black Solider Fly diets b) Tensile stress of bioplastic

This rational study can support the strategical choice of leftovers employment for processing by insects to derive functional products, appealing to the market and satisfying the circular economy requirements. At the same time, this study confirms that proteins extracted from BSF could be used to obtain bioplastic that could be promising with the add value to use proteins deriving by the digestion of waste by insect and then contributing to the circular economy perspective.

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