COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

GRADO EN INGENIERÍA Y TECNOLOGIAS INDUSTRIALES

TRABAJO FIN DE GRADO

Diseño de una planta de tratamiento de insectos y optimización de procesos

Autor: Jose María de Marcos López-Baissón

Director: Maximilien Leclercq

Madrid

Septiembre de 2019

AUTORIZACIÓN PARA LA DIGITALIZACIÓN, DEPÓSITO Y DIVULGACIÓN EN RED DE PROYECTOS FIN DE GRADO, FIN DE MÁSTER, TESINAS O MEMORIAS DE BACHILLERATO

1º. Declaración de la autoría y acreditación de la misma.

El autor D_**JOSE MARÍA DE MARCOS LÓPEZ-BAISSÓN** ___________________________
DECLARA ser el titular de los derechos de propiedad intelectual de la obra: **DISEÑO DE UNA PLANTA DE TRATAMIENTO DE INSECTOS Y OPTIMIZACIÓN DE PROCESOS** _________________, que ésta es una obra original, y que ostenta la condición de autor en el sentido que otorga la Ley de Propiedad Intelectual.

2º. Objeto y fines de la cesión.

Con el fin de dar la máxima difusión a la obra citada a través del Repositorio institucional de la Universidad, el autor **CEDE** a la Universidad Pontificia Comillas, de forma gratuita y no exclusiva, por el máximo plazo legal y con ámbito universal, los derechos de digitalización, de archivo, de reproducción, de distribución y de comunicación pública, incluido el derecho de puesta a disposición electrónica, tal y como se describen en la Ley de Propiedad Intelectual. El derecho de transformación se cede a los únicos efectos de lo dispuesto en la letra a) del apartado siguiente.

3º. Condiciones de la cesión y acceso

Sin perjuicio de la titularidad de la obra, que sigue correspondiendo a su autor, la cesión de derechos contemplada en esta licencia habilita para:

a) Transformarla con el fin de adaptarla a cualquier tecnología que permita incorporarla a internet y hacerla accesible; incorporar metadatos para realizar el registro de la obra e incorporar "marcas de agua" o cualquier otro sistema de seguridad o de protección.
b) Reproducirla en un soporte digital para su incorporación a una base de datos electrónica, incluyendo el derecho de reproducir y almacenar la obra en servidores, a los efectos de garantizar su seguridad, conservación y preservar el formato.
c) Comunicarla, por defecto, a través de un archivo institucional abierto, accesible de modo libre y gratuito a través de internet.
d) Cualquier otra forma de acceso (restringido, embargado, cerrado) deberá solicitarse expresamente y obedecer a causas justificadas.
e) Asignar por defecto a estos trabajos una licencia Creative Commons.
f) Asignar por defecto a estos trabajos un HANDLE (URL *persistente)*.

4º. Derechos del autor.

El autor, en tanto que titular de una obra tiene derecho a:

a) Que la Universidad identifique claramente su nombre como autor de la misma
b) Comunicar y dar publicidad a la obra en la versión que ceda y en otras posteriores a través de cualquier medio.
c) Solicitar la retirada de la obra del repositorio por causa justificada.
d) Recibir notificación fehaciente de cualquier reclamación que puedan formular terceras personas en relación con la obra y, en particular, de reclamaciones relativas a los derechos de propiedad intelectual sobre ella.

5º. Deberes del autor.

El autor se compromete a:

a) Garantizar que el compromiso que adquiere mediante el presente escrito no infringe ningún derecho de terceros, ya sean de propiedad industrial, intelectual o cualquier otro.
b) Garantizar que el contenido de las obras no atenta contra los derechos al honor, a la intimidad y a la imagen de terceros.
c) Asumir toda reclamación o responsabilidad, incluyendo las indemnizaciones por daños, que

pudieran ejercitarse contra la Universidad por terceros que vieran infringidos sus derechos e intereses a causa de la cesión.

d) Asumir la responsabilidad en el caso de que las instituciones fueran condenadas por infracción de derechos derivada de las obras objeto de la cesión.

6º. Fines y funcionamiento del Repositorio Institucional.

La obra se pondrá a disposición de los usuarios para que hagan de ella un uso justo y respetuoso con los derechos del autor, según lo permitido por la legislación aplicable, y con fines de estudio, investigación, o cualquier otro fin lícito. Con dicha finalidad, la Universidad asume los siguientes deberes y se reserva las siguientes facultades:

- La Universidad informará a los usuarios del archivo sobre los usos permitidos, y no garantiza ni asume responsabilidad alguna por otras formas en que los usuarios hagan un uso posterior de las obras no conforme con la legislación vigente. El uso posterior, más allá de la copia privada, requerirá que se cite la fuente y se reconozca la autoría, que no se obtenga beneficio comercial, y que no se realicen obras derivadas.
- La Universidad no revisará el contenido de las obras, que en todo caso permanecerá bajo la responsabilidad exclusive del autor y no estará obligada a ejercitar acciones legales en nombre del autor en el supuesto de infracciones a derechos de propiedad intelectual derivados del depósito y archivo de las obras. El autor renuncia a cualquier reclamación frente a la Universidad por las formas no ajustadas a la legislación vigente en que los usuarios hagan uso de las obras.
- La Universidad adoptará las medidas necesarias para la preservación de la obra en un futuro.
- La Universidad se reserva la facultad de retirar la obra, previa notificación al autor, en supuestos suficientemente justificados, o en caso de reclamaciones de terceros.

Madrid, a …**18**.. de **SEPTIEMBRE**... de …**2019**…….

ACEPTA

Fdo…**Jose María de Marcos López-Baissón**

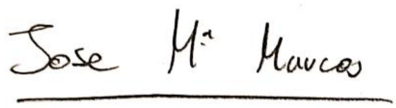
Motivos para solicitar el acceso restringido, cerrado o embargado del trabajo en el Repositorio Institucional:

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título …Diseño de una planta de tratamiento de insectos y optimización de procesos…………………… en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico …2018/2019. es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos. El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido tomada

de otros documentos está debidamente referenciada.



Fdo.: Jose Mª de Marcos López-Baissón Fecha: 18/09/2019

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Maximilien Leclercq Fecha: 18/09/2019

GRADO EN INGENIERÍA Y TECNOLOGIAS INDUSTRIALES

TRABAJO FIN DE GRADO

Diseño de una planta de tratamiento de insectos y optimización de procesos

Autor: Jose María de Marcos López-Baissón

Director: Maximilien Leclercq

Madrid

Septiembre de 2019

Diseño de una planta de tratamiento de insectos y optimización de procesos.

Autor: Marcos López-Baissón, Jose María de.

Director: Leclercq, Maximilien.

Entidades Colaboradoras:

- **ESIEE (Escuela de Ingeniería Eléctrica y Electrónica) – Amiens (Francia).**
- **GNG Distribution. France Insectes. Antoine Garault**

RESUMEN DEL PROYECTO

El Proyecto trata de atender las necesidades de procesado automatizado de insectos de una pequeña compañía con sede en Crevecoeur Le Grand (Departamento de L´Oise, Haut de France, cerca de Amiens - Francia) que se dedica a la producción, procesado, almacenamiento, distribuc.

ión y comercialización física y por internet de insectos con múltiples finalidades como alimentación de mascotas, cebos para pesca, y alimentación animal en general.

Este Proyecto surge en un marco de colaboración entre la Escuela de Ingeniería Eléctrica y Electrónica (ESIEE) de Amiens y la Compañía GNG Distribution. Mediante este acuerdo, tras superar un proceso de selección de candidatos, el alumno autor de este Proyecto fue contratado en prácticas de tres meses por GNG Distribution y fue supervisado por el profesor de la Universidad Mr Maximilien Leclercq para la realización de unos análisis previos de cara a conocer la viabilidad de automatizar la etapa del procesado de la producción de gusanos de harina.

El gusano de harina es la fase larvaria del coleóptero cuyo nombre científico es *Tenebrio Molitor*.

Hasta la fecha la Empresa GNG Distribution se dedica preferentemente al procesado de insectos vivos que adquiere en el mercado internacional (Holanda y Alemania). Normalmente adquiere larvas que engorda para luego envasarlas y comercializarlas y solo eventualmente las produce.

Entre los planes de expansión de la empresa figura la producción propia de insectos y su procesado para el almacenaje de los insectos congelados en su fase larvaria (gusanos). De esta forma, pretende adecuarse al ritmo de suministro al mercado dotándose de un stock de productos finalizados que le permita adaptarse a las variaciones estacionales de la demanda.

Aunque en la actualidad la empresa se plantea su actuación en unos nichos de mercado muy concretos de la alimentación animal mediante insectos (alimentación de mascotas, suministro a zoos y cebos de pesca deportiva), hay que indicar que las posibilidades de la alimentación a partir de insectos para producción de carne para consumo son enormes. El crecimiento de la población mundial y la mejora del nivel de renta en muchas zonas geográficas incrementará la demanda de proteínas de origen animal.

Para cubrir esa demanda, la alimentación a partir de insectos sustituyendo en cierta medida la producción de cereales y soja puede ser una alternativa viable desde la perspectiva económica, social y medioambiental. De hecho, se espera que en un plazo de seis años se triplique en términos económicos el Mercado de producción de insectos para alimentación animal pasando de 400 millones de dólares en 2018 a casi 1.200 en 2023.

De cara a una expansión de la empresa a medio plazo, la dirección de la compañía y con independencia de que comience a producir la materia prima (gusanos) o continúe adquiriéndola en el Mercado, se está planteando **realizar una inversión en una cadena de procesado automatizada** para reducir costes y poder atender unos volúmenes crecientes de producción sin tener que aumentar el personal de producción.

El Proyecto se realizó desde los despachos de la cátedra de Desarrollo Sostenible de la escuela de Ingenieria ESIEE en Amiens con diversas estancias que totalizaron más de 30 jornadas de trabajo en las instalaciones de la Empresa GNG Distribution. En estas Jornadas:

- Se conoció las distintas actividades que se realizan en el seno de la empresa con especial atención a la etapa de producción de los gusanos de harina y de otros insectos como grillos.
- Se asistió a distintas jornadas de trabajo en las que los operarios realizaron el procesado de los gusanos de forma manual, midiéndose los tiempos de trabajo y las productividades obtenidas en las distintas etapas, asi como el proceso de preparación de pedidos mayoristas y al por menor.
- Se tomaron medidas de la nave donde se plantea montar la planta de procesado, características de los suministros de gas y electricidad.
- También se asistió acompañando al director de la empresa a reuniones con suministradores de bienes de equipo en las que estos expusieron las posibilidades y ventajas de algunos de los elementos que comercializan.

Contenido de la Memoria del Proyecto

A lo largo de este informe, en primer lugar **se describe la Empresa GNG Distribution**, una empresa familiar de pequeño tamaño y larga experiencia en la producción de insectos, se expone el estado del arte de la producción de insectos para alimentación de otras especies animales y su utilidad en un entorno de crecimiento sostenible, **se describen las características de la planta de procesamiento** objeto del Proyecto y las distintas etapas y maquinas que lo componen, **se hace un análisis económico considerando los costes de inversión y de operación** a que daría lugar la adquisición de la planta de proceso, con el fin de **estimar un "coste levelizado" de la unidad de producto procesado**.

También se incluye un análisis estadístico de los tiempos de trabajo a los que da lugar en la actualidad el procesado manual de la producción con el fin de facilitar a la Dirección de la empresa información precisa para la toma de la decisión de inversión.

Por último y a modo de **conclusión se recogen una serie de recomendaciones para la mejora del proceso actual y para la puesta en marcha del proyecto**.

Concepción de la planta de proceso

El Proyecto tiene por finalidad analizar cuáles de las máquinas/tecnologías, que están disponibles en el mercado de la industria agroalimentaria para las distintas etapas del tratamiento, se podrían utilizar para montar una línea de procesado con el objetivo de satisfacer razonablemente las necesidades de producción de esta línea de productos a largo plazo.

El esquema de las distintas etapas de procesamiento es el más habitual para procesos de la industria alimentaria, y sigue las pautas para cumplir la normativa sanitaria.

Las etapas que se han contemplado son las siguientes.

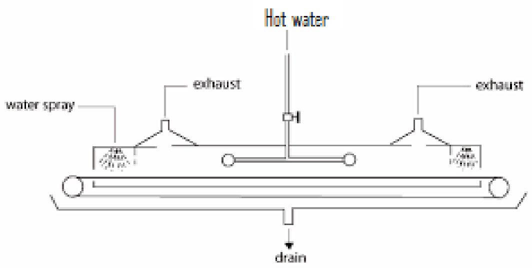
- **Lavado de los gusanos**: para eliminar los restos de piel, harina y heces.
- **Escaldado / Cocción**: para desactivar las enzimas responsables del deterioro del producto.
- **Enfriamiento y Secado**: como requisito previo a la congelación.
- **Congelación:** para aumentar la duración del producto.
- **Empaquetado**: para facilitar la posterior distribución del producto.

Dadas las características cualitativas del producto en cuestión (gusanos de harina) se ha seleccionado maquinaria para las distintas etapas del proceso basada en tecnologías IQx (Individual Quick).

Este tipo de tecnologías de proceso basan su funcionamiento en el tratamiento de cada unidad (gusano) de forma aislada, lo que permite una mayor eficiencia en los procesos térmicos al optimizar el uso de energía.

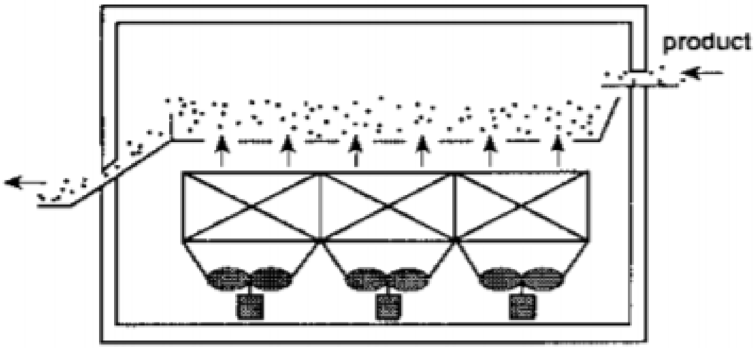
La **etapa de limpieza/lavado**, consiste en aplicar agua mediante **aspersores a temperatura controlada** al producto con suficiente presión para separar el gusano de partículas tales como los restos de mudas (quitina) piel, harina y heces.

La **etapa de escaldado** se prevé realizarla mediante un proceso IQB (Individual Quick Blanching) con un **escaldador en continuo** (conveyor) con aspersión de agua a temperatura próxima a la de ebullición. El producto se desplaza en un tapiz rodante siendo fijos los chorros de aspersión. El agua residual se reutiliza para la propia etapa de escaldado para recuperación térmica. La máquina que se adquiera para esta función podría integrar como una primera fase la etapa de lavado.



Para la etapa de enfriamiento/secado se utilizará un **dispositivo dotado de ventiladores fijos** que crean una corriente de aire sobre la cinta transportadora por el que se traslada el producto. La función principal de esta fase es enfriar el producto y eliminar el agua superficial antes de pasar a la etapa de congelación. Resulta vital el secado superficial para evitar el apelmazamiento de las unidades en el congelado.

Para la **etapa de congelación** se prevé utilizar tecnología (IQF) de **lecho fluido con arrastre por ventilador**. La obtención de frio se consigue mediante corrientes de convección de aire enfriado en un ciclo de compresión-expansión.



Para la **etapa de empaquetado** se prevé usar una **máquina estándar de empaquetado en bolsas del tipo stand-up pouch** que según la dirección de la empresa es la más versátil para distribución mayorista y minorista.

Análisis Económico

En la actualidad estos procesos se realizan de forma un tanto artesanal o manual por los operarios, dado que los volúmenes procesados son hasta la fecha bastante reducidos y solo se recurre a ellos de forma esporádica ya que la mayor parte de la producción se comercializa viva.

En las visitas técnicas que se realizaron a diversos suministradores de estos equipos se puso de manifiesto la gran disparidad de prestaciones y características técnicas de los equipos existentes en el mercado y de precios de los mismos.

Por otra parte, el incremento de producción se acometerá de forma paulatina a lo largo de varios años lo que dificulta la decisión sobre la capacidad de diseño de la planta de procesado.

Con el fin de estimar el coste total unitario del proceso se ha realizado un Análisis de Económico de Costes que se recoge en el informe. Este análisis parte de una estimación de los costes de inversión y de los costes de operación, incluyendo los de mantenimiento de la planta de procesado.

Para el análisis económico se aporta una primera estimación de los costes de inversión y puesta en marcha que conllevaría la automatización de la producción. Dichos costes de inversión de los distintos procesos se han estimado a partir de las cifras proporcionadas por los suministradores de bienes de equipo y los que figuran en la bibliografía y se sintetizan a continuación:

INVESTMENT COSTS	Cost (€)
Rinsing conveyor	8.000
Blanching machine	16.800
Drying conveyor	2.000
Packing machine	21.000
Freezer	40.000
Set up	2.390
Initial investment	90.190

En relación con los costes operativos, siguiendo las indicaciones de la Dirección de la empresa, no se incluyeron los costes directos de personal dado que la explotación de la planta no requerirá durante los primeros años de personal directamente asignado. Serán los operarios actuales los que la operarán cuando se precise (un número reducido de horas al año). Tampoco se ha tenido en cuenta necesidades el coste de construcción de una nave adicional ya que se dispone de suficiente espacio en las instalaciones existentes. Por tanto, los costes operativos que se contemplan son básicamente los relativos a los costes de energía, agua y costes de empaquetado. Para ello se realizaron unas estimaciones de las necesidades de energía que se pueden prever en base a la bibliografía y la experiencia de la empresa:

VARIABLE OPERATING COST							
Subprocess	Consumption						Cost
	Steam (use gas)		Electricity		Water	Packaging	
	BTU/lb	KWh_g/kg	BTU/lb	KWh_e/kg	L/kg	Ud/kg	€/kg
Washing	173	0,112	6	0,004	-	-	0,0077
Blanching	160	0,103	-	-	-	-	0,0066
Cooling	-	-	6	0,004	-	-	0,0006
Freezing	-	-	586	0,379	-	-	0,0546
Packaging	-	-	15	0,010	-	-	0,2094
Water	-	-	-	-	-	-	0,0451
TOTAL	330	0,215	613	0,396	9,84	8	0,3241

Para calcular los costes que figuran en la tabla anterior se han utilizado los siguientes costes unitarios de agua, energía y fungibles de empaquetado:

UNITARY COST	Water (l)	Gas (kWh)	Electricity(kWh)	Standup pouch
Price (€)	0,00458	0,0643	0,1443	0,026

Para calcular los costes anuales de amortización y financiación, se ha asumido una vida útil de 10 años y un coste de capital del 5% como valor medio a lo largo de la vida útil del equipo.

FINANCIAL PARAMETERS		
Machine's lifespan	10	years
Financing cost	5	%
Yearly equipment's capital cost	11.680	€
Yearly operating and maintenance costs	3.607	€
Total	15.287	€

4% of the initial investment

Con estas hipótesis, los Costes de producción totales unitarios para una producción anual estimada en los primeros años de 30.000 kg/año incluyendo el coste de la materia prima, los costes de inversión y los costes de operación variables resultan ser:

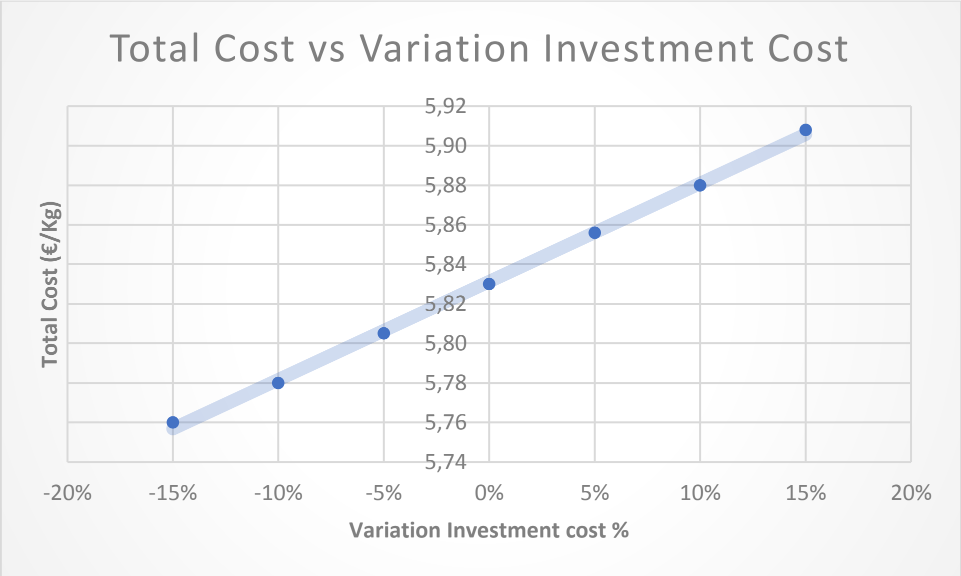
TOTAL PRODUCTION COSTS		
Mealworm's purchase price	5,00	€/kg
Capital costs	0,51	€/kg
Variable costs	0,32	€/kg
Total cost	5,83	€/kg

La tabla muestra los costes del proceso incluyendo los costes fijos y de la materia prima. Los costes totales de procesado son 0,83 €/kg frente a 5,00 €/kg de la materia prima. Es decir, el procesado supone el 14% del coste del producto final ya congelado.

Dentro de los costes de procesado, el 61% (0,51 €/kg) son de carácter fijo, debidos a la amortización y financiación de inversión inicial y el resto, el 39% son variables suponiendo unos 0,32 €/kg.

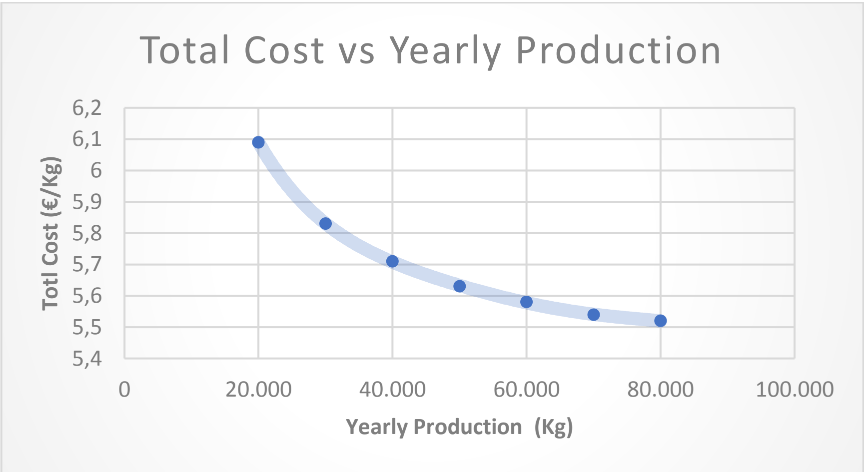
Dada la incertidumbre que presenta en esta etapa inicial los diversos costes contemplados se realizaron diversos análisis de sensibilidad a los parámetros de costes contemplados en el escenario central.

Así, por ejemplo, el siguiente gráfico recoge el coste total de producción frente al desvío positivo o negativo que se puede producir en el coste total de inversión sobre el estimado en el caso base.



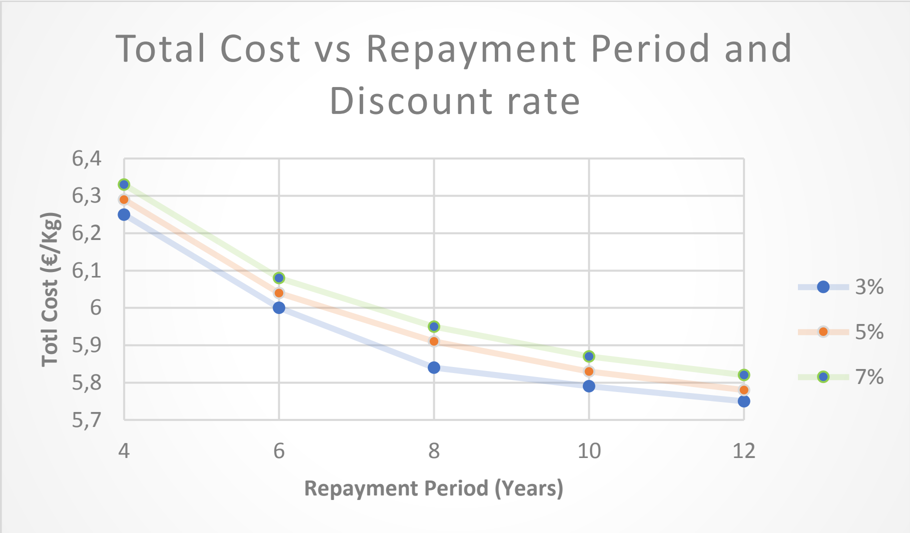
En caso de que la inversión se desvíe un 15% al alza con respecto a la prevista en el caso base, el coste total de producción se elevaría en 0,08 €/kg, lo que supone un 1,33% sobre el caso base.

También es muy relevante conocer cómo puede variar el coste total en función del nivel anual de producción. El siguiente gráfico recoge dicha variación:



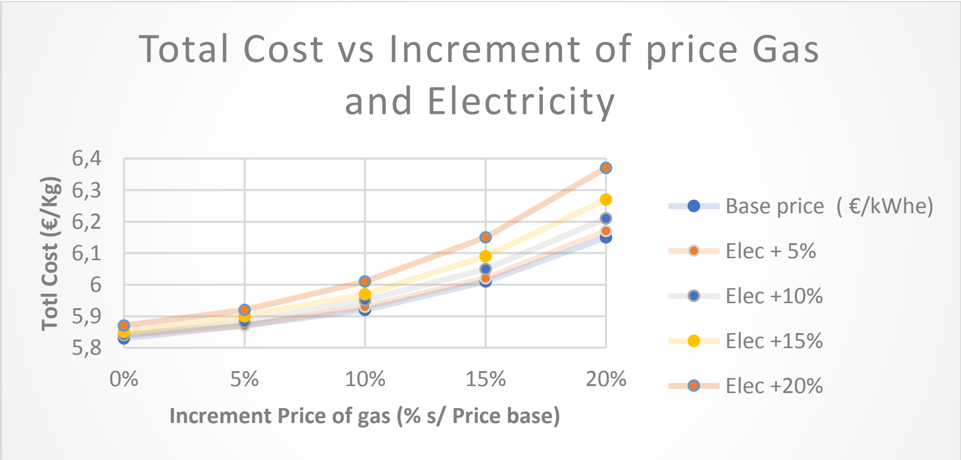
Es decir, si en lugar de los 30.000 kg de producción anual se elevase esta hasta 80.000 kg/año, el coste total se reduciría en 0,31 €/kg pasando de 5,83€/kg a 5,52 €/kg, lo que supone una reducción del 5,3%.

Teniendo en cuenta las circunstancias actuales de los mercados financieros, conviene analizar la sensibilidad del coste total en función del periodo de amortización que se considere y del tipo de interés al que se consiga la financiación, que en cualquier caso sería por la totalidad de la inversión.



De esta forma, si en lugar de obtenerse el préstamo a 10 años y a un tipo de interés del 5% se financiase a una TAE del 7% y a un periodo de 4 años, el coste total de producción se incrementaría en 0,50 €/kg, pasando de 5,83 €/kg a 6,33 €/kg, lo que supone un incremento del coste total del 8,6%

Por último, se ha analizado cual sería la repercusión sobre el coste total de producción de un incremento de los costes del gas natural y de la electricidad, que son los principales costes operativos:



Por lo tanto, si tanto el precio del gas natural como el de la electricidad de incrementasen en un 20% con respecto a los previstos en el escenario central (0,064€/Kwh$_g$ y 0,144€/KWh$_e$

respectivamente), el coste total de producción se elevaría hasta 6,37 €/kg, lo que supone un incremento del coste de producción del 9,3% sobre el escenario central.

Análisis estadísticos de procesos actuales

Por último, a petición de la dirección de la empresa, se incluyen también una serie de análisis estadísticos de distintos procesos de preparación de pedidos para su posterior distribución que se realizan actualmente de forma manual en la empresa. El objetivo de este estudio es la obtención de datos para optimizar estos procesos.

Conclusiones

En primer lugar hay que señalar que si la empresa se decide a ampliar la línea su capacidad de producción de gusanos para comercialización, es prácticamente obligado automatizar el proceso. Los costes adicionales de procesamiento son moderados, suponiendo el 17% del coste del coste de la materia prima (0,83 €/kg sobre 5,0 €/kg). El disponer de producto final ya congelado permitirá reducir notablemente las mermas de producción que se producen actualmente (mortandad, metamorfosis,…) y mantener el suministro al mercado a lo largo de todo el año, atendiendo puntas de demanda. Sis haber profundizado en el conjunto de costes de la empresa, entendemos que el margen bruto permite acometer la inversión.

Sería conveniente analizar la posibilidad de duplicar la cadena de procesamiento, al menos en los componentes críticos (escaldador y congelador) para garantizar y dar mayor fiabilidad a la producción.

Sería necesario profundizar en el mercado de suministradores de estos bienes de equipo e incluso hacer pruebas reales de las máquinas con la materia prima objeto del proyecto para asegurar el adecuado funcionamiento del proceso y contrastar los rendimientos y consumos de agua y energía.

DESIGN OF A MEALWORM PROCESSING PLANT

PROJECT SUMMARY

This Project results from a collaborative framework of the school of Electrical and Electronic Engineering (ESIEE) of Amiens and the GNG Distribution Company. Through this agreement, after passing a candidate selection process, the student author of this Project was hired in internships of three months by GNG Distribution and was supervised by Mr. Maximilien Leclercq University professor for the conduct of analysis of feasibility to know the feasibility of automating the processing stage of the production of mealworms.

The mealworm is the larvae phase of the coleopter whose scientific name is *Tenebrio Molitor*.

To date, the GNG Distribution Company is preferably engaged in the processing of live insects it acquires on the international market (Netherlands and Germany). It usually acquires larvae that it fattens and then stores and markets them and only eventually produces them.

The company's expansion plans include the own production of insects and their processing for the storage of frozen insects in their worm phase. In this way it aims to adapt to the pace of supply to the market by providing a stock of finished products that allows it to adapt to seasonal variations in demand.

Although the company is currently considering its action in very specific market niches of animal feed by insects (pet feeding, supply to zoos and sport fishing baits), it should be noted that the possibilities of feeding from insects for meat production for consumption are huge. The growth of the world's population and the improvement of income levels in many geographical areas will increase the demand for animal proteins.

To meet this demand, feeding from insects by replacing cereal and soybean production to some extent can be a viable alternative from an economic, social and environmental perspective. In fact, the Animal Feed Insect Production Market is expected to triple in economic terms over six years from $400 million in 2018 to nearly $1,200 in 2023.

Considering a medium-term expansion of the company, the management of the company, and regardless of whether it starts producing the raw material (worms) or continues to acquire it in the market, it is considering making an investment in a processing chain automated to reduce costs and to be able to serve increasing production volumes without having to increase production staff.

The project was carried out from the offices of the department of Sustainable Development of the ESIEE Engineering School in Amiens with various stays that totaled more than 30 working days in the facilities of the GNG Distribution Company. In these Days:

- The production stage of mealworms and other insects such as crickets was known.
- Different working days were attended in which operators carried out the processing of the worms manually, measuring the working times and productivity obtained in the different stages
- Measurements were taken of the ship where it is planned to assemble the processing plant,
- The company director was also attended by accompanying meetings with suppliers of equipment goods in which they explained the possibilities and advantages of some of the elements they distribute.

Content of the Memory of the Project

Throughout this Report, it first **describes the GNG Distribution Company**, a small family business with long experience in insect production, exposing the state of the art of insect production for feeding other animal species and their usefulness in a sustainable growth environment, **describes the characteristics of the processing plant** subject to the Project and the different stages and machines that make up it, an **economic analysis** is made considering the investment and operating costs that would result in the acquisition of the process plant, in order to estimate a "levelized cost" of the unit of processed product.

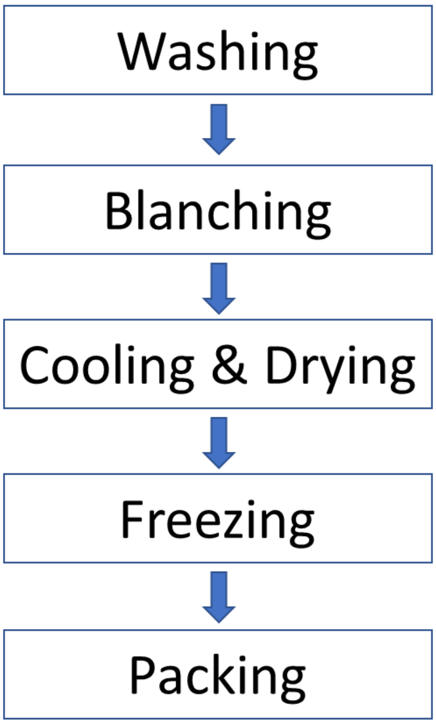
Statistical analysis is included of the working times currently resulting in manual processing of production in order to provide the company's management with accurate information for the decision to make an investment and to conclude a number of **recommendations for improving the current process and for the implementation of the project**.

Processing Plant conception

The project aims to analyze which of the machines/technologies, which are available in the agri-food industry market for the different stages of treatment, could be used to assemble a processing line to meet the production needs of this long-term product line.

The stages of treatment or process that have been contemplated are:

- **Washing**: mealworms should be cleaned in order to get rid of the rests of skin and flour left after sieving.
- **Blanching**: is the final step in raw materials preparation. The primary purposes of blanching are to inactivate enzymes, which can cause changes in colour, flavour and aroma & to destroy any life processes and sicknesses prior to further processing.
- **Cooling/Dewatering**: after blanching, mealworms should be dewatered using screens and cool air blowers prior to freezing, to prevent the formation of clusters of worms and chunks of ice
- **Freezing:** mealworms would be frozen after being dewatered in order to last longer before decaying.
- **Packaging**: after freezing, mealworms would be packaged in small stand-up pouches, which would make it easier to store and distribute.

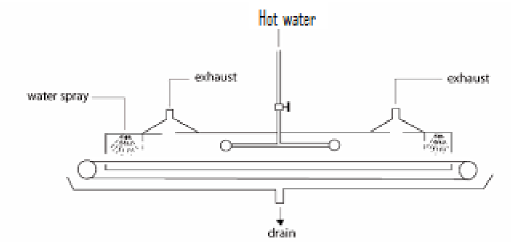


Given the qualitative characteristics of the product in question (flour worms) machinery has been selected for the different stages of the process based on IQx (Individual Quick) technologies.

This type of process technologies bases their operation on the treatment of each unit (mealworm) in isolation, allowing greater efficiency in thermal processes by optimizing energy use.

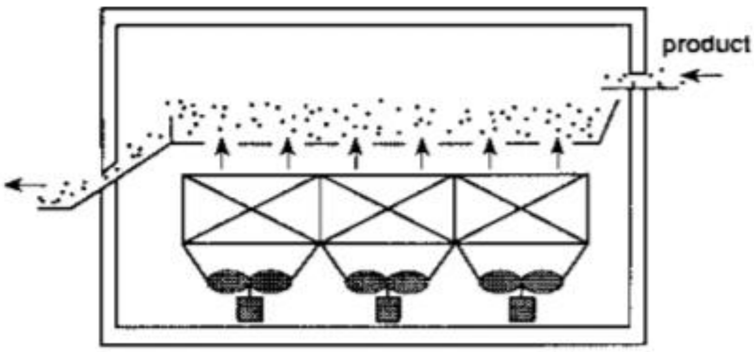
The **cleaning/washing stage** consists of applying **water by sprinklers at controlled temperature** to the product with sufficient pressure to separate the worm from particles such as the remains of moles (quitin) skin, flour and faeces.

The **blanching stage** is planned by an IQB process with a **continuous scalding** (conveyor) with water spray at temperature spree close to that of boiling. The product moves on a rolling tapestry, with spray jets fixed. Waste water is reused for the scalding stage itself for thermal recovery. The machine that this stage could integrate in a first phase the washing stage.



For the **cooling/drying stage**, a **fan-equipped device** whose main function is to cool the product and remove surface water before moving to the freezing stage shall be used. It is vital to surface drying to avoid the clumping of the units in the frozen.

Fluid bed technology (IQF – Individual Quick Freezing)) with fan drag is planned for the **freezing stage**. Cold is achieved by cooling air convection currents in a compression-expansion cycle.



For the **packaging stage** it is planned to use a **standard packaging machine in bags of the type stand-up pouch** which according to the management of the company is the most versatile for wholesale and retail distribution.

Economic Analysis

At present these processes are carried out somewhat by hand or manual by the operators since the volumes processed are to date quite small and are only used sporadically since most of the production is marketed viva.

The technical visits to various suppliers of these equipment highlighted the wide disparity in performance and technical characteristics of existing equipment on the market and prices of the equipment on the market.

On the other hand, the increase in production will be undertaken gradually over several years which makes it difficult to decide on the design capacity of the processing plant.

To estimate the total cost of the process, a Cost Economic Analysis has been performed as set out in the report. This analysis is based on an estimate of investment costs and operating costs, including maintenance costs of the processing plant.

Following the instructions of the management of the company, direct personnel costs were not included as the operation of the plant will not require during the first years of directly assigned personnel. It will be the current operators who will operate it when needed. Therefore, the operational costs covered are essentially those relating to energy, water and packaging costs.

For this purpose, estimates of energy needs were made that can be foreseen based on the benchmarking and the company's experience. A first estimate of investment and operating costs ensuing production automation based on expected energy consumption was also provided. Investment costs have been obtained from the figures provided by the suppliers of equipment goods and those in the literature and are summarized below:

Investments costs estimation	Cost (€)
Rinsing conveyor	8.000
Blanching machine	16.800
Drying conveyor	2.000
Packing machine	21.000
Freezer	40.000
Set up	2.390
Initial investment	90.190

VARIABLE OPERATING COST							
Subprocess	Consumption						Cost
	Steam (use gas)		Electricity		Water	Packaging	
	BTU/lb	KWhg/kg	BTU/lb	KWhe/kg	L/kg	Ud/kg	€/kg
Washing	173	0,112	6	0,004	-	-	0,0077
Blanching	160	0,103	-	-	-	-	0,0066
Cooling	-	-	6	0,004	-	-	0,0006
Freezing	-	-	586	0,379	-	-	0,0546
Packaging	-	-	15	0,010	-	-	0,2094
Water	-	-	-	-	-	-	0,0451
TOTAL	330	0,215	613	0,396	9,84	8	0,3241

The following unit costs for water, energy and packaging consumables have been used to calculate the costs listed in the table above:

UNITARY COST	Water (l)	Gas (kWh)	Electricity(kWh)	Standup pouch
Price (€)	0,00458	0,0643	0,1443	0,026

To calculate the annual depreciation and financing costs, a lifespan of 10 years has been assumed and a capital cost of 5% as average value along the equipment lifespan.

FINANCIAL PARAMETERS			
Machine's lifespan	10	years	
Financing cost	5	%	
Yearly equipment's capital cost	11.680	€	
Yearly operating and maintenance costs	3.607	€	*4% of the initial investment*
Total	15.287	€	

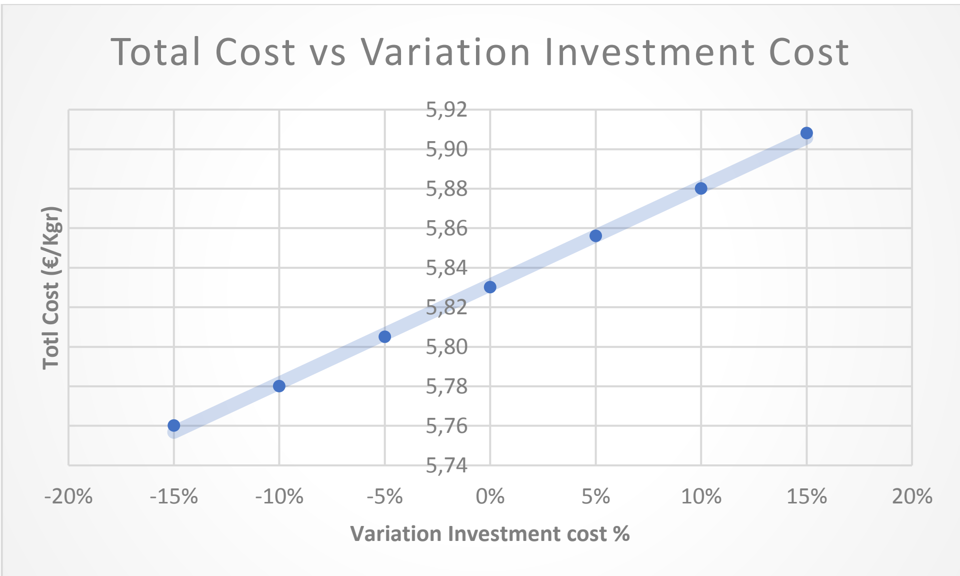
Total unitary cost for a production rate of 30.000 kg/year including raw material and variable processes cost are in the table below:

TOTAL PRODUCTION COSTS		
Mealworm's purchase price	5,00	€/kg
Capital costs	0,51	€/kg
Variable costs	0,32	€/kg
Total cost	5,83	€/kg

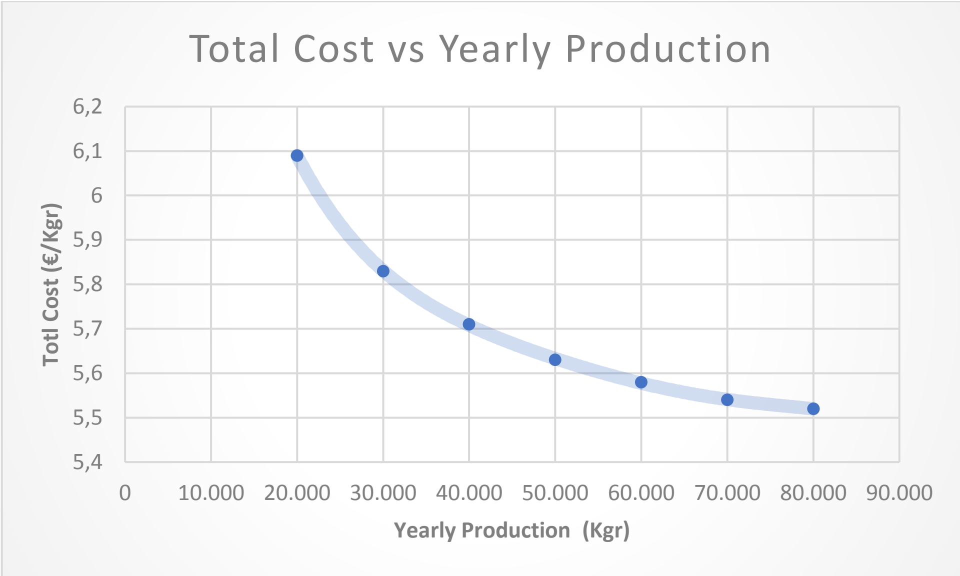
We can see the moderated costs of the process including fixed costs. They are 0,83 €/Kg versus 5,00 €/Kg of the raw material.

Given the uncertainty presented at this initial stage by the various costs contemplated, several analyses of sensitivity of cost parameters referred to in the central scenario were performed:

The following chart shows the total cost of production versus the positive or negative diversion that can occur in the total cost of investment.

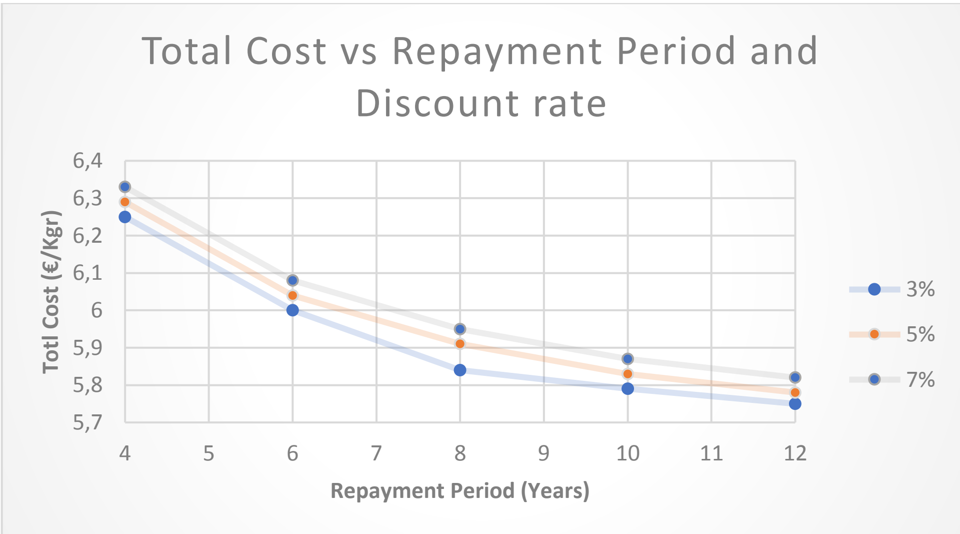


If the investment deviates 15% upwards from that expected in the central scenario, the total cost of production would rise by 0.08 €/kg, which is 1.33% on the central one. It is also very relevant to know how the total cost can vary depending on the annual level of production. The following graph shows this variation:



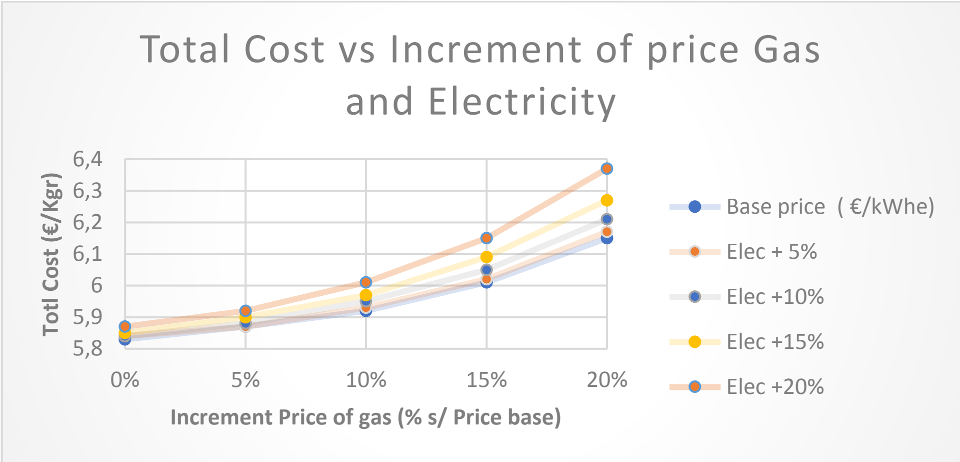
In other words, if, instead of 30,000 kg of annual production, this was raised to 80,000 kg/year, the total cost would be reduced by 0.31/kg from 5.83/kg to 5.52 kg, a reduction of 5.3%.

Taking into account the current circumstances of the financial markets, it is appropriate to analyse the sensitivity of the total cost depending on the repayment period under consideration and the interest rate at which the financing is achieved, which in any event would be for the investment altogether.



Thus, if, instead of obtaining the 10-year loan and at an interest rate of 5%, it was financed at a APR of 7% and over a 4-year period, the total cost of production would increase by 0.50 €/kg, from 5.83 €/kg to 6.33 €/kg, which represents an increase in the total cost of 8.6% .

Finally, the impact on the total cost of production of an increase in the costs of natural gas and electricity, which are the main operating costs, has been analysed:



Therefore, if both the price of natural gas and electricity increased by 20% compared to those expected in the central scenario (0.064/Kwhg and 0.144 o/KWhe respectively), the total cost of production would rise to 6.37 €/kg, representing a increased production cost by 9.3% over the central stage.

Statistical analysis of present process

Finally, at the request of the management of the company, a series of statistical analyses of different order preparation processes are also included for further distribution that are currently carried out manually in the company. The objective of this study is to obtain data to optimize these processes.

Conclusions

First of all, it should be noted that if the company decides to expand the line its production capacity of worms for commercialization, it is practically obligatory to automate the process.

The additional processing costs are moderate, assuming 17% of the cost of the raw material (0.83 euros/kg over 5.0 euros/kg). Having an already frozen end product will allow to significantly reduce the production losses that currently occur (mortality, metamorphosis,...) and maintain supply to the market throughout the year, taking on demand points. If we have delved into the company's set of costs, we understand that the gross margin allows to undertake the investment.

It would be desirable to analyze the possibility of duplicating the processing chain, at least in critical components (scalding and freezer) to ensure and give greater reliability to production.

It would be necessary to deepen the market of suppliers of these equipment goods and even make real tests of the machines with the raw material subject to the project to ensure the proper functioning of the process and to contrast the yields and consumption of water and energy.

DESIGN OF A MEALWORM PROCESSING PLANT

Rapport de PFE I 5 GEDD 2018 - 2019

STUDENT	Jose Maria DE MARCOS LOPEZ-BAISSON
COMPANY'S/ UNIVERSITY'S TUTOR	Antoine GARAULT
ESIEE Amiens TUTOR	Maximilien LECLERCQ

AKNOWLEDGEMENTS

Firstly, I'd like to thank my parents for always supporting me, and for all the things they do for me, which can range from helping me with the paperwork necessary to go on a Erasmus exchange, to waking up to answer a distress call in the middle of the night once I am abroad. I know that being a parent is difficult and it doesn't always pay off, but I am doing my best, and I hope that someday I will be able to repay all the things they have done for me.

Secondly, I would to like to thank my sister for always being there, even if we have not talked that much this year, it's great to know that I have someone that will always lend me a hand no matter what.

Thirdly, I would like to thank my friends; the ones back home, who would never let me down, and for whom distance is but a number, and the ones I've made while in Amiens.

I would like to thank my teachers at ESIEE, who helped me greatly when I came here and my French was not all that good, specially Mr Aroquiadassou, and Mr Coppier for helping me find an internship.

Lastly, I would like to thank Mr Garault, for all the trust and patience he has placed on me.

TABLE OF CONTENTS

List of Figures

List of Tables

1. INTRODUCING THE COMPANY

1.1. GNG DISTRIBUTION LLC

GNG under its brand France Insectes is a company specialized in insect wholesale and distribution.

The company produces insects for animal consumption. Among the many potential uses of insects, the ones that stand out the most are:

- In recreational fishing, as bait.
- For pet owners, pet shops and zoos, insects are used as pet food.

1.2. Some history

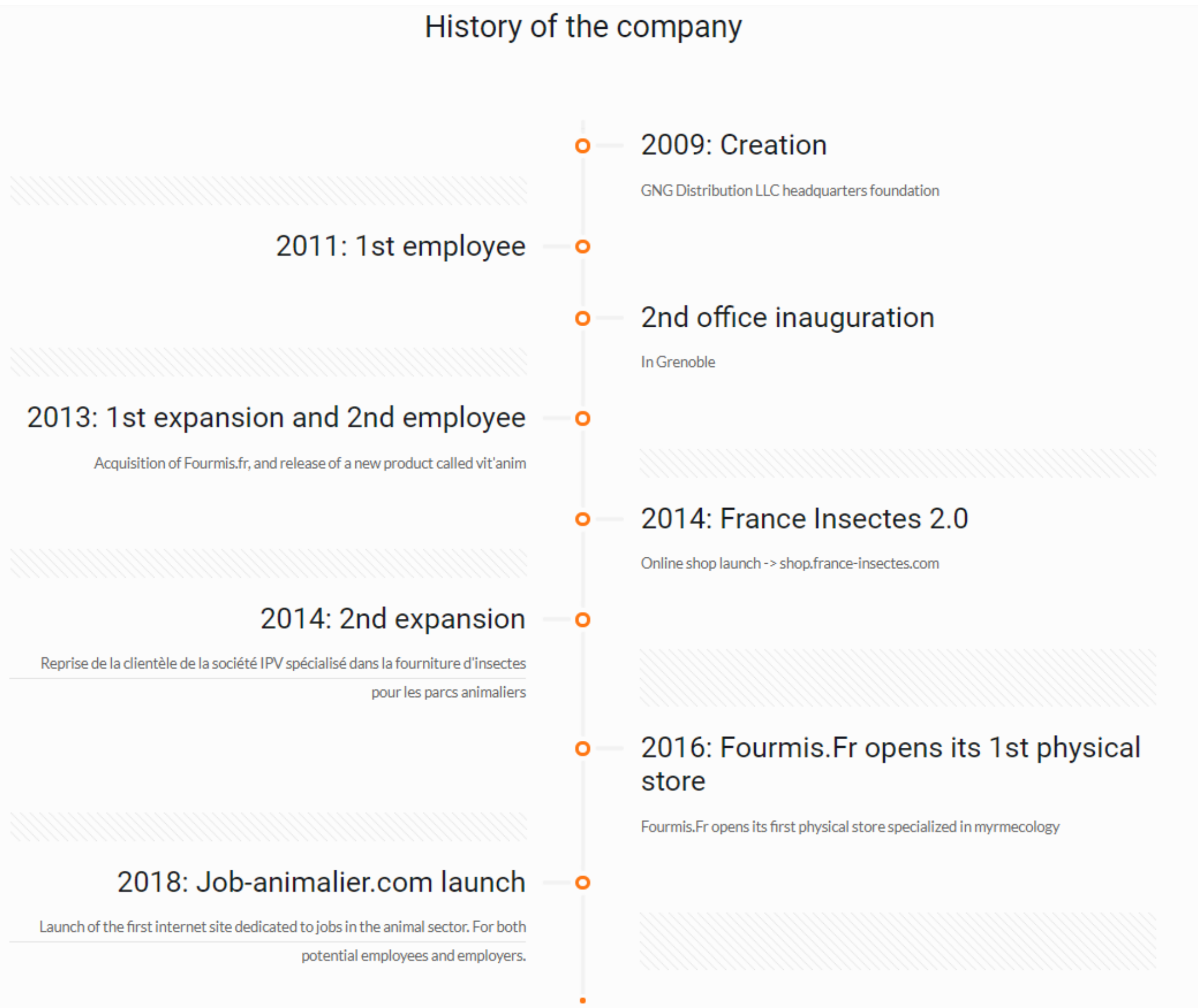


Figure 1 - History of the GNG Distribution Company

Before becoming GNG Distribution, the Garault family had already a long business history in insect sales, starting in the sixties with Mr. Edmond GARAULT, who sold maggots for fishing purposes, and then his son Mr Bernard GARAULT, and lastly, the family business was inherited by his grandson, Mr Antoine GARAULT, who founded the company as we know it today.

1.3. GNG DISTRIBUTION in numbers:

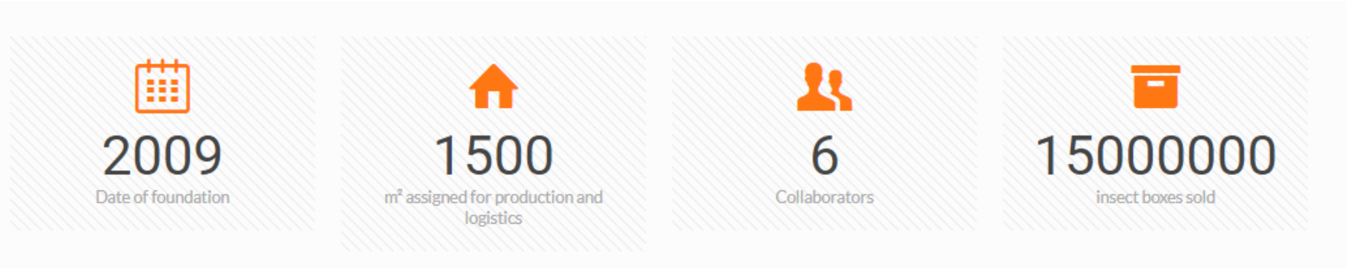


Figure 2 - GNG Distribution in numbers

1.4. Future plans

After being in the industry for so long, company director Mr Antoine Garault decided that they had to expand the business, and the way to do it was to focus more on the production aspect, because up until that point, distribution was a much more important area for the company.

For that reason, they hired a biologist to set up a mealworm raising facility, to produce more insects, and act more as producers instead of as intermediaries in the distribution process.

He also realized that the way to expand was to automate already existing processes, also increasing their production rate, and optimize those processes that could not be automated, and that’s why I was hired.

2. STATE OF THE ART

2.1. Reasons to produce insects for animal feed.

Insect production is nothing new, as humanity have used insects for millennia, for a lot of different purposes.

For example, we raise bees for honey, or silkworms for silk (which in the past was , and still is, a really valuable product, and one of the largest trade routes in history was named after it), and a lot of cultures eat insects as a regular part of their diet.

Still, nowadays, most of western societies would find it gross to eat insects, and some would even be against eating animals fed with insects (producing insects for animal consumption is GNG Distribution's target), even though some animals, such as chickens would eat insects in the wild.

So, what are the advantages of producing insects as of right now?

There are three aspects in which insect production for animal feed would be beneficial, and those would be: economic, environmental, and health related.

2.1.1. Economic and social factors

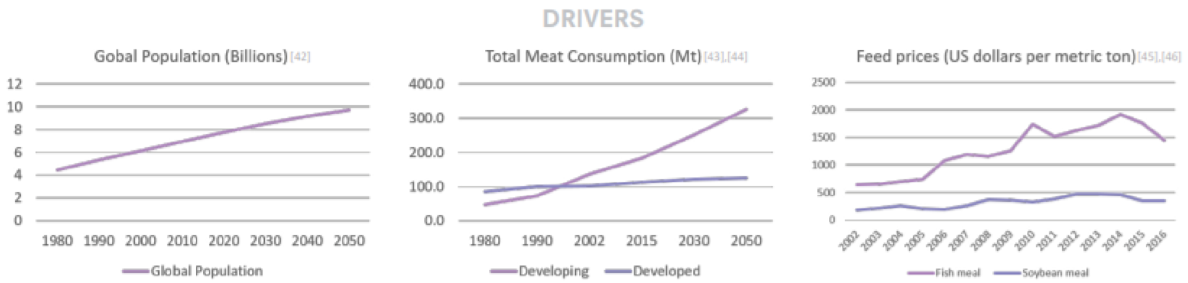


Figure 3 - Economic and social factors [5]

Global population growth, increasing wealth, and urbanization, specially in Asia and Africa, create changes in global consumption patterns, lifestyles and food preferences, leading to an increase in animal protein demands. This will affect traditional protein sources for animal feed, such as soybean and mealfish, that, according to FAO, will have to increase their production by 70% to put up with the growing demand of meat (beef, poultry and pork), which is expected to double.

This increase in protein demand seems unlikely to be covered with these sources alone, and protein shortages are to be expected in the future.

This increase in demand, without a similar increase in supply will most likely rise the prices of animal feed, which already represent a 60-70% of meat production costs.

The urgency to find an alternative livestock feed ingredient for fishmeal and soymeal has led to market recognition of insect protein. Insect production has low requirements for land and water and a high conversion efficiency of feed into insect biomass.

Insect production systems reduce the reliance on conventional feed streams whilst bringing valuable ingredients from organic waste materials from agriculture, food industries and other sectors back into the food chain. [5,4]

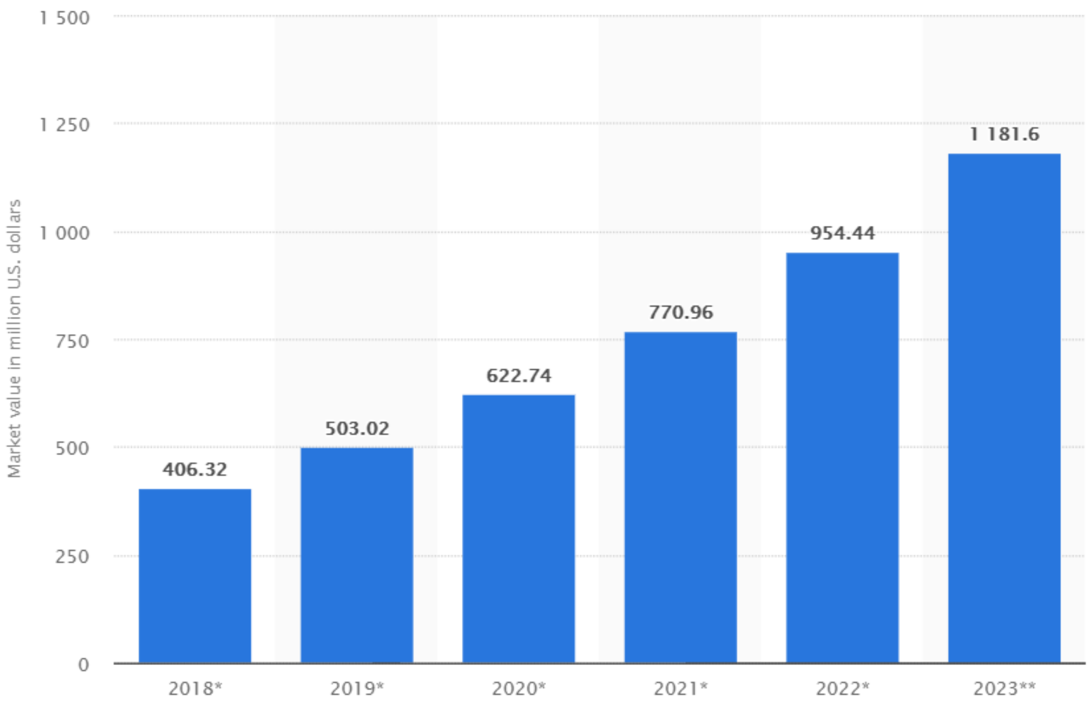


Figure 4 - Expected growth (source: statista)

In this graph we can see how the income from insect production is expected to grow, and in fact, insect production could turn out to be a very profitable business soon.

2.1.2. Health related factors.

As said earlier, most of the meat that is consumed nowadays is produced using soybeans and grain.

The problem with these protein sources is that normally, a lot of pesticides are used during their cultivation, and some of those end up in the meat consumed by humans.

The problem with fish is that usually it is fed with more fish, which is normally fished from the sea, in which traces of heavy metals such as mercury or lead, and more recently, microplastics have been found, and some of that will necessarily pass into farm grown fish.

By feeding insects to fish and chicken, those harmful components are removed from the human food chain.
Also, it should be noted that meat from animals fed with insects has the same nutritional value as meat from animals fed with traditional feed. [4,5]

2.1.3. Insect production as a mean of sustainable development.

As of today, 70% of the world's soy production is fed to animals, with damaging consequences in terms of land abuse, deforestation, and calories waste.

In Brazil (the largest exporter of soybeans in the world, with an astounding expected crop of 114 million tonnes in the year 2018, 2019), greenhouse gas emissions due to deforestation account for a 29% of the total emissions between 1990 and 2010. To put it into perspective, every hour an area of rainforest equal to a football field is cut down to produce livestock feed for Europe.

When compared to soybeans, insects require less space and energy for cultivation, as seen on the following chart

1 metric tonne of product	CRICKETS	SOYBEANS
PROTEIN (kg)	600	50
SURFACE (m^2)	3100	3200
TIME TO GROW	2-3 months	9-11 months

Table 1- Energy ad space requirements [8]

For a similar mass, crickets contain up to twelve times the amount of protein present in soybeans and take approximately 4 times less time to grow. That is a total of 48 times more protein on the same period.

Also, one ton of crickets need a similar surface to a ton of soybean, with one key difference, which is the fact that crickets can be raised everywhere, even in cities.

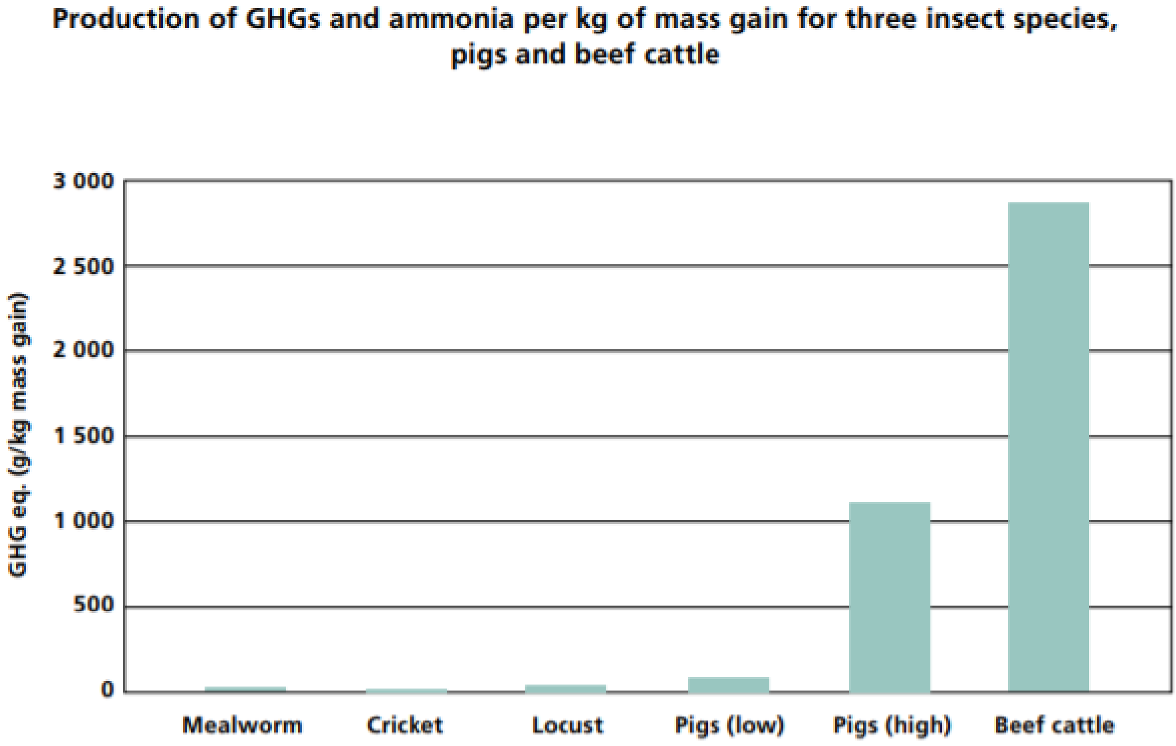


Figure 5 - Production of CHGs [4]

These charts show how insects, and particularly mealworms are almost carbon neutral, while having a higher mass conversion rate (they need less food to produce the same amount of mass) than most livestock. Another point in favor to insect production is the fact that insects can feed on organic waste.

2.1.4. Drawbacks to insect production.

We have seen the many advantages that insect production for animal feed provides, but it also has its drawbacks, the most noticeable of them being:

- **Legislation and risks:** we have talked about how insects can feed on organic waste, which would greatly reduce production costs. Problem is that any chemical or toxin present in that waste would probably accumulate on the insects, and later it would be passed into animals whose meat we eat.

  For this reason, European legislation only allows for insects to be used as fish meal and pet food.
  Also, insects cannot feed on waste, which greatly increases production costs.

- **Research Gap**: Farming insects for feed and food is relatively new; the sector is still in its infancy. Whilst progress is relatively rapid, further research and development is required to provide a strong scientific basis essential for the development of this new industry.
  Also, there is the fact that most of the research on the subject is carried out by private entities whose livelihood depends on that same research, which gives them the edge over their competitors, and so, they don't make it public, which makes it really difficult to start a business on this field.
  During my internship I have faced this problem repeatedly.

- **Costs:** Presently, insect feed prices are estimated to be higher than those of conventional feed, mainly due to the lack of research on the topic. [4,5]

3. PROCESSING PLANT CONCEPTION

3.1. Process description

The goal of this project is to design a small plant to prepare mealworms for animal consumption.

The plant would be made from spare components, after conditioning them for this application.

In order to succeed on this part of the project, it is very important to get as many worms at the exit of the factory as they are put in. That is because the revenue from mealworm wholesale is quite small, almost the same as the growing and processing costs, and so, if worms are lost in the machinery, profit decreases greatly.

It should be noted too that mealworm's sale price is not very elastic, and so, price cannot simply be raised.

Taking all of this into account, in order to create a profitable business model, production rate should be raised as much as possible, assuming there is enough demand.

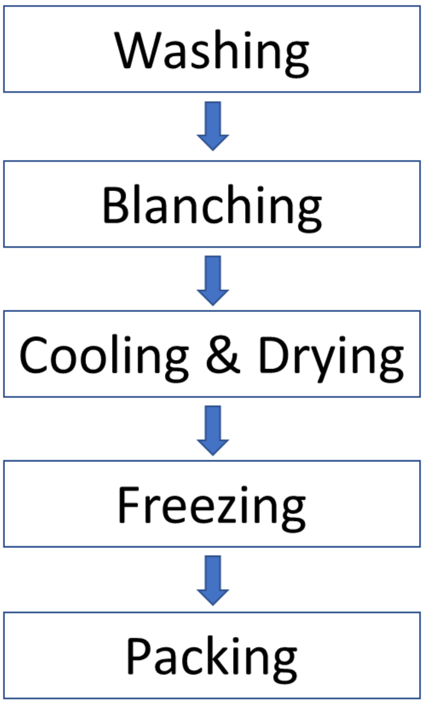


Figure 6 - Process steps

The process consists of 5 parts:

1. Washing: mealworms should be cleaned in order to get rid of the rests of skin and flour left after sieving.

2. Blanching: is the final step in raw materials preparation. The primary purposes of blanching are:

   -To inactivate enzymes, which can cause changes in colour, flavour and aroma.

   -To destroy any life processes and sicknesses prior to further processing.

3. Cooling/Dewatering: after blanching, mealworms should be dewatered using screens and cool air blowers prior to freezing, to prevent the formation of clusters of worms and chunks of ice

4. Freezing: mealworms would be frozen after being dewatered in order to last longer before decaying.

5. Packaging: after freezing, mealworms would be packaged in small stand-up pouches, which would make it easier to store and distribute.

   After all these steps, the worms would be kept stored on a freezing chamber and would get distributed upon request.
   In the end, the goal of this project is both to increase the production rate, and not to be dependent on any kind of seasonality, by being able to stock the product without a noticeable loss in quality.

3.2. Technical solutions

On this section, the experts at FEMIA INDUSTRIE gave their insight on some components, especially on the blancher.

3.2.1. Washing

-Sprinkler washing: it consists in a meshed conveyor belt with sprinklers above which would spray water on the mealworms, in order to detach the rests of skin and flour and make them pass through the belt's holes.

Figure 7 - Sprinkler washer

An individual component may be needed if the blancher doesn't have an integrated cleaning stage, normally in conjuction with the preheating stage of the blanching phase.

3.2.2. Blanching

As stated earlier, blanching (or scalding) is the process by which most frozen and canned foods (specially vegetables and nuts) are treated in order to become safe for consumption.

It is basically a thermal treatment that ensures the following conditions are met:

- Enzymes are deactivated in order to prevent food deterioration which can manifest in the form of changes in flavour, colour, or nutrient loss.
- To eliminate bacteria that causes decay.

There are several industrial blanching methods, that will be explained on the following section, the two most common being steam and water blanching.

Water blanching:

Consists in heating water (normally between 70ºC and 100ºC) and then submerging the product into the water. Depending on blanching time and temperature we can differentiate between LTLT (which stands for low temperature & long time) and HTST (High temperature and short time).
HTST is the most used out of the two, and it normally uses water at ~95ºC and the blanching time normally is in the range of 1-3 minutes.

Regarding the technologies used to implement the blanching into a production chain and to introduce the product into the water, we find:

- **Spray blanchers**.
  They consist in an insulated tunnel where the product runs through a conveyor while hot water is sprayed on it via sprinklers situated above the conveyor. It is virtually identical to a conveyor steam blancher by means of costs and energy efficiency but consumes more water in weight than the steam counterpart.
  Lastly, it is worth mentioning that this type of blanchers are based on the IQB (individual quick blanching) working principle, which means that, by introducing a thin layer of worms into the blancher, each worm can be considered to be blanched individually, that means , independently from what happens to the other worms. That is really useful because the blanching is very uniform.

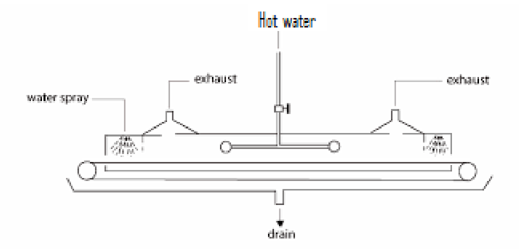


Figure 8 - Spray blancher

– **Pipe blanchers**, in which the product is mixed with hot water and pumped through an insulated pipe.

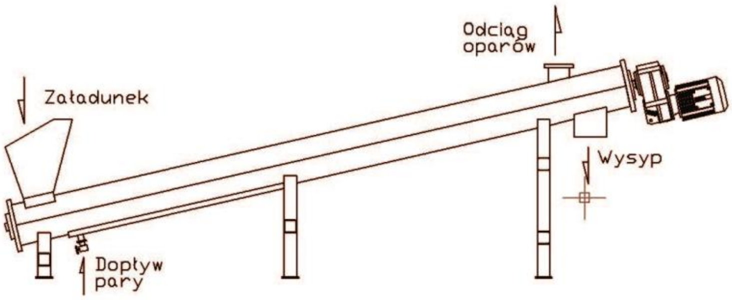


Figure 9 - Schematic of a pipe blancher (Mysak Group)

– **Rotary drum blanchers** (also known as screw blanchers). This tipe of blancher consists in a perforated rotating cylinder with an internal helical scroll. It is enclosed within a cylindrical shell, the lower half of which contains steam coils to heat water.

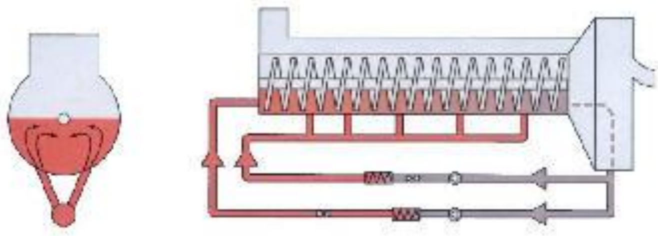


Figure 10 - Schematic of a Rotary blancher (ESC Food Technologies)

Figure 11 - Rotary drum blancher (Elsevier´s food processing) – ICO Industries

Steam blanching: consists in applying steam on the product in order to heat it up to the desired temperature.

Similarly, to water blanchers, there are different types of steam blanchers:

- **Conveyor steam blanchers**: same concept as spray water blanchers, but steam is sprayed instead of liquid water.
  Inside this group of blanchers there are many subtypes depending on the different systems implemented to improve energy efficiency.
  For example, some blanchers incorporate water sealings at the entrance and the exit to the tunnel (either hydrostatic or in the form of a water wall) to prevent steam from escaping the blancher, by making it condense inside the tunnel.
  Also, preheating and heat recovery technologies have been developed to improve energy efficiency. The most common is including a cooling section after the blanching stage. This section will use cold water to remove heat from the product, and then use that same water (which will be now hot) on a preheating section where it heats the incoming product, saving some energy on the actual blanching.

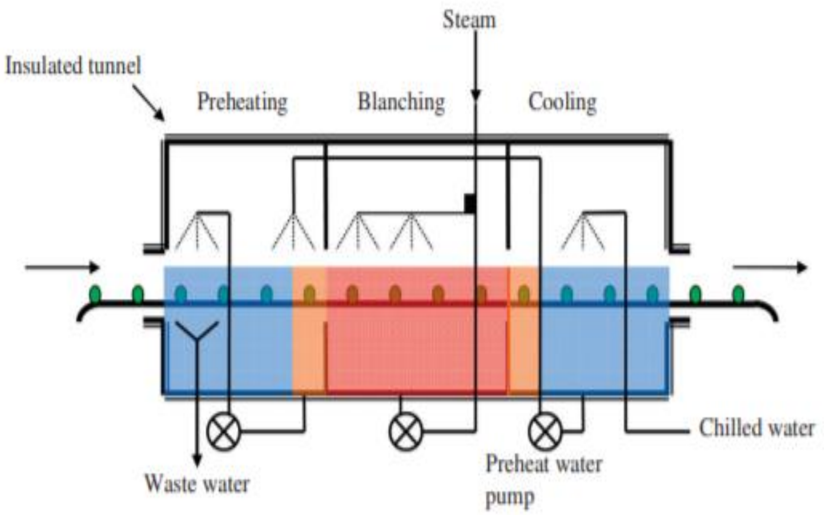


Figure 12 - Conveyor steam blancher [3]

- **Rotary drum blancher**: same as the water one, but it uses steam mixed with the product instead implementing a waterbed on the lower half of the cylinder.

Microwave blanching: it is a very recent technology which is more energy efficient because it heats directly the product instead of adding more intermediate steps.
Also, most food products are in a significant percentage water.
On the other hand, the blanchers are usually much more expensive, and they tend to dry the foods.

	Steam	Water	Microwave
Advantages	Smaller losses of nutrients Smaller water loss Better energy efficiency Better retention of texture and colour	Lowest capital cost More uniform heating Smaller blanchers	Best energy efficiency Best water efficiency Fastest blanching
Limitations	Doesn't clean the foods Uneven blanching (sometimes) Loss of mass due to drying More complex equipment than water blanching Higher maintenance costs	Higher nutrient loss Higher water loss Risk of thermophilic bacteria Turbulence that can damage soft products	Unpredictable heating Highest equipment costs

Figure 13 - Summary of blanchers [1]

In the beginning some test on mealworms were run, and immersion water blanching (either pipe or rotary drum) was thought to be the best possible choice because steam blanching would dry the worms too much, which is a problem because for example hens and chickens can be quite picky and won't eat worms if they look blackened or dry.
On the other hand, worms are to an extent buoyant, and sometimes will stay afloat, while other times they'll drown, so they are difficult to transport through water, and the usual turbulence of water blanching could end up by crushing them, that is why rotary drum water blanchers were discarded.

So, in the end, a water spray blancher was chosen because it does not dry the mealworms nearly as much as the steam blancher, and neither blackens them.

Regarding water efficiency, water spray blanching uses less water than other water blanching methods, but more than steam blanching.

Energy efficiency wise, water spray blanching consumes less energy than steam blanching because although liquid water has typically a lower convection coefficient than steam, spray water blanchers heat the water to a lower temperature, and it is easier to pump water than compressing steam.

One drawback of using spray water blanchers is that blanching times are usually longer than on the steam counterpart.

3.2.3. Cooling/Drying

Normally, the blanching stage is followed up by a cooling stage, because hot temperatures are partly responsible for the appearance of bacteria and other microorganisms, and thus accelerate the decay process.

On the other hand, this process includes a freezing phase, and freezing equipment is normally quite vulnerable to thermal shock, and so, continually introducing hot objects in a freezer (~95ºC in this case) would most likely end up breaking the freezing components. Normally, the highest safe temperature prior to freezing is 37ºC.

Cooling can be done by either spraying cold water on the mealworms or by air convection, normally by using fans.

If cold air was used, it would also remove the water on the worms' surface. This event is known as dewatering, and it is really useful in processes that involve freezing, because, by removing the water on the surface of a product (mealworms in this case), the formation of clumps of that same product and the formation of chunks of ice is avoided.

Lastly, same as with the rinsing stage, modern blanchers sometimes come with an integrated cooler, that can be either water (also part of the heat recovery system) or air based.

Figure 14 - Cooling System

Otherwise, if there was not a cooling phase, or if there was a water-cooling system, an air-cooling conveyor would still be required for dewatering.

3.2.4. Freezing

Freezing is a thermal treatment that consists in lowering a product's temperature to the point where most biological processes are deactivated, and thus the product's lifespan is increased greatly.

The usual temperature for industrially frozen foods is between -20ºC and -30ºC, and for industrial freezing, the most common freezing method is deep freezing, which consists in freezing the products in a short time to minimize the product's quality loss.

Freezing is the most energy intensive stage on food treatment processes, and so, special care should be taken when choosing a freezer, in order to maximize energy efficiency. The most important parameters that should be looked at when choosing a freezer are:

- Product size and shape.
- If the food enters the freezer already packaged.
- Desired production rate.
- Target temperature.
- Level of automation of the process.

There are a lot of different freezing technologies, but this study will focus on the two that are best suited for this application: continuous belt freezers and fluidized bed freezers. Both of these freezers are based upon the IQF (individual quick freezing) technology, which is usually employed on products of small size, and consists of introducing the product into the freezer in thin layers in order to freeze them individually.

Continuous belt freezers: they involve the product passing continuously through an insulated tunnel on a conveyor belt, where air is blasted perpendicularly to the belt's direction. Such freezers are normally used for small unpacked products with uniform shape. The air velocities typically range from 1 to 6 m/s. By running the product through the belt on a thin layer, high rates of heat transfer are achieved, and that is why sometimes more belts are included at a different height (like steps) in order to ensure the even distribution of the product over the belt's surface.

Also, sometimes this kind of freezers include a precooling section to maximize energy efficiency.

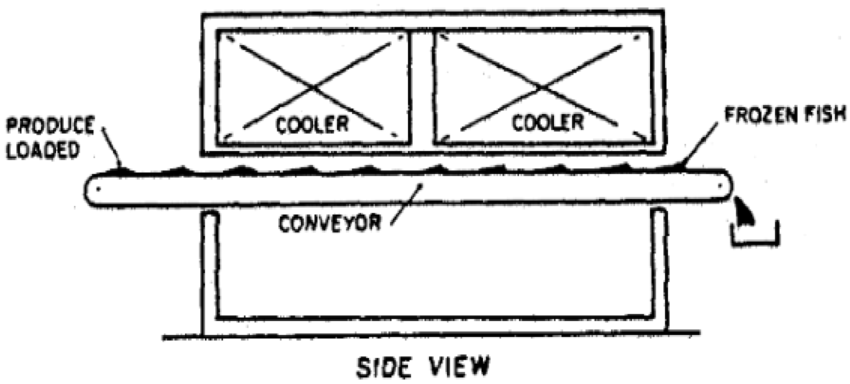


Figure 15 - Continuos belt freezer [1]

Fluidized bed freezers are specifically designed for small unpacked products of uniform size and shape for which the energy requirement for fluidization are not excessive. In fluidized bed freezers cold air is blasted through the perforations made on the lower plate of the freezing tunnel at a flowrate high enough that fluidization is achieved.

Thanks to fluidization, a good distribution of the product is achieved, and clumping is avoided. All of this while keeping the freezing times short and the freezer size small.

All these advantages are explained by the fact that the rates of convective heat transfer are quite high, because each piece is frozen individually.

Only drawback to this type of freezer is that, contrary to belt freezers, where the product follows a clear path, on fluidized bed freezers the product sometimes stays some time circling around before finally exiting the freezer. Normally on the data-sheet of this type of freezer it specifies the mean freezing time, as well as the variance.

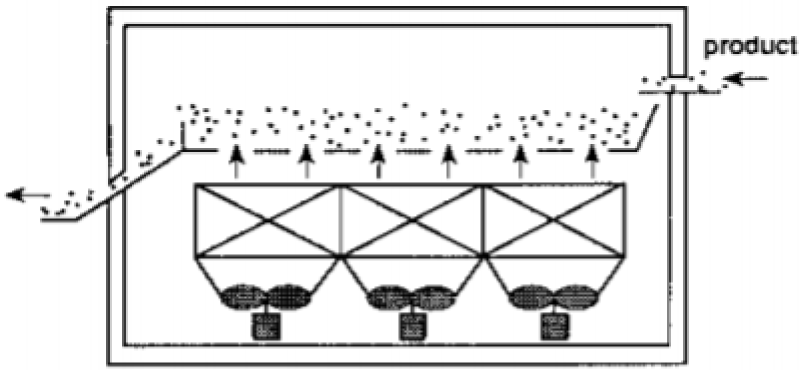


Figure 16 – Fluidized bed freezing [1]

Taking all this information into consideration, in the end the fluidized bed freezer was chosen because of the smaller machine size, since the space available to install the processing plant is limited.

3.2.5. Packing

Figure 17 - Packing machine

Packing is the most time-consuming stage of the process when done manually, so automating it is a really good idea from a time efficiency perspective.

On the other hand, packing technology is sophisticated, and thus expensive, although operating costs are lower than on the rest of the components on this process.

For this case, 750mL Stand-up pouches were chosen as packing, because they are good for both retailing and wholesale. Stand up pouches are also easy to store.

Figure 18 - Stand-up pouch

Stand up pouch by polybag uk (https://www.polybags.co.uk/shop/metallised-stand-up-pouch_p1439.htm)

When packed, mealworms have a density of 0.16kg/L, that is 0.125kg/pouch.

The desired production rate is 250kg/h, which translate into a machine capable of packing 2000 pouches/h

Packing machines that use stand-up pouches work by opening the pouch, then putting the product inside the pouch, and finally sealing the pouch, effectively closing it.

3.3. Power calculations

Thermic parameters of the mealworms were calculated, and using those parameters, both the blanching and freezing powers required were calculated (power consumptions for the rest of the stages on the process were not calculated because they consume much less, enough to be negligible).

This was useful afterwards, when the process' components were chosen.

The following hypotheses were applied:

- The specific heat both above and below the freezing point is constant and equal to the highest for a specific temperature increase.
- The temperature of the phase change is constant, as well as the latent heat.
- Each mealworm is individually heated and cooled (IQB and IQF). This way, the power required to fully blanch and freeze the mealworms is independent of how they are disposed.

	Component fraction (%)		
	Mealworms	Beef Carcass	Potato
Protein	17,92	17,32	2,07
Fat	21,93	24,05	0,1
Carbohydrate (Fiber)	2,33	0	17,98
Ash	1,55	0	0,89
Water	56,27	57,26	78,96

Table 2 – Composition of different products [6] [7]

Looking at the composition of mealworms and comparing them to other foods, we find that the most similar is beef, and with that, we extract the values for specific heat (both frozen and not frozen) and the latent heat.

	(ºC)	(KJ/kgºC)		(KJ/kg)
	Initial freezing point	Specific heat +	Specific heat -	Latent heat
Potato	-0,6	3,67	1,93	264
Beef	-2,2	3,24	2,31	191

Table 3 - Parameters for calculation [6]

We then compare those parameters with those of potatoes, which is the product with the process most similar to this one, and the one process whose normalized consumption values are known. This way the total consumption costs can be estimated later, and it can be checked if standard machinery for frozen fries would work in this case.

$$\dot{Q}_{blanching} = \dot{m} \cdot c_p \cdot \Delta T = \frac{250}{3600}\left(\frac{kg}{h}\right) \cdot 3{,}24 \cdot (95 - 20) = 16{,}92KW < 19{,}11KW$$

$$Q_{liquid} = m \cdot c_p \cdot \Delta T = \frac{250}{3600}\left(\frac{kg}{h}\right) \cdot 3{,}24\left(\frac{KJ}{kg \cdot ºC}\right) \cdot (-2{,}2 - 25)(ºC) = -6{,}18KW$$

$$Q_{solid} = m \cdot c_p \cdot \Delta T = \frac{250}{3600}\left(\frac{kg}{h}\right) \cdot 2{,}31\left(\frac{KJ}{kg \cdot ºC}\right) \cdot (-25 + 2{,}2)(ºC) = -3{,}66KW$$

$$\dot{Q}_{phase} = \dot{m} \cdot c_l = \frac{250}{3600}\left(\frac{kg}{h}\right) \cdot 191\left(\frac{KJ}{kg}\right) = -13{,}264KW$$

$$\dot{Q}_{freezing} = \dot{Q}_{liquid} + \dot{Q}_{phase} + \dot{Q}_{solid} = -23{,}1KW < 27{,}99KW$$

When blanched, foods are heated from room temperature (20ºC) up to 95ºC.

Normally, foods are cooled after blanching between 37ºC and 12ºC, and they are frozen between -30ºC and -20ºC, so the mean values of those were chosen.

	BTU/lb	KWh/kg	KW(250kg/h)
Heating	333	0,215	53,75
Freezing	586	0,378	94,5

Table 4 - Heating an frozen temperatures [2]

Source: Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and vegetable Processing Industry. An ENERGY STAR. Guide for Energy and Plant Managers.

$$\eta_{blanching} = \frac{16,92}{53,75}100 = 31,47\%$$

$$\eta_{cooling+freezing} = \frac{23,104}{94,5}100 = 24,4\%$$

After these calculations, it is safe to say that most of the machinery specifically designed for processing frozen French fries would work as well on mealworms, with maybe some penalties to energy efficiency. Both the processing time and the heating/cooling power should be adjusted.

4. ECONOMIC ANALYSIS

4.1. Methodology

The following section presents an economic analysis including the investment and operating costs of the process under study.

We have classified costs in two types, **Investment cost**s of the machinery and equipment set up, and **Operating costs mainly** related to production which includes the cost derived from the utilization of hydraulic resources (water used to cook, wash and cool the worms), the energy consumed (gas and electricity) and other direct costs such as bags and packaging material.

The Operating costs also include the annual Operation & Maintenance costs, estimated as a percentage of the initial investment and the fixed term of the energy supplies (gas & electricity).

Investment costs

In the Investment cots we have included all the machinery costs and the equipment setup of all components of the production chain at this initial stage of the project, although the machinery necessary for some steps of the process could be incorporated later.

Due to the difficulty to access to real costs of the different suppliers, at this initial stage of the project, reference prices obtained through their web pages have been used

We have calculated the investment cost to pass on to the product unit assuming that it is financed with bank loan, during the lifespan of the installation considered as 10 years with an annual interest rate of 5%.

The annual financial cost with the criteria of annuity payment (principal + interests = constant) is added to each unit of the final product.

Operational costs

We have included all costs related to energy and water consumption and packaging if all of them are proportional to the production level.

The personnel costs dedicated to the process have not been taken into account because they are currently allocated for the realization of the manual process, it will continue being operated part-time by the operators a reduced number of days per year and therefore does not imply an increase in personnel costs.

We have calculated the cost (€/kg) of processed product without the initial steps of breeding or buying larvae and the final steps of frozen product storage, marketing, distribution and transportation to point of sale, marketing ...

Other economic indicators as internal rate of return or net present value have not been calculated because processing of the worm is only a part of the industrial cycle. The rest of the costs of the complete industrial cycle are not part of the present analysis and the required information is not available.

In the next section we detail all the aspects already described.

4.2. Investments Cost

Investments costs estimation	Cost (€)
Rinsing conveyor	8.000
Blanching machine	16.800
Drying conveyor	2.000
Packing machine	21.000
Freezer	40.000
Set up	2.390
Initial investment	**90.190**

Table 5 - Investments costs estimation

Investment costs estimation is based on standard components of food (fruits and vegetables) industry.

Due to the difficulty to access to real costs of the different suppliers, at this initial stage of the project, reference prices obtained through their web pages have been used

The variable operating costs have been obtained from the specific consumptions of the food industry applying average costs of the consumption elements in France., that are listed below.

4.3. VARIABLE OPERATING COSTS

VARIABLE OPERATING COSTS	Consumption						Cost
	Steam (uses gas)		Electricity		Water	Packaging	
	BTU/lb	kWh/kg	BTU/lb	kWh/kg	L/Kgr	Ud/kgr	€/kgr
Washing	173	0,11177732	6	0,00387667			0,00774669
Blanching	160	0,10337787					0,0066472
Cooling			6	0,00387667			0,0005594
Freezing			586	0,37862146			0,05463508
Packaging			15	0,00969168		8	0,20939851
Water					9,84		0,04507666
TOTAL		**0,2151552**		**0,39606647**	**9,84**	**8**	**0,32406353**

Table 6 - Variable estimation costs [2]

*The conversion rate between BTU/Lb and kWh/kg is 0,00064611

Source: Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and vegetable Processing Industry. An ENERGY STAR. Guide for Energy and Plant Managers.

UNITARY COST	Water (l)	Gas (kWh)	Electricity(kWh)	Stand up pouch
Price (€)	0,00458	0,0643	0,1443	0,026

Table 7 - Energy unitary costs

4.4. Annual depreciation and financing cost

To calculate the annual depreciation and financing costs, a lifespan of 10 years has been assumed and a capital cost of 5% as average value along the equipment lifespan.

Machine's lifespan	10	years	
Financing cost	5	%	
Yearly equipment's capital cost	11.680	€	
Yearly operating and maintenance costs	3.607	€	(4% of the initial investment)
Total	**15.287**	€	

Table 8 - Annual depreciation

Total cost estimation for an annual production of 30.000 Kgr/year

The impact of these fixed costs per unit of product in the case of an annual production of 30.000 kgr is equivalent to 0,51 € / kgr

Anual production	**30.000**	**Kgr/year**
Cost increase	**0,51**	**€/Kgr**

Table 9 - Fixed costs impact

4.5. Total costs

Total unitary cost for a production rate of 30000kg/year including raw material and variable processes cost are in the table below:

Mealworm's purchase price	5,00	€/Kgr
Capital costs	0,51	€/Kgr
Variable costs	0,32	€/Kgr
Total cost	**5,83**	**€/Kgr**

Table 10 - Total costs

We can see the moderated costs of the process including fixed costs. They are 0,83 €/Kgr versus 5,00 €/Kgr of the raw material.

The detailed cost structure for 30.000 kg/year is in the next table:

Detailed cost table	Yearly(€)	Unit cost (€/kgr)	%
Investments costs	11.680	0,389	47%
Operation & maintenance costs (including fixed terms of gas & electricity)	3.608	0,120	14%
Gas costs	415	0,014	2%
Electricity costs	1.715	0,057	7%
Water costs	1.352	0,045	5%
Packaging costs	6.240	0,208	25%
Process costs	**25.010**	**0,83**	**100%**
Raw material	150.000	5,00	
TOTAL	**175.010**	**5,83**	

Table 11 - Cost structure

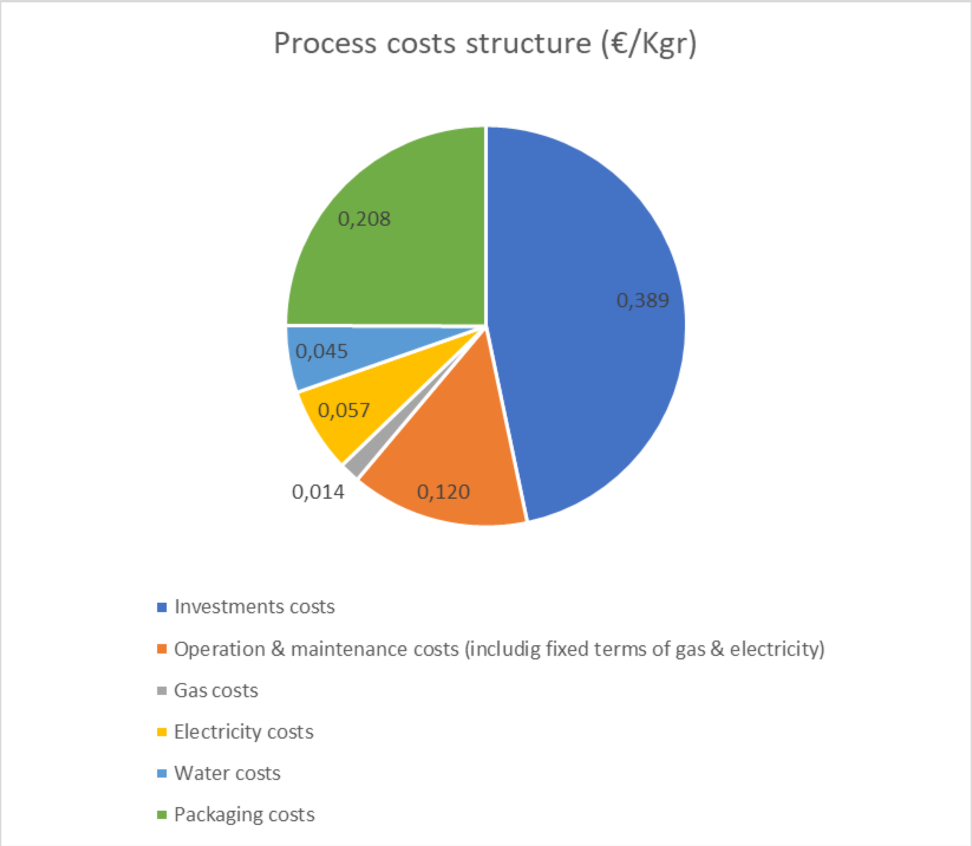


Figure 19 - Procees costs structure

4.6. Annual process capability of the plant

In the first years, the plant production will increase from a level of 30.000 Kgr/year to 70.000 Kgr/year or more. The plant has been dimensioned to attend production increase working a limited number of days per month. The plant will be operated by poly-valent personnel that will perform other functions in the factory.

Utilization rate for a production of:	**30.000**	**70.000**		**kgr/year**
Regular production rhythm	250	250		Kgr/h
Daily production hours	6	6		h
Hours of annual operation at usual Rate	120	280		h/year
Production days	20	47		days/year

Table 12 - Utilization rate

The plant has a low rate of utilization, and that allows perform maintenance tasks during the stop periods.

4.7. Analysis of sensitivity to variation of various parameters.

1) Total cost against the deviation of the investment cost

Difference	Investment Cost(€)	Total Cost(€/Kgr)
-15%	76.662	5,76
-10%	81.171	5,78
-5%	85.681	5,81
Central Case	90.190	5,83
5%	94.700	5,86
10%	99.209	5,88
15%	103.719	5,91

Table 13 - Total cost / deviation of the investment costs

This table is especially important in case the price of the components was either underestimated or overestimated.

2) Total cost for different levels of annual production

Yearly Production (Kgr)	Total Cost (€/Kgr)
20.000	6,09
30.000	5,83
40.000	5,71
50.000	5,63
60.000	5,58
70.000	5,54
80.000	5,52

Table 14 - Total costs for levels of production

3) Total cost for different periods of financial amortization and discount rates

Total Cost (€/Kgr)							
		Discount Rate					
		2%	3%	4%	5%	6%	7%
Repayment period (years)	4	6,23	6,25	6,27	6,29	6,31	6,33
	6	5,98	6,00	6,02	6,04	6,06	6,08
	8	5,85	5,87	5,89	5,91	5,93	5,95
	10	5,78	5,80	5,81	5,83	5,85	5,87
	12	5,73	5,75	5,76	5,78	5,80	5,82

Table 15 - Repayment periods

4) Total cost against increases in the price of gas and electricity compared to the central case

			Increase on the price of electricity			
		Base price (€/kWhe)	+5%	+10%	+15%	+20%
Increase on the price of natural gas		0,144	0,152	0,159	0,166	0,173
Price base (€/KWhg)	0,064	5,83	5,84	5,84	5,85	5,87
+5%	0,068	5,87	5,87	5,88	5,90	5,92
+10%	0,071	5,92	5,93	5,95	5,97	6,01
+15%	0,074	6,01	6,02	6,05	6,09	6,15
+20%	0,077	6,15	6,17	6,21	6,27	6,37

Table 16 - Gas and electricity increase

This table is especially important if the reference power consumptions are different than the actual ones.

5) Total cost versus the cost of the raw material

		Total Cost (€/Kgr)	Process Cost (€/Kgr)
Cost of raw Material (€/Kgr)	3	3,83	0,83
	4	4,83	0,83
	5	**5,83**	**0,83**
	6	6,83	0,83
	7	7,83	0,83

Table 17 - Cost of raw material

*Worm costs range from 3 to 7 €/kg when wholesale purchased.

5. WEEKLY ORDER PREPARATION

5.1. Catnip plants packaging

We measured the time needed to package catnip plants trays on carboard boxes for two different workers, and then studied how varied this time depending on the worker.

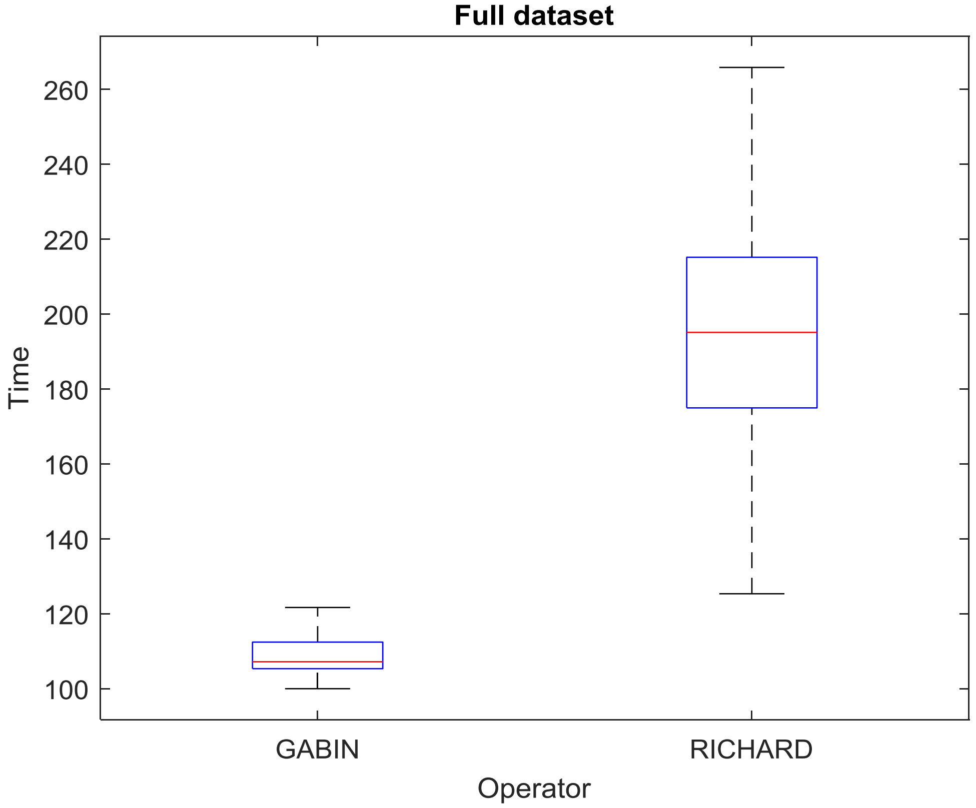


Figure 20 - Meassure of process time /worker

ANOVA Table

Source	SS	df	MS	F	Prob>F
Groups	121984.6	1	121984.6	192.48	4.22062e-21
Error	41194	65	633.8		
Total	163178.6	66			

Table 18 - ANOVA Table

After measuring the time for both workers, we made an analysis of variance (ANOVA) study on MATLAB.

We found that manual packaging is quite unreliable, and the time needed to prepare a single box changes a lot depending on who does it, whereas a machine always takes the same time.

5.2. Order preparation

Time (minutes)	Boxes	Number of items
5	6	22
4	1	92
2	2	24
3	2	40
4	2	43
4	1	81
4	3	69
4	2	22
3	1	47
3	3	33
3	6	9
2	2	2
3	6	6
5	3	17
6	1	104
4	2	9
8	1	13
19	3	175
6	1	43
14	1	113
18	2	149
10	1	107
11	3	144
120	10	462

Table 19 - Order preparation

We took a sample of all the orders that were made during a week, and we analyzed it on MATLAB with the regression app inside the Statistics and Machine Learning Toolbox™, that calculates the linear regression model using the least-squared estimation method.

For this analysis, we studied the relation between the time needed to prepare an order, and the number of items included in that same order, and also, the number of cardboard boxes utilized to fit all the items.

5.2.1. Multiple regression model.

First of all, we studied the correlation between the diferente variables in our study, which are showed down below.

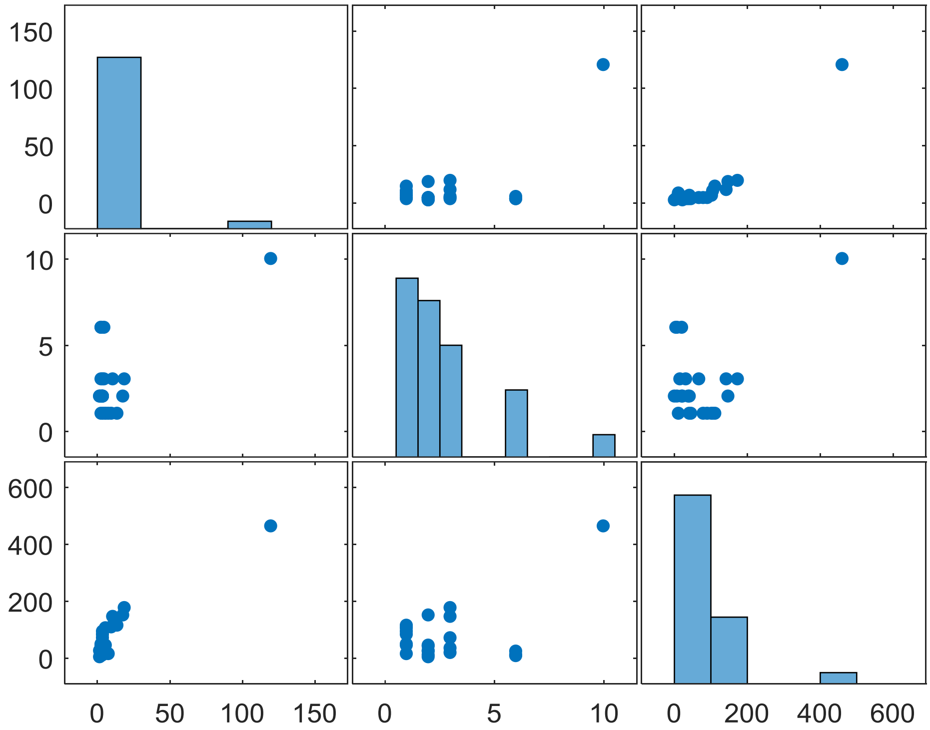


Figure 21 - Multiple regression model

```
Correlation matrix:
    1.0000    0.6652    0.9219
    0.6652    1.0000    0.4862
    0.9219    0.4862    1.0000
```

The cell corresponding to the first row and second column, shows the relation between the time to prepare an order, and the number of cardboard boxes used to prepare that same order.

The cell corresponding to the first row and third column shows the relation between the time to prepare an order, and the number of items of which that order is made.

The cell corresponding to the second column, third row shows the relation between the number of boxes and the number of items.

As we can see, the correlation between the time and the number of boxes is not very high.

Nor is the correlation between the number of items and the number of boxes.

So it seems as there is not a lineal relation between these parameters, but there could be another kind of relation.

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	-11.843	2.4326	-4.8683	8.1849e-05
colis	3.0379	0.79416	3.8253	0.00098575
boites	0.19264	0.018259	10.551	7.5175e-10

Number of observations: 24, Error degrees of freedom: 21
Root Mean Squared Error: 7.38
R-squared: 0.912, Adjusted R-Squared 0.903
F-statistic vs. constant model: 108, p-value = 8.76e-12

Table 20 - Multiple regression

After the multiple regression test, we can conclude that a model taking into account both variables is significant, but one of the individual variables is not.

In this case, it is the number of boxes parameter, so we are going to discard it.

5.2.2. Linear regression model.

Now, we are going to repeat the lineal regression test, but only taking into account the number of items in a specific order.

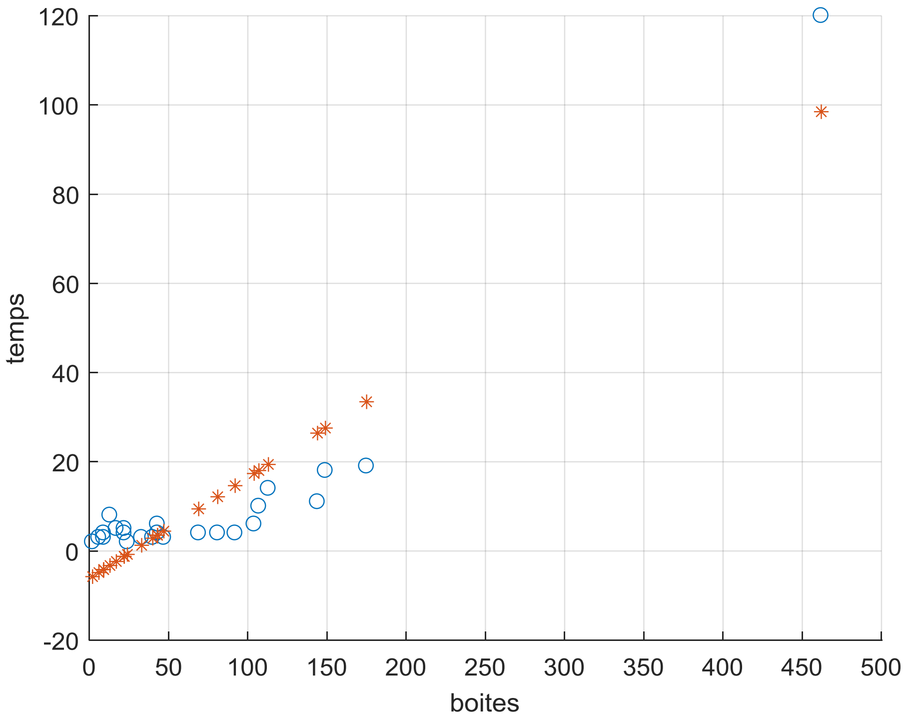


Figure 22 - Linear regression

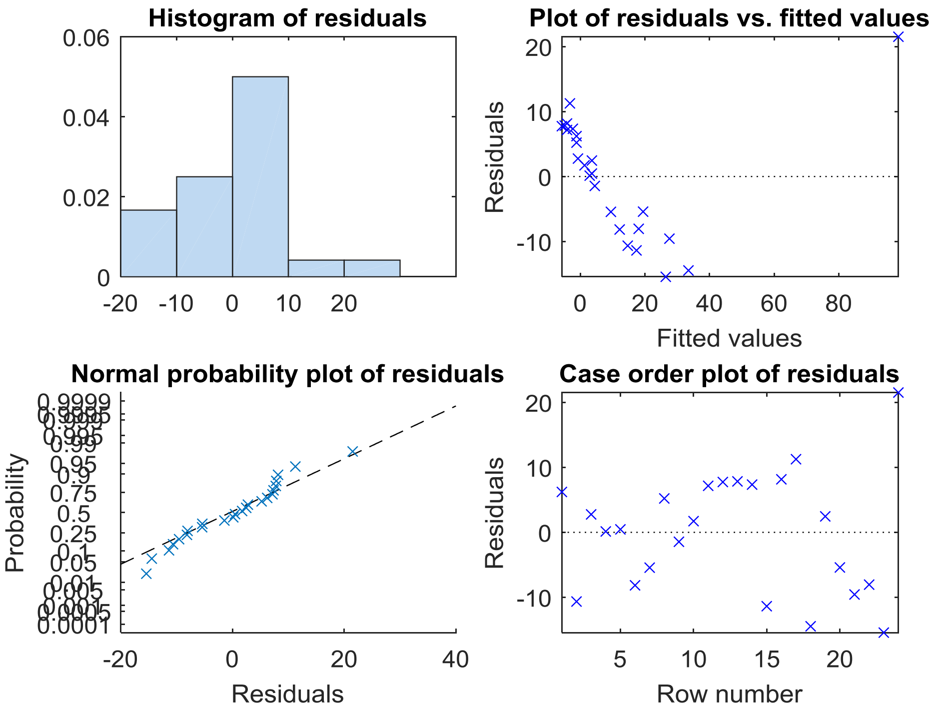


Figure 23 - Histogram

Seeing the results on the histogram of residuals, we can discard the normality hypothesis, which implies that the model is not very good.

Estimated Coefficients:

	Estimate	**SE**	**tStat**	**pValue**
(Intercept)	-6.1985	2.4614	-2.5183	0.019569
boites	0.2266	0.020306	11.159	1.5838e-10

Number of observations: 24, Error degrees of freedom: 22
Root Mean Squared Error: 9.39
R-squared: 0.85, Adjusted R-Squared 0.843
F-statistic vs. constant model: 125, p-value = 1.58e-10

Table 21 - Linear regression

Seeing the results on the simple lineal regression test, we cannot accept this model, specially because the term for the intercept is not significant at all.

As this model was no good, we are going to look for a quadratic one to see if it is more adequate.

5.2.3. Complete quadratic model.

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	3.668	0.77272	4.7468	0.0001092
boites	-0.014563	0.013352	-1.0907	0.28776
boites^2	0.00057727	2.9834e-05	19.349	7.2597e-15

Number of observations: 24, Error degrees of freedom: 21
Root Mean Squared Error: 2.21
R-squared: 0.992, Adjusted R-Squared 0.991
F-statistic vs. constant model: 1.31e+03, p-value = 9.29e-23

Table 22 - Complete quadratic model

After running a lineal regression test for a complete quadratic model, we see that it is very satisfactory, because the model is significant, with a good coefficient of determination (0,99) and a low RMSE.

Only problem is that the lineal term is superfluous, so we are going to repeat the test for a quadratic model but removing this term.

5.2.4. Quadratic regression model without the lineal term.

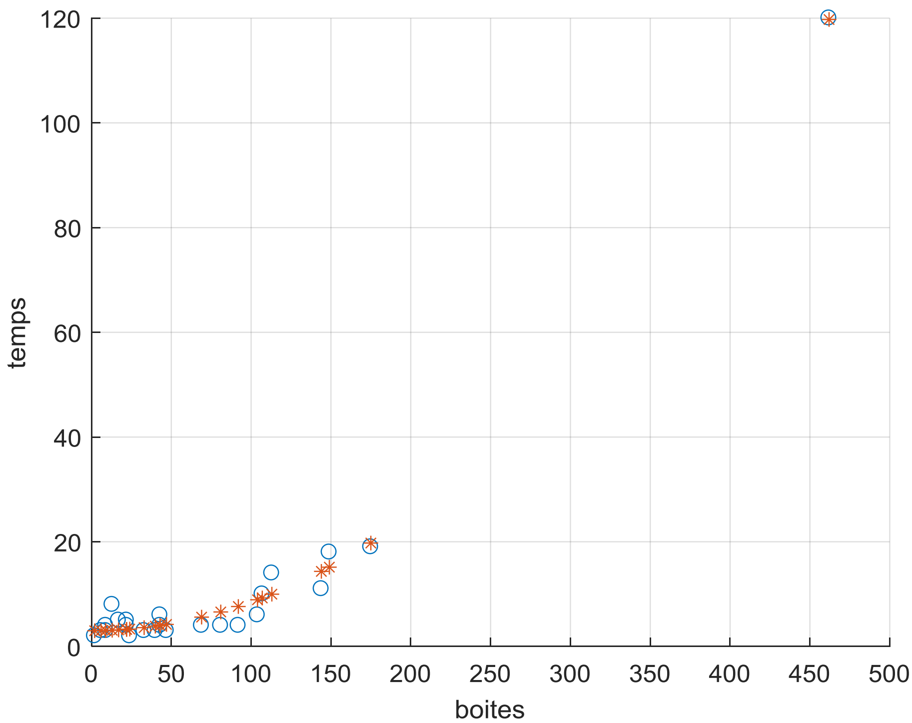
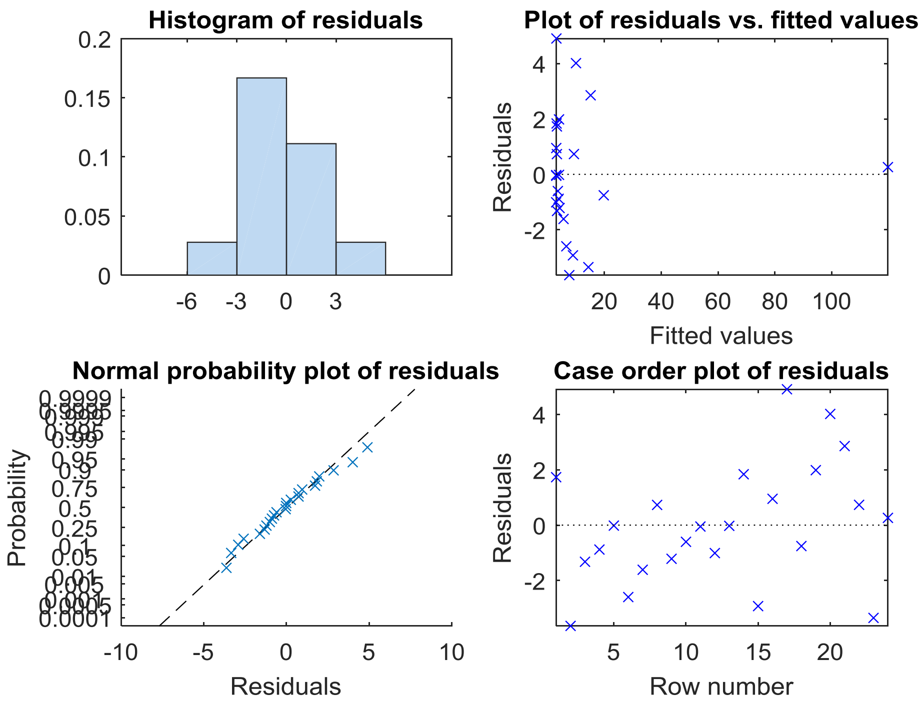
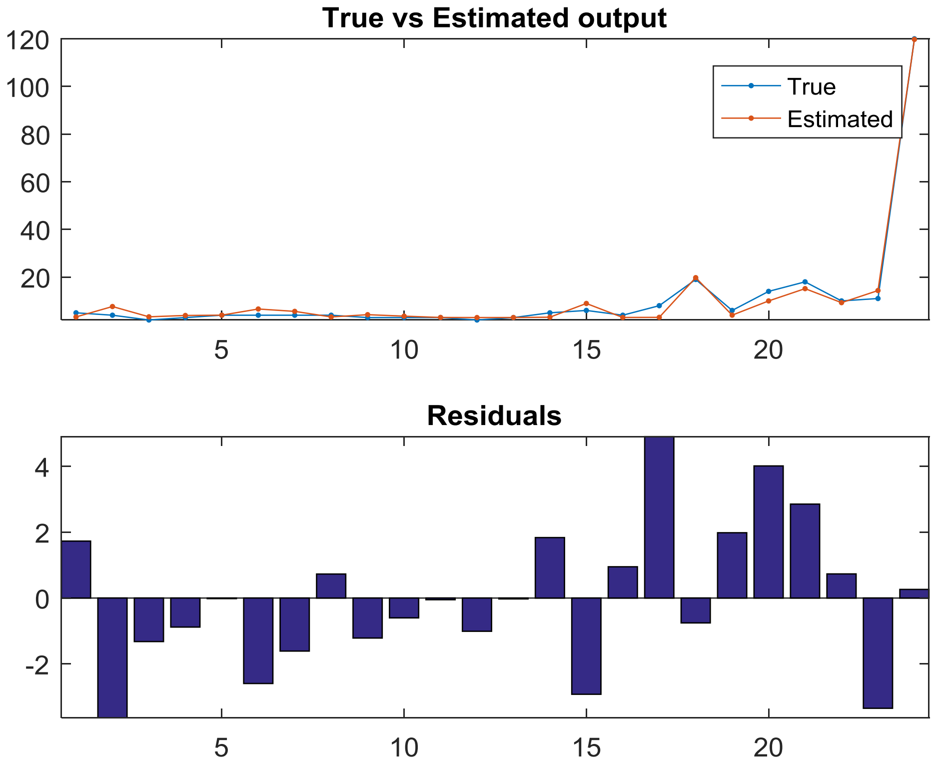


Figure 24 - Quadratic regression model





Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	3.0063	0.48061	6.2551	2.6987e-06
boites^2	0.0005469	1.0749e-05	50.881	2.5674e-24

Number of observations: 24, Error degrees of freedom: 22
Root Mean Squared Error: 2.22
R-squared: 0.992, Adjusted R-Squared 0.991
F-statistic vs. constant model: 2.59e+03, p-value = 2.57e-24

Table 23 - Quadratic regression model

After running the test for the quadratic model without the lineal term, we see that this is an astounding model that really succeeds at estimating the time needed to prepare an order depending on the number of items.

We have good p-values for the individual terms, as well as the model, with a good coefficient of determination and a RMSE, and we can check the independence and normality hypothesis for the residuals.

5.2.5. Assessment on the order preparation model

In the end, we have found that the model that best adapts to our sample is a quadratic one without the lineal term.

That means that apparently, from a time efficiency standpoint, it would be better to shift away from wholesale business to a retail oriented one, because the time to prepare an order depends on the square of the number of items, so the less items, the better.

Still, our study could be biased, and there is a lot of room for improvement in our model.

To improve our model, we could do the following things:

- Increase the sample size.
- Increase the interval width; that means measuring the time needed to prepare a bigger order.
- Taking more measurements at the interval's center, as there were not many data on medium sized orders.

5.2.6. Insect boxes preparation.

2 workers		Weight or number of	Total number of	Time			Boxes/hour
				Start	End	DIFFERENCE	
Insect type	Morios	50	100	09:09	09:52	43	139,53
	Mealworms	50	100	11:18	11:30	12	500
		100	47	11:40	11:46	06	470
	Dubia	10	83	13:22	13:45	23	216,52

Table 24 - Boxes preparation time

On this part, we measured the time needed to prepare the boxes containing different insects.

We found out that batches of the same insects take similar times, and depending on the insect type, the time needed to prepare one box can become almost four times higher.

2 workers	Number of nets	Time (min)	Nets/hour
Mealworms (nets+cardboard boxes)	51	53	57,74

Table 25 - Productivity of boxes preparation

6. CONCLUSION

- First of all, it should be noted that if the company decides to expand the line its production capacity of worms for commercialization, it is practically obligatory to automate the process.

- The additional processing costs are moderate, assuming 17% of the cost of the raw material (0.83 euros/kg over 5.0 euros/kg). Having an already frozen end product will allow to significantly reduce the production losses that currently occur (mortality, metamorphosis, ...) and maintain supply to the market throughout the year, taking on demand points. If we have delved into the company's set of costs, we understand that the gross margin allows to undertake the investment.

- It would be desirable to analyze the possibility of duplicating the processing chain, at least in critical components (scalding and freezer) to ensure and give greater reliability to production.

- It would be necessary to deepen the market of suppliers of these equipment goods and even make real tests of the machines with the raw material subject to the project to ensure the proper functioning of the process and to contrast the yields and consumption of water and energy.

7. REFERENCES

[1] Valentas, K. J., Rotstein, E., & Singh, R. P. (1997). Handbook of food engineering practice. Boca Raton: CRC Press.

[2] Masanet, E. (2008). *Energy efficiency improvement and cost saving opportunities for the fruit and vegetable processing industry: an Energy Star® guide for energy and plant managers*. Berkeley, CA: Energy Analysis Dept., Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, University of California.

[3] Fellows, P. (2017). *Food processing technology: principles and practice*. Amsterdam: Elsevier.

[4] Huis, A. van. (2013). *Edible insects: future prospects for food and feed security*. Rome: Food and Agriculture Organization of the United Nations.

[5] Behre, E., Heukels, B., Merino, A., Verschuur, A. Insects as Livestock feed. Brief policy commissioned by UN to Wageningen University. (https://sustainabledevelopment.un.org/content/documents/12867Policybrief_Insects.pdf)

[6] ASHRAE. (2006). *2006 Ashrae handbook: refrigeration*. Atlanta, GA.

[7] Siemianowska, Ewa & Kosewska, Agnieszka & Aljewicz, Marek & Skibniewska, Krystyna & Polak-Juszczak, Lucyna & Jarocki, Adrian & Jędras, Marta. (2013). Larvae of mealworm (Tenebrio molitor L.) as European novel food. Agricultural Sciences. 4. 287-291. 10.4236/as.2013.46041.

[8] Banis, D. (2019, June 14). Can Using Insects As Animal Feed Reduce The Climate Impact Of Meat Production?. Forbes. Retrieved from https://www.forbes.com/sites/davidebanis/2019/06/14/can-using-insects-as-animal-feed-reduce-the-climate-impact-of-meat-production/#584afa44404a

[9] Evert, A. (2018,December 18). Insects – THE New Animal Feed in the EU. (n.d.). Technology networks. Retrieved from https://www.technologynetworks.com/applied-sciences/articles/insects-the-new-animal-feed-in-the-eu-312079